10th Resilience Engineering Symposium

Resilience at frontiers, frontiers of resilience

26-30 June 2023

Sophia Antipolis, France

Preface

Resilience at frontiers, frontiers of resilience

General theme

The 10th Resilience Engineering Symposium's theme focuses on understanding how systems adjust their behavior when approaching boundaries. The theme will explore the limits and scope of the Resilience Engineering perspective to support systems coping with the actual and future complexities.

Using concepts of frontiers, borders, or boundaries in Resilience Engineering involves a paradox. On the one hand, they are omnipresent; on the other hand, the nature of boundaries and their neighborhood is rarely elaborated. Boundaries can be broadly defined as categories of difference that create distinctions between systems. They are a line between order relationships that creates a fuzzy zone-like phenomenon of inclusive disjunction identified as "neither/nor" or "both/and." The goal of the symposium is to deepen the description of relationships between resilience capacities and boundaries:

- What is the nature of boundaries to be considered by Resilience Engineering studies?
- How do their nature and dynamic affect adaptive capacities?
- How do other boundaries (organizational, national, or geographical) affect systems adaptive capacities?

The Resilience Engineering perspective emerges to support organizations coping with the increasing complexity of their environment. Since the first symposium, the Resilience Engineering community has proposed theoretical and practical solutions to contribute to this issue. During the same period, globalization, conflicts, technological innovation, digital transformation accelerated the complexification of an organization's environment. Therefore, the second ambition of the symposium is to study how the Resilience Engineering perspective adapts to support organizations coping with the next generation of complex threats and opportunities.

- How does the Resilience Engineering perspective adapt to support organizations coping with this new complexity?

- What is the actual and future nature of complex threats and opportunities?
- What are the limits of the Resilience Engineering perspective towards their complexity?
- Are there principles, concepts and practices that can be scaled-up (or not) from resilient systems to resilient organisations towards resilient societies?

Sub-theme

Contributions related to the traditional Resilience Engineering topics are also welcomed.

Industrial panel

An industrial panel is to provide a forum for stakeholders to discuss issues relating to adoption of Resilience Engineering in Industry. Contact us if you would be interested in being involved.

Visualizing resilience

We will welcome contributions studying how Resilience captures the popular imagination and inspires creative works, which influence the forces shaping Resilience, such as analysis of photography, painting, poetry, short fiction, movie, video, comic, music, documentary, and other forms of artistic visualization of Resilience.

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Work-as-Imagined vs. Work-as-Done during a Hospital Response to a Disaster

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In this study, data collected during hospital disaster exercises are analyzed to elucidate the adaptive responses and potential problems of the emergency medical care system. The analysis compared what was done during an exercise and what was imagined before the exercise as the expected normative response. To understand what the exercise participants actually did, we analyzed the observation and communication data collected at a disaster base hospital in Japan during the response to a mass casualty incident. In addition, we interviewed exercise planners and analyzed related documents, such as the hospital's business continuity plan and exercise scenarios, to understand the normative responses. We presented the results of the analysis using a Universal Modeling Language Activity Diagram and attempted to identify the differences between descriptive and normative responses, i.e., between "what was done" and "what was *imagined", consequently determining three main reasons for such differences, namely, staff shortage, participants' lack of understanding of standard procedures, and constraints of the exercise settings.*

Keywords: task analysis, disaster exercise, mass casualty incident, WAD and WAI, disaster base hospital, agent-based simulation.

1. Introduction

Work-as-done (WAD) and work-as-imagined (WAI) are concepts used in Safety-II (Hollnagel, 2014), which have recently attracted the attention of safety engineering professionals. Better understanding the gap between WAD and WAI can contribute to the development of resilient systems because it helps to uncover hidden or unexpected problems in the work contexts, as well as opportunities to implement adaptive responses. Many studies have examined this gap in daily work contexts, such as air traffic control, railroad operations, healthcare practices, and chemical and power plant operations. However, less attention has been paid to the emergency response to disasters, even though it is also an important scenario in resilience engineering (Kanno and Furuta, 2006).

This study considered this gap during a disaster response exercise at a major hospital in Japan. We analyzed observation and communication data collected at a disaster base hospital during a mass casualty incident exercise to understand what the participants actually did (WAD). In addition, we interviewed exercise planners and analyzed related documents, such as the hospital's Business Continuity Plan (BCP) and exercise scenarios, to understand the normative responses (WAI).

Section 2 describes the current state of disaster preparedness in Japanese hospitals. Section 3 describes the collection of data for analysis. Section 4 presents the analysis results and discussion, followed by the conclusions in Section 5.

2. Disaster Preparedness in Japanese Hospitals

Japan is a disaster-prone country that has experienced several such events, including earthquakes, tsunamis, floods, typhoons, heavy rains, landslides, massive snowfalls, pandemics, and man-made disasters. Hospitals are the last line of defense to save lives during a disaster; therefore, they must be prepared to accommodate a surge in demand from injured people. Following the Great Hanshin-Awaji Earthquake in 1995, the Japanese Ministry of Health, Labor, and Welfare (MHLW) issued guidelines to improve and strengthen the initial emergency medical care system (MHLW, 1996). These guidelines urged local governments to prepare disaster base hospitals with sufficient capacity to provide the emergency medical care demanded in their respective regions. To date, 765 disaster base hospitals have been designated in the country. Following the Kumamoto Earthquake in 2016, the MHLW ordered disaster base hospitals to prepare BCPs (MHLW, 2017).

Although all disaster base hospitals already have BCPs and conduct disaster exercises at least once a year, preparing for exercises and improving their emergency medical care system and BCPs based on the evaluation of such exercises still require significant effort, extensive data collection, and a thorough analysis of the exercises.

3. Data collection during a disaster exercise

We collected data during an annual disaster exercise conducted at a disaster base hospital in the Kanagawa Prefecture on the 16th of November 2021 (Ideguchi et al., 2023). This exercise was designed to care for the mass casualties caused by a major earthquake. As this exercise was conducted during the COVID-19 pandemic, it was held in an auditorium, using dummy patients printed on paper and involving a limited number of participants (Figure 1).

Table 1 provides an overview of the data collected during the exercise. To record activities and communications, we used nine action cameras attached to key players, such as area leaders, and twelve station cameras in selected areas, including the command post and red area. We also referred to the documents used in the exercise, such as triage tags and medical records, to analyze what was done during the exercise.

This study was approved by the Ethical Review Committee of the School of Engineering at the University of Tokyo (KE22-7).

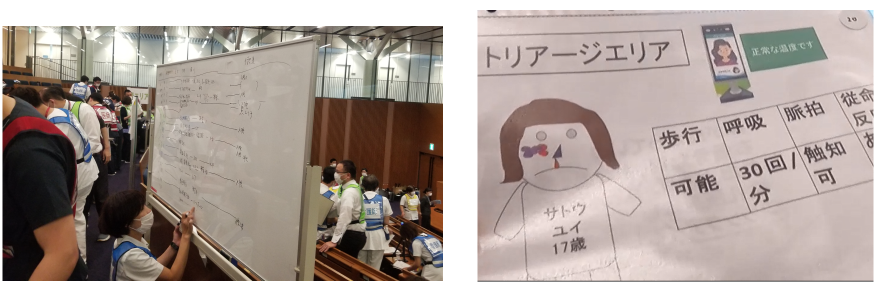

Figure 1: Exercise scene (left) and a dummy patient (right)

Table 1: Overview of collected data

Scope	What	How
Decision-making	• Triage • Diagnose and treatment	• Triage tags • Medical records
Flow of staff and stuff	• Transfer and movement of patients and staffs • Procurement of medical materials and instruments	• NSF tag and reader • Chronology on whiteboards • Inventory records
Communication (Flow of information)	• Communication within an area • Situation awareness	• IC recorders for inter-area communication by PHS • Zoom recordings of inter-area meetings

4. Task analysis

We analyzed five major interarea tasks that required coordination and sharing of information across different areas: patient transfer after the second triage, laboratory testing, radiology testing, surgical requests, and hospitalization requests.

The purpose of this task analysis was twofold. On the one hand, to understand disaster medicine and gain insights into how to improve disaster exercises. On the other hand, to formalize the disaster medicine process and provide a basis for agent-based modeling of disaster medicine for computer simulations (Umemoto et al., 2023). To represent disaster medicine workflows involving many actors we adopted a partitioned Universal Modeling Language (UML) activity diagram.

4.1 What was imagined (Normative response)

With the help of Subject Matter Experts (SMEs), including an exercise planner, we clarified the expected normative responses to the situations and patients in each area, as well as the required coordination between different areas.

Figure 2 shows the activity diagram for a hospitalization request from the red area, as it should be performed in disaster medicine at this hospital. As shown by the blocks in the figure, three areas –the red area, command post, and headquarters– are involved in hospitalization procedures. Each column represents an actor such as an area manager, doctor, or nurse. The rectangles represent actions and the lines represent task flows or information/object transfers within or between areas. The small box on top of or below each action rectangle indicates the information or objects transferred between the actors and areas.

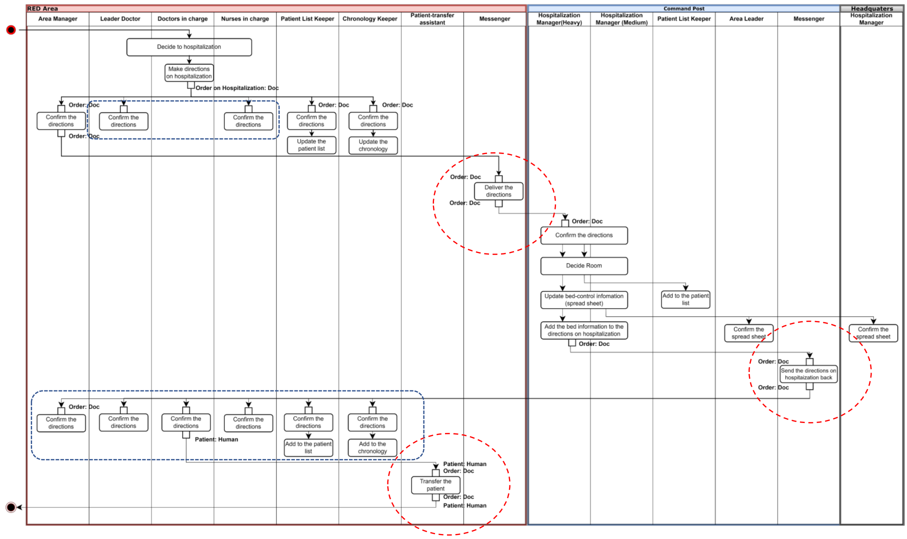

Figure 2: Hospitalization procedures (WAI)

4.2 What was done (Descriptive response)

We watched video recordings together the SMEs and analyzed what the exercise participants were doing compared with the corresponding normative task flows. All verbal communications in the video recordings were transcribed and referred to in the task analysis. Figure 3 shows the activity diagram for a hospitalization request, as was actually performed during the exercise. The grey columns indicate the roles that were not assigned to any participant, due to the limited number of participants in this exercise.

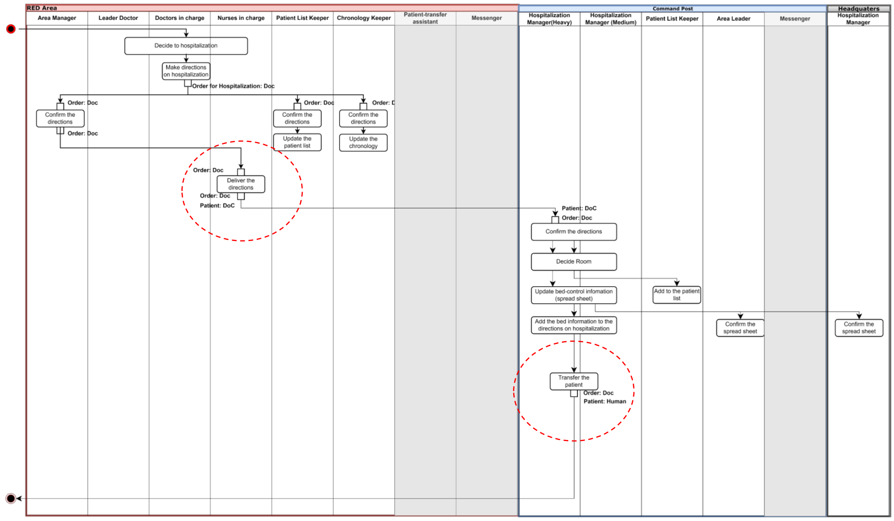

Figure 3 Hospitalization procedures (WAD)

4.3 Differences between WAI and WAD

The actions marked with red dashed circles in Figures 2 and 3 represent the differences observed between WAI and WAD, i.e., the actions that were performed differently from what the normative response dictated. With the help of the SMEs, we inferred the reasons for these differences. For example, because no participant was assigned as a messenger during the exercise, the nurse-in-charge delivered hospitalization requests to the command post. In addition, because paper dummies were used in this exercise, the patients were sent to the command post together with the request and then directly to the ward from the command post, which cannot occur in real situations.

We analyzed the five aforementioned tasks and found that the three typical causes of the differences between WAI and WAD, excluding simple mistakes, are as described below:

1. *Staff shortage* was often observed during the exercise and occurs in actual situations. During a staff shortage, dynamic task assignment is required, sometimes resulting in the omission or modification of some tasks in the normative procedures. As it is virtually impossible to know how many personnel will be available during a real disaster situation, to improve BCPs and exercise scenarios, it is important to estimate the number of participants needed for providing disaster medicine according to normative procedures. It is also important to assess the extent to which staff shortages degrade response performance.

2. *A lack of understanding of standard procedures* leads to inappropriate responses and unnecessary inquiries to the command post or headquarters. For example, early in the exercise, we observed that confusion was caused by surgery requests being sent to the waiting area instead of the command post.
3. *Constraints of the exercise settings* forced the participants to respond differently than expected. As mentioned above, paper dummies were often moved around different areas because it was easy and convenient for sharing patient information. Another example was the task length. In this exercise, we shortened the duration of most actions, except for triage, decision-making, and communication. Therefore, although the actions performed were the same as the normative ones, their durations were not as expected in a real scenario, which could lead to significant differences in the overall performance of WAI and WAD, such as in the congestion experienced in each area.

4.4 Simulation to better understand WAI and WAD

Because it is impossible to enact real situations during exercises, what was done in the exercise was not exactly a WAD but rather a quasi-WAD. Therefore, BCPs and response plans, as well as the overall performance during the exercise, cannot be fully evaluated based on the recorded observations. This is different from the WAD studied during day-to-day situations, because it is impossible to collect data on a real WAD during a disaster response unless a real disaster occurs. However, computer simulations help approach real WAD. For example, by incorporating a more realistic completion time for each task into a descriptive model based on the collected data, we can reconstruct what actually happened during the exercise much closer to the real WAD. We can also use a normative model to assess the performance of BCPs and response plans, which are equivalent to WAI, under different conditions through what-if simulations. We are currently developing such simulations to assess the resilience of disaster base hospitals and their BCPs (Umemoto et al., 2023).

5. Conclusions

This paper presents the data collection and analysis of a hospital disaster exercise to clarify the difference between what was done during the enacting (WAD) and what was imagined as a normative response before the exercise (WAI). We identified three main reasons for this difference: staff shortages, participants' lack of understanding of standard procedures, and constraints of the exercise settings. The third reason sometimes acts as an unrealistic constraint, allowing participants to respond differently to both the WAI and realistic WAD; therefore, we should be cautious when assessing the performance of an exercise based on the observations. Computer simulation using a normative and a descriptive model can bridge the gap between WAI, quasi-WAD, and WAD, and we can expect enable a better assessment of BCPs and response systems.

Acknowledgements

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From academia to society: How to empower citizens in times of crisis

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The paper presents a body of work conducted within the framework of the EU- funded ENGAGE project in the field of resilience. ENGAGE seeks to enhance societal resilience by combining different intervention methods to make communities more aware and prepared to face disasters or crises together. It aims to facilitate the movement of resilience beyond academia and make it a resource for the entire society. The project will conduct four exercises in Romania, Spain, Italy, and Norway, where citizens will play a significant role before, during, and after disasters or crises. The current paper focuses on two exercises in Italy and Norway, where heatwaves and quick clay disasters are prevalent, respectively. The Rome exercise aims to enhance awareness of health risks associated with heat waves and increase adherence to the regional Heat Adaptation Plan through community-based actions of awareness-raising and reinforcement of a network of local stakeholders. The Trondheim exercise aims to evaluate the effectiveness and resilience of the evacuation process, in terms of preparedness, response time, coordination among emergency services as well as citizens, and the management of the potential aftermath of such an event. The ENGAGE project seeks to empower citizens in times of crisis by taking a step beyond the academia walls.

Keywords: Disaster management, Emergency response, Societal Resilience, Citizen engagement

Introduction / Background

The current global state is increasingly exposing human society to greater risks, requiring that all individuals in particular and civil society in general acquire the ability to be ready and quickly respond to the case of a disaster or crisis- related emergency of any kind. Risk awareness is a top priority and societal resilience is required to empower citizens and enhance successful responses to disasters or crises. In current strategies, there is a gap between the formal effort of public authorities to enhance citizens preparedness, to protect them during an adverse event as well as from the consequences of disasters or crises, and to efficiently collaborate with those provide a voluntary support when disasters or crises occur. Unfortunately, societal resilience is still very much a concept within the walls of academia.

Starting from this challenge, the ENGAGE project is directed at the whole of society and seeks to combine the different methods of intervention to make communities more aware and prepared to face disasters or crises together and therefore more resilient. In this way, it aims to facilitate the move of resilience across the academic border and make it a resource for the whole society.

Citizens can play a significant role before, during and after disasters or crises, whether they possess invaluable resources, specific knowledge and information or because they are directly at the scene and can therefore act promptly.

The ENGAGE project brings together citizens with authorities and formal stakeholders through four large scale exercises. Thanks to an extensive analysis of various case studies and existing literature, solutions adopted by citizens, local communities, non-governmental organizations from one side and authorities as well as formal stakeholders on the other side in disasters or crises have been identified and the possibility of "exporting and adapting" them in different contexts has been evaluated. The four exercises will take place in Romania (May 2023), Spain (June-July 2023), Italy (July-August 2023), and Norway (September 2023). During the exercises, citizens will be engaged in various ways. The current paper will focus on two exercises and different types of disasters or crises, such as heat wave in Rome and the quick clay in Trondheim, and will provide some suggestions on how to empower citizens in times of crisis with the aim of taking an initial, small step beyond the academia walls.

Be ready for a heatwave in Italy

Heat waves caused many fatalities in Europe in the period 1998-2009 and they are going to become more frequent and intense in the coming years, especially in the Mediterranean area. Therefore, one of the four exercises will take place in the city of Rome, where heat wave events occur regularly and local populations living in the urban area are more at risk due to the urban heat island phenomenon and higher nighttime temperatures. Not all of the population is equally at risk. Vulnerable sub-groups include those with chronic health conditions, the elderly and those living in deprived areas with limited resources. The exercise will enhance awareness of the health risks associated with heat waves and aim to increase adherence to the regional Heat Adaptation Plan [1], through community-based actions of awareness raising and reinforcement of a network of local stakeholders. The exercise will be coordinated and manly carried out by three project partners: i) the Local Health Authority (ASL Roma 1), who managed the heat warning system and active surveillance during past heat waves as defined in the regional heat plan, ii) an Italian non-profit citizens organization (Cittadinanza Attiva), who brings together volunteers at local and national level, and iii) a research and consultancy Italian small and medium-sized enterprise (Deep Blue) as validation expert.

Citizens' involvement

The existing heat adaptation plan developed by the Lazio Regional Healthcare System includes a 3-day heat warning system, the identification of vulnerable people and the active surveillance (home visits or tele-medicine services) of these by health care services and general practitioners. The current system has been developed and refined along the years and it now based on a digital platform interacting with an App for surveillance.

The exercise will validate solutions including the development of an information campaign, to enhance awareness of citizens on the health risks of heat waves and prevention measures available through the Lazio Regional Heat Plan, and the building of capacity of volunteers and local NGOs already operating in the area and in contact with vulnerable people. Furthermore, the solutions will aim to extend the network of stakeholders focusing on a community-based approach for information sharing and promotion of preventive actions at local level.

This means that citizens will be part of the exercise in two ways. Vulnerable people will form the target group of the solutions that will be evaluated. In addition, local people will be engaged to increase the coverage of active surveillance of vulnerable people.

In order to get a better idea of local citizens' current risk awareness and experience with crises, a workshop was organized by Deep Blue.

Ongoing activities and initial findings

The citizen workshop was organized on Wednesday the 30th of November at a local library in Rome. About 50 citizens participated in the event and shared their personal experiences and opinions. They were asked whether they knew what the most likely risk events are for the area where they live, whether they had ever been involved in a disaster or crisis or in the preparation for possible disasters or crises, how they were informed/involved, and whether they did get adequate support from first responders in case they had been involved in a disaster or crisis.

From the earthquake in Aquila to the Covid-19 pandemic, many citizens had been involved in disasters or crises. They expressed a need for training in preparing for disasters or crises and a point of contact during adverse events. The citizens expressed the necessity for leadership but also a mutual relationship with the authorities. When it comes to risk perception, the main challenge is to stay vigilant even when disasters or crises have not taken place recently.

The Heat Wave exercise will take place in July and August. The validation process will be twofold. Firstly, the implementation level of the solutions will be evaluated and, secondly, the effectiveness of the solutions to improve the societal awareness and preparedness to deal with heat waves will be evaluated. In order to evaluate the implementation level of the solutions, the number of stakeholders included in the proximity network as well as the dissemination of informative material at local level and the number of community focal points will be measured. The effectiveness of the solutions to improve the societal awareness and preparedness to deal with heat waves will be assessed by looking at the number of vulnerable people monitored, the influence of local information campaigns, and through a final event with questionnaire.

Be ready for a quick clay in Norway

Quick clay is the term used for a special type of clay which totally collapses and flows like a liquid when overloaded. Indeed, this clay is characterized by its high sensitivity to changes in water content, which causes it to quickly transform from a solid state to a liquid state. This sudden loss of strength and stability can lead to quick clay landslides, which can be extremely dangerous since its slides can propagate very quickly over large areas, and the slide debris can float over considerable distances. This type of landslide has caused significant damage and loss of life in some cases, such as Rissa in 1934 [2], which resulted in the death of 40 people, or the most recent one in 2014 in Sweden [3], and in United States (Oso, Washington)[4], resulting in the death of 43 people and widespread damage to the surrounding area. Quick clay is found primarily in Norway and Sweden, but also exists in Finland, Russia, Canada and Alaska.

This validation exercise will aim to simulate an evacuation in the city of Trondheim in the coming Fall, with a particular focus on the historical center (such as Bakklandet area), which is susceptible to the risk of quick clay landslides. The proposed exercise is designed to emulate an evacuation of the citizens from this area and is modeled on the 2019 Directorate for Civil Protection and Emergency Planning (DSB) report [5]. The purpose of this exercise is to evaluate the effectiveness and resilience of the evacuation process, in terms of preparedness, response time, coordination among emergency services, and the management of the potential aftermath of such an event. The findings of this study are expected to contribute to the development of improved strategies and policies aimed at enhancing the resilience of communities vulnerable to the threat of quick clay landslides.

The exercise will be coordinated and manly carried out by four project partners: i) the Trondheim Red Cross that plays a pivotal role in training volunteers, as well as engaging with citizens, and effectively communicating during and after such adverse events, ii) one of Europe's largest independent research organizations (SINTEF) who serves as the coordinator of the project and oversee its validation process, iii) a research institute (NTNU Social Research) that generates knowledge across a broad range of societal concerns, and iv) a leading technology firm specializing in providing communication channels for crisis management (Everbridge Norway) that leverage its expertise in facilitating effective communication prior to, during, and after such adverse events.

Citizens' involvement

The planning and execution of a "live" and realistic exercise such as the one proposed in Trondheim necessitates the active involvement of citizens in all phases, including the planning, execution, and evaluation processes. To ensure successful and meaningful engagement, it is imperative to adopt a dedicated approach, including the use of specific messages and means to effectively communicate and engage citizens in a participatory manner. This approach recognizes the importance of close interaction between the formal actors and the citizen to build and enhance societal resilience, and the need to develop tailored strategies to involve them at every stage of the exercise.

Effective communication between local authorities and the public is crucial to the success of the proposed validation exercise. Dedicated awareness campaigns can be initiated during the preparation phase, and a public warning system can be utilized during the exercise to communicate timely and relevant information to citizens. Another critical factor to consider is the identification of vulnerable groups, such as children and young adults, and an understanding of their specific needs, including how to prepare them for the event of a quick clay landslide. This can be addressed through dedicated training courses or educational programs offered during the school period. As is often the case with adverse events, many individuals express a willingness to help, but lack the necessary knowledge or training. Therefore, offering courses and training for these volunteers can be a valuable resource in case of an adverse event. By leveraging these approaches, the validation exercise can enhance public engagement, foster a culture of preparedness, and ultimately improve societal resilience.

In order to get a better idea of local citizens' current preparedness level and experience with adverse events, different initiatives have been organized by Trondheim Red Cross and SINTEF.

Ongoing activities and initial findings

Over the past year, a number of initiatives have been undertaken to enhance citizen preparedness and participation in all phases of disaster management. Specifically, local partners have focused on three main streams. The first involves refining and enhancing one of Trondheim Red Cross' developed solutions, namely the Preparedness Guard [6]. This initiative seeks to coordinate volunteer efforts in local communities during emergency situations, with the primary objective of facilitating efficient resource allocation via readily accessible and prepared volunteers. Notably, it represents a low-barrier opportunity for citizens to engage in volunteer work, while also providing training opportunities such as the November exercise, which saw the participation of Preparedness Guard volunteers, Trondheim Red Cross Search and Rescue staff, and other citizens in various roles. The exercise brought together over 60 individuals and offered a valuable opportunity to assess volunteer and Trondheim Red Cross staff collaboration in a simulated scenario, similar to one planned for the upcoming fall exercise [7].

The second stream focuses on improving citizen awareness of disaster events and preparedness strategies. By partnering with local citizen organizations that work primarily with students and young adults, information days and workshops have been planned to better understand the specific needs of these segments of the population.

Finally, to foster greater collaboration among citizens, authorities, and formal stakeholders, workshops and meetings have been held to develop a realistic exercise scenario. Follow-up activities have been planned for each stream.

Next steps and way forward

The citizen workshop in Rome was very successful as it led both to citizen engagement (even on a small scale) and to more insights into the perspective on societal resilience from citizens. The workshop material will be reviewed and translated so that it can be used in future citizen workshops.

In the upcoming months, ASL Roma, Cittadinanza Attiva and Deep Blue will prepare the heatwave exercise. In addition to engaging citizens through workshops and through the Heat Adaptation Plan, a survey will be conducted to deepen the point of view of citizens with respect to the role they can play during emergencies. The survey will be disseminated in the coming weeks and the goal is to reach at least 400 citizens by April.

To facilitate the successful execution of the Trondheim exercise with optimal citizen participation, several initiatives have been devised for the forthcoming months. In March, an information day will be held at the international school near the Bakklandet area, which aims to educate students about potential risks and provide them with effective means of managing such risks. With the support of Trondheim Municipality, an awareness campaign will be launched on official channels during the summer period. Additionally, dedicated workshops and table-top exercises involving relevant stakeholders will be conducted in August to simulate the envisioned exercise in the fall. These initiatives are critical in ensuring the seamless execution of the Trondheim exercise and enhancing citizen preparedness in the face of potential risks.

Conclusion

In conclusion, the concept of societal resilience is still evolving and presents several open questions that require careful consideration. The delineation of boundaries between various groups, including citizens, (trained) volunteers, and off-duty formal actors, is not clearly defined, posing challenges to effective coordination and communication. This has profound implications and fundamental changes are required to better accommodate multi-directional communication in which the role of authorities and professionals adapts to one of enablement, rather than control [8]. Furthermore, citizens can assume multiple roles simultaneously, necessitating a proactive approach and sustained engagement in building resilience. Authorities play a key role in enabling citizens to contribute effectively, and their involvement is critical to enhancing the resilience of the community. The importance of research and collaboration among stakeholders cannot be overstated in deepening our understanding of societal resilience and strengthening its impact. Continued efforts in this direction are essential to building a more resilient and sustainable future for our communities.

Acknowledgement

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Resilience and initiative: actions of informal actors in disasters

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Disasters and crises highlight repeatedly how members of the population take an active role during such events and resilience at the societal level is the result of actions of both formal actors such as authorities and emergency organizations, and informal actors. Drawing from investigations of the involvement of the population in disaster management, the paper contributes to a discussion on the nature of resilience, in particular of the notion of initiative, which takes a more prominent role when considering the actions of informal actors. We describe these actions by relating them to research in the field of Resilience Engineering*. The paper also describes some solutions to better involve the population in disaster management, from improving preparedness to integrating spontaneous volunteers in operations. To support authorities and the society as a whole, we need to pay more attention to initiative as a characteristic of resilience and investigate it more explicitly. Such investigations will allow us to better understand associated challenges and potential approaches.*

Keywords: disaster management, public involvement, informal actors, resilience, initiative, preparedness, maladaptive patterns.

1 Introduction

Man-made or natural disasters, as well as longer-term crises such as the COVID-19 pandemic, highlight repeatedly how members of the population take an active role during such events, and do not remain passive bystanders (Whittaker, McLennan and Handmer, 2015). The capacity to handle challenging and surprising events is therefore the result of actions of both formal actors such as authorities and emergency organizations, and informal actors such as members of the population. In other words, informal actors contribute to the resilience of the affected community in the face of disasters and crises.

Research on the nature of resilience in the fields of Resilience Engineering (RE) or High Reliability Organization (HRO) originates from studies of safety in *professional* settings, particularly in high-risk / high-consequence environments. The past decades have also shown a growing interest in the notion of resilience in the context of crisis and disaster management, as demonstrated by influential international policies such as the Sendai framework (UNISDR, 2015). The latter context requires that we include the population at large as part of considerations about a system's capacity to prepare for, respond to or recover from challenging and surprising events. In other words, the actors of resilience include here actors who might not possess the training, skills, equipment or decision-making structure to face these events.

This paper draws from research conducted in European project ENGAGE, which central topic is the involvement of the population in disaster management. Based on project results and insights, the aim is to contribute to a discussion on the nature of resilience. We describe the contribution of populations to resilience by relating it to research in the field of RE, in particular by mapping it to the 3 maladaptive patterns proposed by Woods and Branlat (2011). Considerations of the wider societal scale then allows us to reflect on some of the assumptions made about resilience, such as the focus on expertise, and discuss the notion of initiative, which takes a prominent role when considering non-formal actors. The practical objective of the paper is also to describe solutions, such as strategies or technologies, that have been proposed or implemented to better involve the population in disaster management.

2 Background: notion of resilience

Resilience can be understood, in its large meaning, as the capacity of a system to handle a disruption, in particular one of unexpected nature or scale for which a specific pre-established response does not exist. In spite of the challenging nature of such events, a system expressing resilience is able to maintain basic functions (i.e., avoid collapse) and recover from the event, potentially improving as a result. Resilience is linked especially to the notions of adaptation and adaptive capacity.

In fields concerned with safety in processional settings (RE, HRO, NDM), actors of resilience are the operators, managers and organizations confronted with the perturbations at hand. Adaptation typically occurs at the sharp end, i.e. at the level of the operators, favored or hindered by conditions defined at the blunt end, i.e. at the level of managers. Technological agents participate in the control of the system within their design envelope (anticipatable conditions). Adaption itself is of diverse nature. Cook and Nemeth (2006) describe resilient performance as the capacity of the system as a whole to *reconfigure* in the face of the disruption, as in the case of an Israeli hospital responding effectively to a bus bombing by dropping non-urgent (e.g., administrative) tasks in order to focus on new and urgent tasks demanded by the situation (e.g., informational needs from victims' families or media in addition to care of victims). Adopting a systemic view requires that we discuss adaptation in the context of complexity, i.e. of the interconnectedness of agents or processes in the system. Based on insights from firefighting and crisis management, Woods and Branlat (2011) proposed three basic patterns of adaptation to qualify whether a system exhibits resilience or its absence, brittleness, in the face of disturbances. The patterns are "(1) decompensation – when the system exhausts its capacity to adapt as disturbances / challenges cascade; (2) working at cross-purposes – when roles exhibit behavior that is locally adaptive but globally mal-adaptive; and (3) getting stuck in outdated behaviors – when the system over-relies on past successes." Woods (2019) proposed the notion of *graceful extensibility* to emphasize how avoiding the pitfalls captured in these patterns corresponds to the capacity to manage adaptive capacity – a second order of adaptation.

In the context of disaster research, the notion of resilience is typically applied to communities or the society at large. *Community resilience* emphasizes characteristics of groups that seem to explain their capacity to respond or recover successfully from disasters, for instance cultural factors or the level of bonding between members of the community. *Societal resilience*, on the other hand, includes all actors of society. A significant part of the discussion on societal resilience is related to its political aspect (Haavik, 2020). Indeed, a *disaster*, as defined by organizations such as the International Federation of Red Cross and Red Crescent Societies, is the result of different factors, including the limitation of local capacities or the vulnerabilities in the face of the event – both of these points being related to the actions of government at different levels. In line with the work in project ENGAGE, we will consider that societal resilience corresponds to "the potential for all types of social actors, formal and informal, to effectively cope with an adverse situation and the social context influencing this potential" (ENGAGE, 2023). This definition appears largely consistent with the RE view but corresponds to a broadening of the system of interest.

3 Participation of informal actors in disasters and crises

Decades of investigations and observations demonstrate the critical role informal, non-professional members of society play in the response to, and recovery from, disasters (e.g., Whittaker *et al.*, 2015). The recognition and, especially, institutionalization of such role is nonetheless particularly challenging. Through surveys and interviews, we find different opinions from formal actors (authorities, emergency organizations) about the participation of the population (ENGAGE, 2021). The involvement of civilians is seen as positive when related to the preparedness or recovery phases. In the first case, preparedness, mostly in terms of the need for the population to be prepared (e.g., authorities conduct awareness campaigns targeted at the population). In the second case, recovery, their role is limited to well-defined and non-technical functions that do not require disaster-critical skills or equipment, such as supporting logistics, or providing food and shelter. However, participation to the response phase, i.e. the emergency or acute phase of a disaster, is typically viewed negatively, as a liability or nuisance: a major risk, a source of chaos (i.e. loss of control) and hindrance to the efficient management of the situation (e.g., responders are disrupted unnecessarily and cannot concentrate on their tasks). Note that the view from professional actors mirror central RE concerns: issues in the response phase are seen in light of their fundamental objective, the control of the situation as a whole (and the fear of losing control).

Professionals' concerns are of course valid since civilians are often untrained and lack the safety protection or special equipment formal actors have. But the reality is that civilians are often the *de facto* first responders, i.e. the first people addressing the emergency, sometimes long before formal actors can reach the scene. Research in disaster management challenges the assumptions of formal organization by highlighting the active participation of civilians as a major resource to fill in the gaps of the formal response. For instance, based on numerous case studies of earthquakes, Peleg *et al.* (2018) found that "50–95% of survivors are rescued within the first 24–48 h [by] untrained individuals, using whatever they can find to support their efforts, e.g., metal rods, car jack, etc."

Among other case studies, project ENGAGE investigated in depth the participation of informal actors during the July 22nd, 2011, Utøya attack (Aalberg and Bye, 2021; ENGAGE, 2023). The official investigation report explicitly mentions that informal actors present near the island played a major role in reducing the impact of the attack. Before police and emergency organizations were able to reach the scene, local residents and campers indeed helped secure and care for victims, sometimes taking considerable risks. Once formal actors deployed, these spontaneous volunteers supported them in various ways, for instance by guiding special forces to adequate areas to land their boats. It appears from the investigation that actions were undertaken without any explicit coordination. Rather, individuals or very small groups acted on their own, reacting to immediate needs to carry a specific task, potentially observing others acting around them (but actions occurred in various locations). While informal, tasks conducted could be related to formal categories of disaster response, such search-and-rescue, evacuation or victim care (physical or psychological). Actions appeared facilitated by different factors, such as: extensive knowledge of the area (which formal actors did not possess), shared values and equipment in this camping community, relevant skills or professional competence.

4 Connecting societal resilience and Resilience Engineering

We can relate insights and results from disaster research to the maladaptive patterns mentioned in section 2. This analysis allows us to understand the contribution of informal actors to resilience and to suggest ways in which the patterns can be better avoided and the potential for resilience increased.

Pattern 1 (decompensation) – The most obvious contribution of the population during disasters concerns the additional capacity individuals and groups bring to the response and recovery phases. Members of the population provide a valuable resource in order to address the first maladaptive pattern in two major ways. First, as an extension of formal responders, by providing more capacity to conduct similar tasks, helping formal operators directly or providing relevant equipment (e.g., a tractor in rural areas where formal resources are scarce). A special case is when people act in the immediate onset of an event, before formal responders are present on the scene. Second, as a way for formal organizations to offload some of the demands, allowing responders to concentrate on the tasks for which they are the most needed (e.g., tasks that require professional competences and/or equipment). This can be seen as a form of system reconfiguration, as described by Cook and Nemeth (2006), in which civilians take care of non-operational tasks and formal actors focus on emergency and safety-critical ones. A key issue lies in the need for informal actors to act safely so that risks taken do not end up creating more demands. One approach is to actively build basic knowledge or event skills in the population through awareness or training campaigns (such campaigns often target schools and the youth). For instance, in Israel, a country exposed to significant earthquake risks, high-school students are trained to conduct light search and rescue, resulting in trainees' increased perception of resilience, self-efficacy and knowledge (Peleg *et al.*, 2018). This is a pragmatic approach: acting quickly, even with limitations or in non-ideal conditions, has significant impact.

Pattern 2 (working at cross-purposes) – The involvement of informal actors makes avoiding this pattern particularly challenging – and is part of the core issue in the view of formal actors. The Utøya case analysis suggests a relative absence of coordination between informal actors, or between them and rescuers. In this case, it does not seem to have resulted in negative consequences, but this aspect of the case should certainly not be seen as contributing to overall resilience. One approach to this pattern is about increasing preparedness of the population, especially related to knowledge of roles and responsibilities. This can be achieved through information campaigns or, ideally, through organizing exercises involving both formal and informal actors; however, the challenging scale of such exercises means that they remain rare. Organizations such as FEMA have also proposed frameworks targeting specifically the integration of spontaneous volunteers in disaster management, both with regards to the operational structure and from a legal standpoint. Apps and platforms have been proposed to register and track affiliated or unaffiliated volunteers, as well as to register and use capabilities they provide. However, the latter approaches are targeted at formal organizations, therefore do not apply when these are not yet on the scene.

Pattern 3 (getting stuck in outdated behavior) – A significant contribution of individuals or groups of the population relates to initiatives developed to address gaps in the formal management of situations. Numerous examples of civilian- or business-based initiatives arose during the COVID-19 pandemics and received considerable publicity, such as networks emerging to support vulnerable groups of the population with basic food or other needs. Often, such initiatives emerged quickly and took the form of innovative solutions or use of existing means (such as social media platforms). An example of such innovation is the development of the "Week-Ends solidaires" (*Solidarity Weekends*), an association that emerged in Nice, France, in 2020 to organize volunteers in rebuilding nearby rural communities affected by the storm Alex. An organizer of large events, the founder of the association innovated through applying his competences in logistics to rally and transport each weekend significant amounts of volunteers and supplies to areas in needs of help. Due to its scale and diversity of competences, the population can greatly multiply the capacity of formal actors to innovate in the face of new challenges. Sometimes, civilian-based initiatives are recognized and formalized, as with the "Week-ends solidaires", which later managed to gather financial help and build cooperation with businesses to support its activities. However, the capacity to capture innovations from the population would be improved through more systematic involvement in the learning efforts following disasters – a recognized gap in disaster management.

5 Discussion

The consideration of the contribution of informal actors to resilience does not fundamentally change its nature or components as understood in RE and associated domains of study. However, the broadening of the system of interest and inclusion of non-professional actors shifts our attention.

The typical focus on developing professional skills (technical and non-technical, e.g., joint activity) and high value put on expertise shift towards supporting initiative: understanding how it is motivated, how it can be better integrated in the larger system that addresses the demands of an event, including how we can learn from it to develop new strategies. The importance of initiative is recognized in RE literature but, in our mind, has not received as much explicit attention as other topics. The results described here are consistent with the "additional essentials of resilience" described by Woods (2019): (1) initiative, (2) managing the expression of initiative, (3) reciprocity. In that paper, (1) and (3) are discussed in professional settings, in response to plans that no longer fit the situation at hand or in preparation activities (e.g., in anticipation of workload crunch). In the context of informal actors involved in disasters, initiative stems from individuals with no formal role, no pre-established plan or contingency measures and in reaction to events (not in anticipation). Also, initiative is associated in RE with a general deference to expertise. Here also, we find an important difference in the fact that the (formal) actors in charge are usually not willing to adopt such stance. Furthermore, informal actors often act *against* requests from actors with authority, as was the case in the Utøya event. Actions from non-professionals (or, more accurately, non-specialists of disaster management) suggest forms of resilience that are distinct from capacities also connected with robustness, i.e. trained capacities to react and adapt to planned disruptions. These actions can draw from skills and competences acquired in other, potentially non-professional, domains. Finally, when members of the population act, reciprocity is also cited as a motivation for action but it is perceived in a much larger and more hypothetical social and temporal context (e.g., the belief that somebody else would do it for you or your own loved ones).

The traditional focus on control of the situation as a whole shifts in recognition of the pragmatic need to have an impact quickly in the face of demands at the local level and in spite of sub-optimal conditions (e.g., absence of visibility of the whole situation). Actions taken by informal actors appear to be motivated by the recognition of a specific and immediate need. If control is still the issue, it is that of the situation immediately at hand, not of the whole situation. What makes the difference in the situation as a whole is not that a careful response is coordinated across actors, but rather that individuals or small groups take the initiative to address a gap, an urgency they experience in front of them, thereby reducing the overall demand. However, the "audacity" described by Woods (2019) might appear to be a double-edged sword: events in which informal actors played a decisive role (e.g., Utøya, Thalys train attack) risk leading to positive judgments after the fact but could have had other outcomes in other circumstances.

6 Conclusion

The consideration of informal, non-specialist actors emphasizes the value of initiative in supporting overall resilience. However, initiative in disaster situations might involve high risk for the individuals acting as well as for the overall management of the situation. We are therefore put in a paradoxical situation, in which we observe, over and over, that the population is a major source of resilience through initiative but, at the same time, we cannot take a normative approach and systematically advocate for such active role.

The societal nature of disaster resilience highlights the political nature of these questions: there is a risk of transfer of responsibility to communities, expecting them to "be resilient" – including without appropriate capabilities and resources. Similarly to work organizations relative to safety-critical operations, authorities ultimately have the responsibility to create the conditions for initiative to be possible in safer ways. To support authorities and the society as a whole, we need to pay more attention to initiative as a characteristic of resilience and investigate it more explicitly. Such investigations will allow us to better understand associated challenges and potential approaches.

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Flightdeck Observation for Learning from Successful Daily Operations: Development of JAL Resilience Operation Monitoring

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One of the critical challenges for Safety-II is to realize learning from things that go well in daily operations to improve resilience potential. However, further case examples and practical knowledge are still required to exemplify what lessons can be learned from daily successes and how the lessons can be applied. This paper presents an overview of the Resilience Operation Monitoring (ROM) framework, a flightdeck observation from a Safety-II perspective for learning from successful daily flight operations, developed in cooperative research of Japan

Airlines (JAL) and the socio-technical systems research team in Tohoku University in Japan. Up to date, 199 flight observations have been completed by nine ROM observers and proceeded to the data analysis phase. The preliminary analysis of the collected observation data suggests that crew behavior during the preflight and cruise phases might have some effect on crew resilience potential. Further detailed qualitative and quantitative data analysis is planned to reveal the characteristics of the resilient performance of flight crews.

Keywords: Learning from normal operations, resilience potentials, flightdeck observation, flight crew.

Introduction

One of the critical challenges for Safety-II is to realize learning from things that go well in daily operations to improve resilience potentials (Hollnagel, 2011). In practice, however, learning from day-to-day successes is more challenging than conventional learning from failures. The first is the difficulty in identifying the target to be learned. Failures can be defined clearly as deviations from the expected range of performance, deviations from prescribed procedures, etc., and, thus, identified relatively easily. In addition, the number of failures (undesirable performance) is much smaller than the number of successes (desirable performance). This is an important feature for conducting practical case analyses and countermeasures with limited time and resources. In contrast, successes exist in myriad ways in daily work. Therefore, it is necessary to consider from which of these we can learn valuable lessons and to clarify the criteria for extracting from the myriad of successes that should be the subject of learning. Second, further case examples and practical knowledge are still required to exemplify what lessons can be learned from daily successes and how the lessons can be applied. Accumulating such knowledge and experience through exploratory research is indispensable to making learning from successes in normal operations practical.

An example of an organizational effort to learn from successful daily operations in aviation is the development and implementation of flight deck observation from Safety-II perspectives by American Airlines' Learning and Improvement Team (LIT) (American Airlines' Department of Flight Safety, 2020; American Airlines' Department of Flight Safety, 2021). The flightdeck observation developed by LIT records positive aspects of crew performance in normal operations. The recorded data is coded and analyzed using behavioral markers called LIT Proficiencies. In Japan, Japan Airlines (JAL) and the socio-technical systems research team at Tohoku University have been developing Resilience Operation Monitoring (ROM). This flightdeck observation aims to learn from successful daily operations based on LIT efforts. The authors participate in the development and implementation team and are engaged in collaborative research. As of February 2023, the development and implementation team of ROM (from now on referred to as the "ROM Team") has completed observations of all 199 flight legs and proceeded to the analysis phase of the collected data. This paper presents an overview of the ROM, some preliminary analysis results of the observation data, and our future work.

Overview of ROM

Purposes

The ROM has been developed jointly by JAL's Flight Safety Management Department, Flight Training Department, and the socio-technical systems research team at Tohoku University. The ROM team comprises about 20 people, including captains serving as ROM observers, researchers, project management staff, and a data scientist. The practical objectives of the ROM are as follows:

- To gain knowledge contributing to planning measures for safety enhancement from a perspective different from that of Line Operation Safety Audit (LOSA), which has been conducted conventionally.
- To evaluate the effectiveness of Evidence-Based Training (EBT), which has been introduced as one of the main objectives to enhance the resilience potential of pilots, by analyzing Work As Done during actual flight operations and to utilize the results for further improvement of EBT.

The ROM team began studying the design and implementation of ROM from June 2021 onward and conducted trial observations over three months starting in May 2022. Then, flightdeck observations were conducted for 199 flight legs over six months from August 2022 to January 2023.

Procedures

The ROM observers conduct flight observations and prepare data for analysis following procedures.

1. With the crew's consent, an observer accompanies the crew on the flightdeck to conduct the observation. The briefing is also subject to observation but is not observed in case the schedule does not allow it. The observers this time were the nine captains from the flight safety management and flight training departments participating in the ROM team.
2. After the flight observation, the observer generates the following raw data:

- General description of the flight
- Descriptions of respective situations (narratives) where resilient crew performance was observed (hereafter referred to as "events")
- Resilient performance at each event was coded using two behavioral markers, which were modified LIT Proficiencies and Performance Indicators (PIs) used in EBT.
- If necessary, threats during the event were recorded as Pressures. Pressures were in accordance with those defined by LIT.
- In addition to the above, an optional online questionnaire on psychological safety (Edmondson, 2018) was requested to be completed.

3. The above data was cleaned and verified, basically, by three or more observers.

Coding Framework

Narratives recording the events were coded using the following behavioral markers.

Resilience Potentials and Their Behavioral Markers

In the coding framework of LIT, the four resilience potentials consisting of Respond, Monitor, Learn, and Anticipate proposed by Hollnagel (2011) were adapted to the daily works of flight crews and redefined as the LIT potentials consisting of Adapt, Coordinate, Learn, and Plan (American Airlines' Department of Flight Safety, 2020). The narratives were then coded using behavioral markers named Proficiencies, which indicate the behaviors in which each potential was expressed.

In ROM, the LIT potentials were also adopted. Still, its explanatory model incorporated the concept of time frames to make it practical to support coding by the observers (Fig. 1). Figure 1 shows a typical example of the timeframes in which behavior based on each potential can be observed and interrelationships between potentials, in contrast to the timeframes in which crews face manifest disturbances and opportunities. In reality, however, multiple processes shown in Fig. 1 may occur simultaneously, such as anticipating and planning for the subsequent development while adapting to present disturbances. In addition, the modified Proficiencies were used as the behavioral markers in ROM. The modification added some behavioral markers with reference to PIs to allow smooth coding of communication-related behaviors often reported as the crew's positive performance during the trial observation.

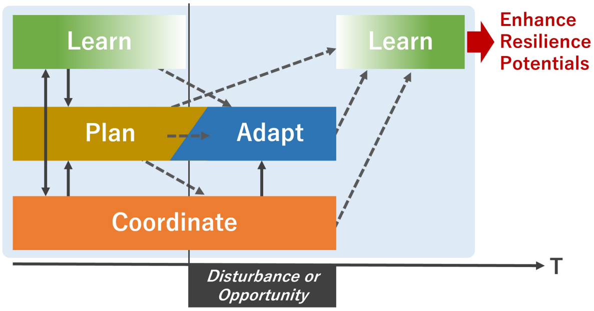

Fig. 1 ROM Resilience Potential Model

Performance Indicators

Recorded narratives were also coded using PIs, which are behavioral markers corresponding to respective competencies used in JAL's EBT. By using the same behavioral markers as EBTs, it is possible to evaluate the effectiveness of EBT based on obtained data from actual flight operations.

Observation Guidelines

Learning from daily successes is difficult because there are numerous successes, or desirable resilient performances, in normal operations. In particular, crews that achieve safe and efficient flight operations in a dynamic environment on a daily basis are, to a greater or lesser extent, performing resiliently, going beyond regulations. Recording and analyzing all the resilient performances would be impossible and would not lead to extracting practical and effective lessons. Therefore, ROM decided to exclude positive performance that most pilots would naturally behave that way. Furthermore, the following three guidelines were defined to support the observers in extracting the crew's positive behaviors in fluctuating human performance in dynamic contexts.

- The presence or absence of deviations from Standard Operation Procedures (SOPs) is not included in the criteria for determining the crew's positive performance. Even if there were unavoidable deviations from SOPs in light of the circumstances, the crew performance can be considered positive if the crew demonstrated excellent resilience.

- The outcome of behaviors is not included in the criteria for determining the crew's positive performance. Even if the outcome of behaviors is a failure or the behaviors are unnecessary as a result, the crew performance can be considered positive if valuable lessons can be learned from the process. Whatever the origin of the undesirable event (even if it was an obvious misjudgment or mistake), the crew performance can be considered positive if valuable lessons can be learned from the recovery process from the undesirable event.

In addition, not only resiliently dealing with predictable or apparent disturbances but also being alert and prepared as a crew for unexpected disturbances under changing conditions (from now on referred to as Readiness) is considered important as an example of resilient performance. Therefore, so that the resilient performance of flight crews, including the aspects of readiness, can be recorded and analyzed, ROM prepared the R+ marker. The R+ marker is awarded to flights where it is felt, based on the subjective judgment of the observer, an experienced captain, that "the crew would be able to handle the unexpected disturbance resiliently," regardless of whether or not an actual disturbance occurred during the flight under observation. That can make it possible to analyze the characteristics of crew performance on flights with R+ markers.

Results

ROM has completed flight observations and data validation and then proceeded to data analysis. Some preliminary results available at this stage are presented in this section, although they are based on simple aggregate results. ROM observed 199 flight legs and recorded 1194 events (including events where only one of the Proficiencies or PIs was registered) and 2629 proficiencies. At the moment, proficiencies were aggregated for each resilience potential and will henceforth be referred to as Resilience Potential (RP) markers.

Figure 2 shows the average numbers of respective RP markers per flight. Similar to the results reported by LIT, COORDINATE is the most frequent, followed by PLAN and ADAPT, and LERAN is the least frequent. Figure 3 compares the average number of RP markers per flight phase between flights with and without R+ markers. In the preflight and cruise phases, where the briefing takes place, there are differences between the flights with ad without R+, especially concerning COORDINATE and PLAN potentials. In addition, the number of markers of LEARN potential seems different in the preflight phase. Because these preliminary results are based on a simple aggregation of the number of each RP marker, more detailed analyses are planned in our future work.

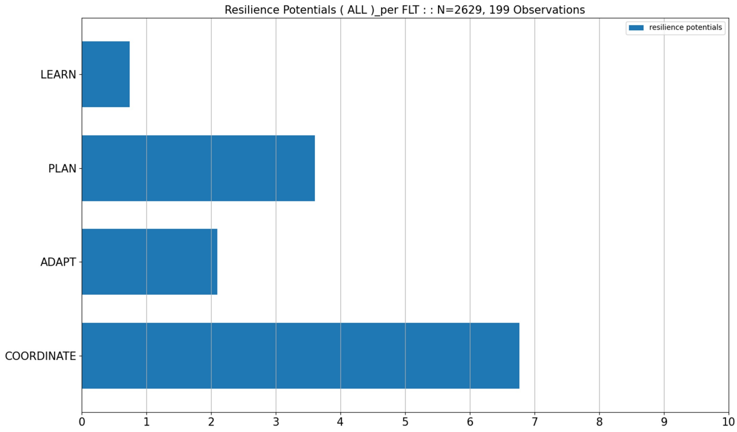

Fig.2 Average number of resilience potential markers per flight

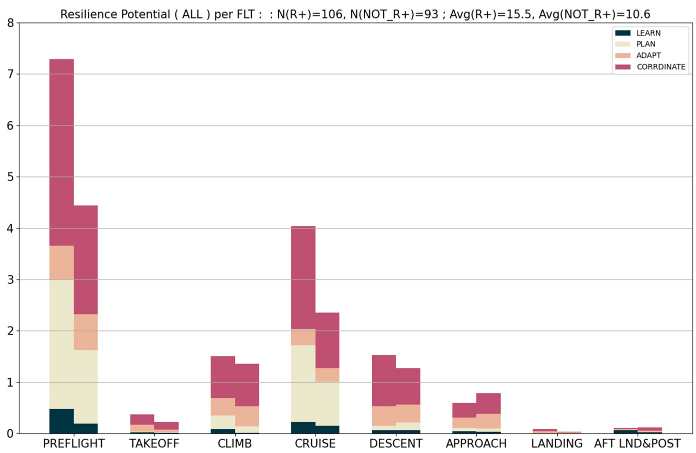

Fig.3 Average number of resilience potential markers per flight phase (Left: Flights with R+ marker, Right: Flights without R+ marker)

Summary

This paper presents an overview of the Resilience Operation Monitoring (ROM) framework, a flight observation from a Safety-II perspective, and preliminary analysis results of the collected observation data. The preliminary analysis suggests that crew behavior during the preflight and cruise phases might have some effect on crew resilience potential.

Our future work contains the improvement of the accuracy of quantitative analysis, taking into account various conditions to better understand the overall trends in the collected data. In addition, for extracting insights that can lead to improvements in safety measures and training, further detailed analyses of observation data using PIs, competencies, narratives as well as narratives are conducted to clarify "why and in what aspects the recorded performance is resilient" and "what behavioral characteristics are involved in the background of such performance."

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Learning and Improvement team

Nicholas Peterson

The Learning Improvement Team is a safety program designed to learn what makes flight operations at a major worldwide airline successful. Developed as a partnership between and airline and its pilot labor union, the program uses four primary methods of data capture: flight observation, pilot interviews, pilot surveys and learning teams. Because the Learning and Improvement Team is looking at safety differently (Sidney Dekker, 2022), it has faced some challenges in its development. Awareness of the program and a general understanding of what the program is trying to accomplish have been slow to develop but are improving. Additionally, data analysis and presentation have proved problematic because the data looks very different than data currently available to the airline. Despite these challenges, the Learning and Improvement Team has steadily been and has found a place of permanence within the airline's Safety Management Systems. The data captured has given the airline an additional stream of information not previously available and has been fed back into the operation as content for training courses attended by pilots and reviewed on a monthly basis at airline safety meetings. By being able to look at all operations, not just the negative outcomes, the airline and its pilots can be better positioned to learn, both as individuals and as an organization.

Keywords: Learning and Improvement Team, Shop Talk, Learning Team, Learning Teams, Safety II

Introduction

The Learning and Improvement Team (LIT) was established in 2019 as a proof of concept in adopting Safety II concepts to airline safety. The task was to develop a method for collecting data from normal flight operations where no unwanted or undesired outcomes occurred. Traditionally, aviation safety has studied risk by looking at incidents and accidents, in efforts to learn about and control said risk. As these events decreased in number and aviation became less risky the vast majority of operations were not studied at all. To understand how the system is working, good or bad, it must be looked at it as a whole, studying both success and failure (Hollnagel, n.d.). LIT was designed to be complementary to the other SMS programs to help the airline learn from all operations (FSF, 2021). Support and funding for LIT exists at the highest levels within airline management as demonstrated by the growth from a team of two to the current 20 between 2019 to 2022.

Methods

Since no other program of its kind existed, LIT had to discover and understand which collection methods would be most effective in capturing the desired data. The solution was a combination of traditional social science methods including observation, interviews, and site surveys.

The first LIT method of data collection is direct flight observation. Hundreds of real-world lights flights have been observed by LIT *Learning Navigators;* pilots who have had special training in flight observation. Data from these flights provide opportunities to witness and learn about the human contribution to safety and what pilots do on a day-to-day basis.

Navigators also conduct interviews, or "Shop Talks," with pilots discussing a variety of topics. Shop Talks are typically 30-45 minute facilitated interviews using a format that allows for exploration of pilots' critical thinking and decision making, helping the airline gain insight into how its pilots think and why they make the decisions they do.

Currently, the airline is experiencing a significant loss of experience in its pilot workforce due to the mandated retirement age of 65 and is in the middle of a wave of retirements with approximately 30 percent of its total pilot population retiring over the next five years. This has caused the time for a first officer to upgrade to captain to fall from above 15 years to below three years. While there is no way to compress 15 years of experience and knowledge into three, efforts must be made to facilitate this knowledge transfer.

For this reason, LIT placed a survey within the airline's Professionalism, Leadership and Mentoring (PLM) course. PLM is a mandatory class that all captains and long-haul first officers (any pilots that will command and aircraft) must attend. Survey questions asked current captains questions about the challenges of being a captain and what advice they would give to new captains in.an effort to capture and transfer as much knowledge and experience as possible. These experienced captains are an invaluable resource, and every effort is being made to retain as much of their knowledge and experience as possible. By learning from their decision-making process can help the training department prepare new captains for command. Additionally, these skills can be used to mentor first officers and prepare them for their eventual command. To help improve the captain and first officer information exchange, LIT has added data content from flight observations to the PLM course to educate captains on how best to utilize their first officers and to mentor them for the future.

In December 2022, LIT debuted its first two *Learning Teams*. These took place at two major operating airports for the airline and LIT Navigators facilitated individual discussions with more than 130 pilots on a variety of operational challenges specific to those airports. In particular, questions were aimed at what considerations those pilots had when trying to operate within those challenges.

Through its efforts, LIT has observed or had direct contact with over 1,400 pilots and gathered data on how everyday work is carried out by these pilots. The data is shared internally during monthly safety meetings as well as the above-mentioned PLM course and Recurrent Human Factors (RHF), a course every pilot must attend annually as part of recurrent training. All pilot participation is voluntary, and all data is de-identified.

A dedicated taxonomy was created to aid in data collection from flight operations. Comprising of four Potentials, this taxonomy is based on the Resilience Analysis Grid by Erik Hollnagel. At Professor Hollnagel's recommendation, the potentials were modified slightly based on the dynamic environment of a modern flight deck. The four LIT potentials are *Learn, Plan, Adapt* and *Coordinate*.

Within each potential there, is a subset of Proficiencies. These 28 proficiencies are observable actions LIT Navigators can witness pilots carrying out during flight. Proficiencies are captured with a collection tool and exported to a database for data analysis. By studying these proficiencies, the airline can begin to understand what actions and adaptations pilots make in their complex and changing environment.

LIT has gained some fascinating insights that would not have been possible prior to its creation. The relationship between captain and first officer can be viewed in ways not previously possible, showcasing how they interact and what the strengths and weaknesses are. This has given the airline a better understanding of its flight deck culture and how to promote leadership development and mentoring. What is remarkable to note is that, many times, pilots are unaware of the accommodations and tradeoffs they are making every day, as they are doing them instinctively based on years of experience. Capturing proficiencies can provide the airline opportunities to track changes in pilot behavior over time and the impact of training changes.

Practical Challenges

Despite its success, LIT has faced some challenges to this new view of safety. One of the challenges facing LIT is how to present the data it collects, given that the data looks quite different from other data presented within the airline's SMS.

Interviewing pilots can provide tremendous insight into their thought and decision-making processes and has produced some incredibly rich data, but because this data is entirely in narrative format, and it looks very different from other SMS data. Finding a way to translate this into presentable content is still a work in progress. Significantly, because LIT highlights normal work that didn't result in incidents or accidents, that data may be perceived as less stimulating or important because nothing bad happened. However, this data can be extremely valuable because it provides opportunities to look at how things went, even when nothing significant enough occurred to manifest itself in other data streams as an exceedance. Additionally, LIT data is exploratory; thus, more qualitative than quantitative. This creates a challenge as demonstrating why it is important to look at all outcomes, not just the undesired ones. Airline safety leaders are used to studying known rates of occurrence for known things and are not as familiar with studying a new data stream that has only recently become available. This will improve over time as the material becomes more familiar.

Another challenge was lack of internal awareness within the airline about LIT and the work it is doing. This is true for both the airline itself as well as the pilot group. Externally, LIT has become well known for its efforts and progress but, unfortunately, such awareness did not exist internally for some time. Through perseverance and persistence this lack of notoriety is changing. As time has passed, more and more pilots are becoming aware of LIT and what the program is doing. Buy-in and support from both the pilots and airline management has continued to increase and has significantly improved since mid-2022.

Conclusion

Despite these challenges, LIT has become a valuable program because it is able to capture data that was not available in the past, simply because there was not a program designed to capture it. The challenge currently facing LIT is data analysis and presentation. Moving forward, the focus for LIT, besides continued data collection, is to intently review the data collected thus far, continue to discover what it contains, present findings to both AA safety and its pilots, and continue the journey of learning what goes well, and why it goes well.

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Post Incident Learning

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I am a Distinguished Engineer at IBM, working in our CIO organization which is responsible for all the IT systems that keep our large, global, complex enterprise up and running. I was fortunate to attend, and present at the REA symposia in 2017 and 2019. Over the past 13 months, our organization has made significant and rapid progress transforming our approach to post-incident learning. We have moved from a traditional RCA-based approach toward a resilience engineering approach to learning from incidents. I described our adoption journey in our recent presentation at the Learning from Incidents in Software conference. A centerpiece of our Learning from Incidents (LFI) Program is a monthly meeting in which executives, our most senior technical leaders, and many others gather to review and discuss the story of one recent incident.

In the context of this symposium's theme of *boundaries*, I will note that my lens is through that of a large-scale organization in which boundaries are a prominent feature at multiple levels and in multiple dimensions. For example, with respect to cross-company boundaries, we are both dependent on other companies (the many vendors who provide software services that we consume) and we are depended upon by other companies (our customers for who we provide services). This pattern is replicated internally with many cross-team dependencies across internal service consumers and service providers. Our LFI monthly meetings frequently feature discussions about the challenges that we observe at these boundaries.

These monthly LFI meetings are also notable in the way that they break down traditional boundaries with respect to *seniority*. The attendance of these meetings features great diversity of seniority levels, with vice presidents attending along with junior engineers, new hires, and every role in-between. The meetings create a unique opportunity for team members to observe how their leaders react to hearing about surprises, and (most importantly for adoption) for them to observe their leaders' *interest in* learning about surprises.

Our adoption journey also provides an opportunity to explore how boundaries affect adaptive capacities. In software systems, boundaries are dynamic in both the technical and social dimensions. For example, incident response in software systems frequently involves the appearance and disappearance of ad hoc boundaries based on the demands of the response effort.

Our efforts to scale up adoption by providing enablement materials and other artifacts is likely relevant to scaling efforts in many other organizations.

I can also speak about how my role as a Distinguished Engineer is specifically designed to be cross-boundary in nature, with the responsibility of driving transformation across a large organization with significant *influence*, but without any direct *authority*.

Thank you very much for your consideration.

Deep down and up high resilience in systems recovery - studying the San José Mine (2010) and Apollo 13 (1970) accidents

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Deep down in the Atacama Desert, on August 5th, 2010, a series of explosions cause the collapse of San Jose copper-gold mine, trapping workers 700 meters underground under tons of rocks and debris. Up high in the space, about 400,000 kilometers from Earth, a fire followed by an explosion severely destroyed the Apollo 13 spacecraft on April 14th, 1970. Two distinct accidents, separated in time and space, but that share the same resilience in the face of emergencies in inhospitable environments. Based on the official reports, books and scientific publications, a systematic and comprehensive study was developed using FRAM (Functional Resonance Analysis Method), identifying how the integration between human skills and technology contributes to overcome the adversities arising from these accidents. From this, it was possible to observe how human competences are essential to not only promote safety in work activities, but also build the resilience of a system, enhancing workplace's capacity to receive disturbances and generate stability, even in the face of situations never before foreseen in extreme work environments.

Keywords: Resilience, FRAM, non-technical skills, accident, mining, aerospace.

1. Introduction

Since Jacob Bigelow's Elements of Technology publication in 1829, definitions of technology have been stated, having evolved as much as technology itself (Carrol, 2017). In a concise and direct way, technology can be understood as the practical application of scientific knowledge, through instruments, creating something useful for the development of Society. Having time as a defining element, (Kay, 2020) states that technology is everything invented after someone is born. Having as reference the artifacts built by man, technology can be discerned between things that are human-made and those that can be naturally find in nature (Brey, 2009), having a clear boundary between what is from/placed in nature and, and what is created by human intervention. This concept is very well observed since the first hominids, when their action on rocks, wood, animals and vegetation transformed these elements of nature into tools, weapons, clothing and shelter (Condemi & Savatier , 2018). Moreover, technology can also be understood as a system, a compendium of interactions between people and things, created by humans that uses their knowledge and social organization to produce objects, procedures and techniques aimed for a specific goal (Volti, 2009). Adopting these references and contextualized in the industrial accidents studied by this research, technology is defined as everything that is conceived, built, manipulated, transformed and it is in constant interaction and evolution with human.

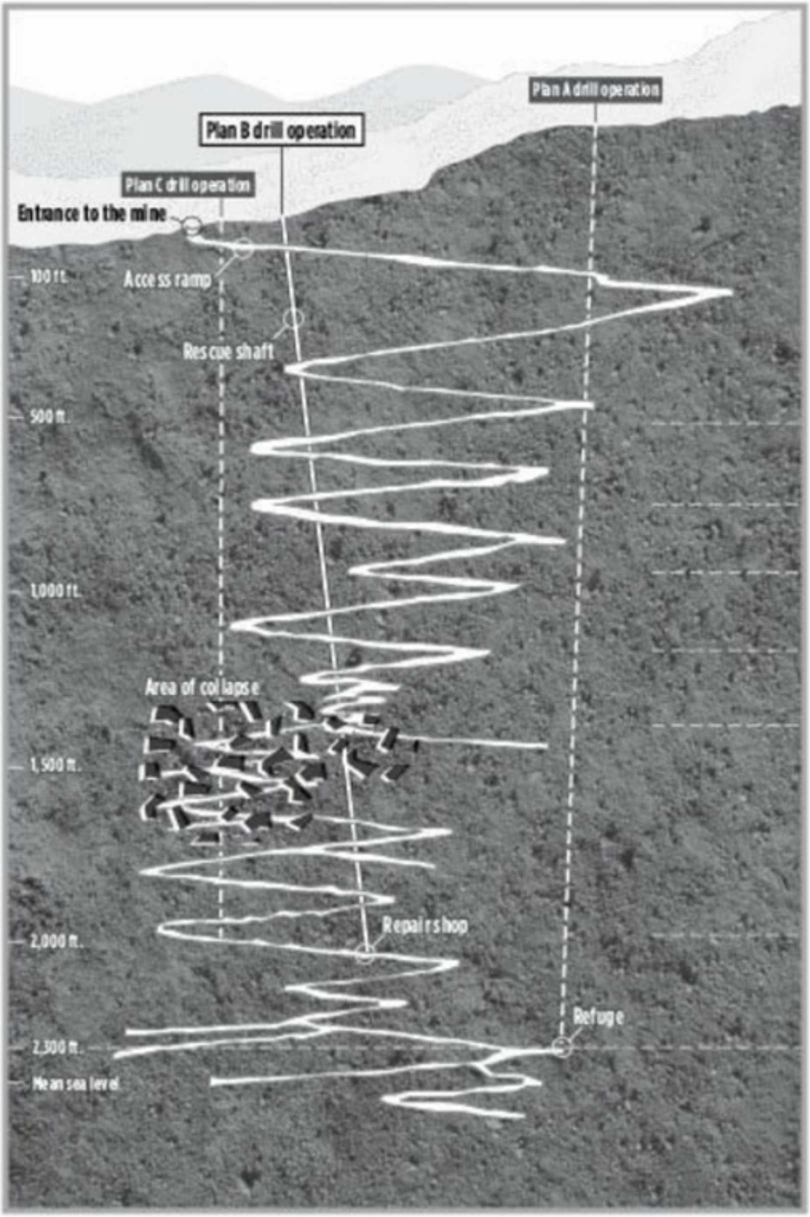
Therefore, technology forms, while is formed by, Society, from the simplest objects, such as a fork or a pen, to the most complex, such as a spaceship or an aircraft. Technological evolution, therefore, is intertwined with the social evolution of humanity itself, when, for example, a piece of rock became a hunting and cooking resource, a heap of ores became a weapon and tool and a set of simple elements, such as machines, process, procedures and workers, today, interacting together, form a complex sociotechnical workplace. In this research, three of these workplaces are the object of study, from the event of an accident. In this study, performed by FRAM (Functional Resonance Analysis Method), it is possible to perceive that the interaction between people (workers) and the technology present in these complex sociotechnical systems, enables an enhancement in the emergency and contingency actions, allowing that even in a catastrophic accident, human actions can result in system-wide recovery. In other words, the system's resilience, its ability to receive disturbances and continue to function, adapting to the imposed changes, is the result of the interactions of this system itself, having as resources human skills - technical and non-technical, as well as the available technology.

2. The Functional Resonance Analysis Method - FRAM

The Functional Resonance Analysis Method is a methodology that enables a graphical analysis of how things happen, from a simple production line, till a complex operational cockpit of a spaceship or civil aircraft (Hollnagel, 2012). Due its structure, it can be used to analyse past events, such as an accident investigation, as well as the actions to recover from this, as will be presented by this study. The analysis performed by FRAM is not a mathematical analytic process, but rather a gradual development of an integrated understanding among professionals over a given situation, context and premises (França, Hollnagel & Praetorius, 2022). This analysis allows the understanding of how people interact with the technology of the systems in which are inserted, collectively or individually. To build a FRAM, four steps are needed, starting with the identification and the description of the functions, which can be human, technological, or organizational, depends on its natures in the system (Hollnagel, 2012). Once the functions description is done, the second step is the set of the output variability of each function, characterizing each one with its potential and actual performance variability (Hollnagel, Hounsgaard, & Colligan, 2014). The third step is the examination of the system's functioning, analysing the variability of each function (internal variability) and the variability deriving from the outputs of the other functions (Hollnagel, 2012). And finally, in the fourth and last step, it is done the monitoring and managing of the performance variability of the entire system, identifying the functional resonance that characterizes the performance variability of sociotechnical system (França et al, 2019). The FRAM function is formed by six aspects in the corners of the hexagon, being Input, Output, Time, Control, Precondition and Resources. The function has five potential input connection from the system (Input, Time, Control, Precondition and Resources), and only one output (Output), which will be the input to another function. Appling FRAM to analyse the recovering actions of San José Mine and Apollo 13 accidents will conceive a systematic and integrative view of the resilience behind these events.

3. The accident of San Jose Mine, in 2010

The San José Mine accident happened in August 2010, inside of a copper-gold mine, located in the Atacama Desert, at Copiapó, in Northern of Chile (Franklin, 2011). After the occurrence of a series of explosions, 33 workers got trapped 700 m directly underground, but 5 km from the mine's entrance via spiralling underground ramps, as showed in figure 1.



Source: Franklin, 2011.

After 69 days underground "Los 33", as called by the Chilean rescue team, were rescue alive, owing to a joint effort of people and technology: a complex sociotechnical combination of high-tech drilling equipment, human skills (technical and non-technical), non-conventional operational procedures, psychological support and a cooperation between entities. Soon after the accident, Codelco, the Chilean state-owned mining company, took over rescue operations, and made few exploratory boreholes to assess and develop a rescuing strategy (Aronson, 2019). From one of those, 17 days after the accident, a note was sent from underground: "Estamos bien en el refugio los 33" (Franklin, 2011). After this, a cooperation between drilling rig teams companies, Chile government, NASA, and few non-mining companies around the World develop a tailored rescue system with special escape capsules, using high-tech technologies from NASA and drilling companies (Aronson, 2019). On 13 October 2010, the miners were winched to the surface one at a time and, with few exceptions, they were in good medical condition with no long-term physical effects anticipated. Analysing these rescue actions with FRAM, the model of figure 2 was developed, showing how this complex combination of high-tech equipment, human skills, psychological support and special procedures culminated in one of the most successful rescues of the mining History

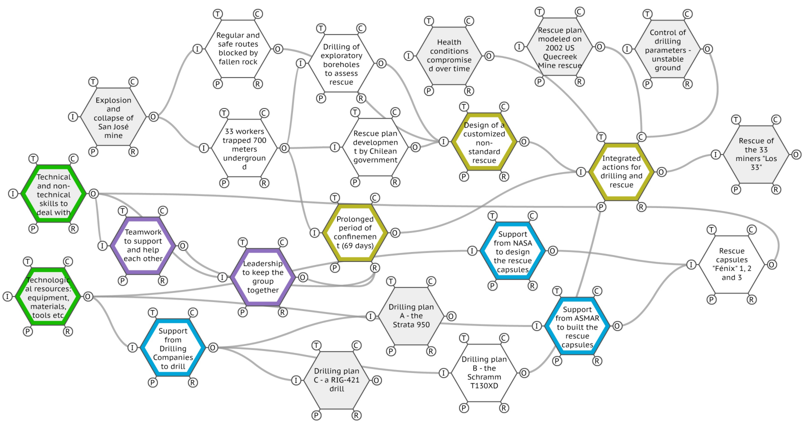


Figure 2: The FRAM of the rescue of the 33 miners "Los 33".

Source: The Authors, 2022.

4. The accident of Apollo 13 Spacecraft, in 1970

The Apollo 13 accident occurred on April 13, 1970, approximately 400,000 kilometres from Earth, having a fire followed by an explosion that severely damaged the SM (Service Module) of the CSM (Commander/Service Module), blasting away an external panel of the SM, as can be seen in figure 3 (Lovell & Kluger, 1994). There was an explosion and rupture of oxygen tank number 2 in the service module, rupturing a line (or damaged a valve) in other oxygen tank, number 1, causing it to lose oxygen rapidly. The Service Module Bay number 4 cover was completely destroyed. All oxygen stores were lost within about three hours, along with loss of water, electrical power, and use of the propulsion system (Clemons, 2018).

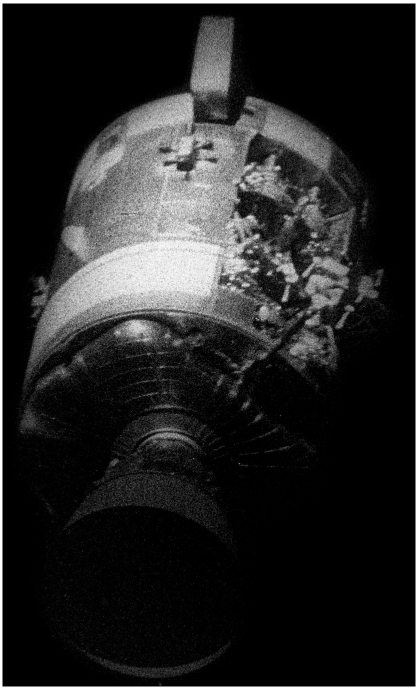


Figure 3: The external panel of the SM of Apollo 13 CSM.

Source: Lovell & Kluger, 1994.

A series of actions, onboard, in the spacecraft, and on land, in Mission Control, coordinated and connected, made the accidental scenario of the Apollo 13 mission able to recover and bring the entire crew back to Earth. But for that, it took many hours of training and preparation, refining the technical and non-technical skills of pilots, navigators, engineers, leaders, mathematicians and several other professionals. In fact, the Apollo 13 prime crew undertook over 1,000 hours of mission-specific training, more than five hours for every hour of the mission's ten-day planned duration (Kranz, 2009). Each member of the prime crew spent over 400 hours in simulators of the CM (Command Module) and of the LM (Lunar Module) at NASA's training facilities, some of which involved the flight controllers at Mission Control. The integration between different areas, of a complex sociotechnical workplace, is a key-element for the emergencies preparedness, enhancing the resilience of the entire system (Clemons, 2018). Additionally, for Apollo 13 mission, flight controllers participated in many simulations of problems with the spacecraft in flight, which taught them how to react in an emergency scenarios and losses of system control, working together with the crew mission (Kranz, 2009). Having this information and focusing on emergency actions to bring the crew of Apollo 13 safely back to Earth, the FRAM of figure 4 was developed, showing how the set of technological artifacts, human skills and training culminated in recovery of the complex sociotechnical system.

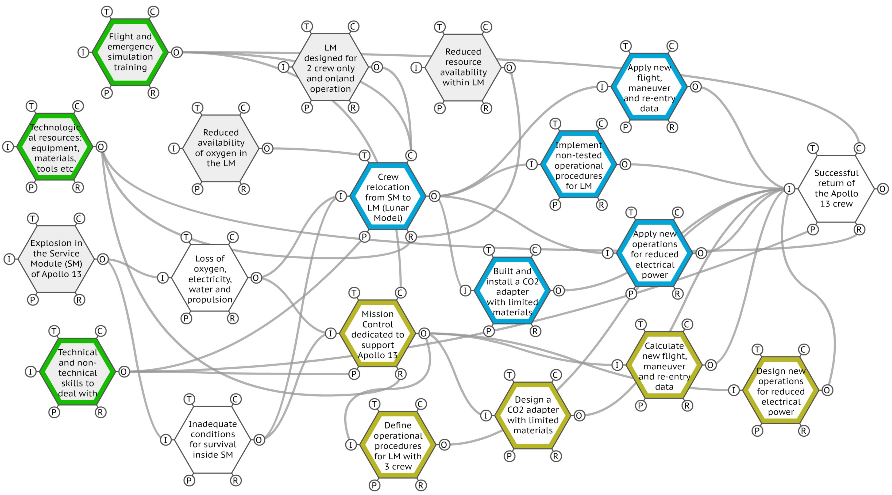


Figure 4: The FRAM of the Apollo 13 recovering actions. Source: The Authors, 2022.

5. Results and findings - comparative analyses of the accidents

Examining the FRAM models of each of the recovery actions of these accidents, it's possible to notice that, despite the domain's difference and the 40 years of time lapse (1970 – 2010), there are more coincidences than differences in between them. Some non-technical skills are observed in the actions and activities performed by rescue teams, such as communication and teamwork. Non-technical skills are defined as the cognitive and social skills that complement technical skills and contribute to safe and efficient task performance (Flin & O'Connor, 2016). From this comprehensive set of skills, five of them denote different importance: communication, leadership, teamwork, situational awareness, and decision making (França et al., 2022). Specially in work environments that have a massive technology and human interaction, the complex sociotechnical systems, these five non-technical skills support the necessary adaptability to deal with different and dynamic constrains that emerges from the system itself. Analysing these concepts in the recovery actions of these two events – San José Mine and Apollo 13 – it is possible to notice that the system's resilience it is supplied by the worker's skills who compose this.

In the San José accident, the teamwork, was present both in rescue teams and in the trapped works, forming a self-sustain network of support to deal with the reduced resources and the aggressive environmental conditions underground. The leadership from the captains in Apollo 13 was a key-element to make efforts and resources during the crisis, holding the team together and focusing on a common goal. Additionally, in Apollo 13, both teams – in the LM module and in the Mission Control – despite the extreme distance that reached more than 400 thousand kilometres in its limit, they had worked in tune and focused on the objective of returning the LM from space, even with the limitations of resources that the situation imposed (Kranz, 2009). Teamwork is an essential human competence to develop safe operations in workplaces where there are intense interactions between state-of-the-art technology, highly qualified professionals, and high-level technical results (Johnson, 2015). Regarding technology, the artifacts itself were essential not only for rescue actions, such as the Fénix rescue capsules in San José mine, but also in the recovery actions of systems corrupted during the crisis, such as the adaptation of the CO_2 filter system for survival inside the LM of Apollo 13. Additionally, it is noticed the teamwork of both, integrating NASA, ASMAR and the Chilean Government for the Fénix, and Mission Control, Engineers, and Apollo 13 crew for CO_2 filter adaptation. In the two modelled FRAM, it is possible to see that the function "Technical and non-technical skills to deal with emergencies", highlighted in green, is precisely the system interaction representation of the presence of the non-technical skills during the emergency and rescue activities performed by the workers. This function is presented in figure 5.

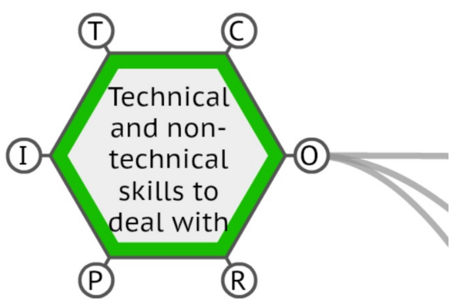


Figure 5: The function "Technical and non-technical skills to deal with emergencies". Source: The Authors, 2022.

Conclusion

The human capacity to adapt, overcome and evolve is something that has been demonstrated, not only in scientific studies, but in the evolution of humanity itself, as something essential for the continuity of all Humankind, overcoming natural disasters, pandemics, engineering accidents and so on. Examining closely the FRAM models of each of the analysis present in this research, it is noticed how the combination of workplace technologies, including those dedicated to rescue, with human skills, technical and non-technical, allows a degree of adaptability possible to meet the dynamics demands of extremely complex sociotechnical systems. Therefore, it seems a myopic conclusion to assume that the causes of an industrial accident, in a complex workplace, are the mistakes that workers make. Analysing human capacity associated with technology, contextualized in the current workplaces, it is perceived that the error is indicative of a system failure, where a complex combination of factors, including the human element, resulted in an accident. Considering this combined with the research findings, when it comes to extremely complex workplaces, such as spacecraft, mining and civil aviation, people, workers, are not the problem, but rather the solution, contributing to the resilience of the entire system.

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Safety culture specialists as resilience professionals – insights from NPP construction

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Nuclear power plant construction projects are complex endeavors involving hundreds of companies from all over the globe. Strong focus on nuclear safety is required from the very beginning of the life-cycle of the plant. The context and its conflicting requirements set demands for safety management, requiring adaptive working practices based on resilience thinking. Reiman et al. has proposed an adaptive model of safety management which identifies eight safety management functions with four tensions, each consisting of a conflicting pair of management goals. The paper builds on this model and uses it to elaborate the different roles of safety (culture) specialists in nuclear power plant construction. Based on our empirical experience, we propose ten integrative working practices for safety specialists that fulfill the management functions and promote resilience in the organization. The framework proposes that ideas and working practices from both Safety-I and Safety-II are required to ensure safety, especially in complex contexts such as nuclear power plant construction. These practices need to be balanced according to the contextual requirements.

Keywords: safety culture, safety professionals, nuclear safety, construction, safety management, resilience.

1. Introduction

Nuclear power plant (NPP) construction projects are complex endeavors involving hundreds of companies from all over the globe. Strong focus on nuclear safety is required from the very beginning of an NPP life-cycle, to avoid immediate and latent defects in the design, or inadequate development of a competent operator. The plant owner (and future operator, the licensee) is responsible for nuclear safety from the beginning of the project. To facilitate the importance of nuclear safety, organizations in the nuclear industry are required to have a good safety culture. This requirement is set in regulatory requirements and industry standards. It applies to all organizations participating in the design, construction, operation, or decommissioning of an NPP.

In NPP construction, challenges are created by the sheer number of companies and contracts involved, long supply chains, continuously changing workforce, multiple languages and nationalities and multi-location activities. Many tasks require specialized expertise, and tailored methods and equipment are used. Quality requirements, including the required documentation, are different and typically higher than in the non-nuclear construction projects. With the construction and decommissioning included, a nuclear power plant has over a hundred-year life-cycle. This highlights the importance of the high quality of processes (including documentation) as well as the quality of the physical systems, structures, and components.

The context of the paper is thus at the same time a project context, but also a nuclear power context. And specifically, the design and construction phase of the nuclear power plant life-cycle. The context and its conflicting requirements set demands for safety management, requiring adaptive working practices based on resilience thinking.

2. Adaptive safety management framework

The relevance of understanding and managing trade-offs or tensions has been widely recognized in management science (Cameron & Quinn, 2006) as well as in safety science (e.g. Amalberti, 2013; Woods & Branlat, 2011; Hollnagel, 2009). The conflicting requirements of safety professionals have been studied by e.g. Provan et al. (2017) and Reiman et al. (2015).

Reiman et al. (2015) has proposed an adaptive model of safety management which identifies eight safety management principles with four tensions, each consisting of a conflicting pair of management goals: 1) system goals versus local goals 2) repeatability and systematic response versus flexibility and adaptability, 3) low system variance versus high system variance, and 4) few strong ties versus multiple weak ties. The model suggests that safety practitioners need to be able to recognize and manage the tensions adaptively, depending on the context. They need to use different practices depending on the situation.

Provan et al. (2020) propose that safety management literature describes two distinct modes through which safety is achieved: safety management through centralized control, or safety management through guided adaptability. We attempt to bridge the gap between these two modes by proposing how methods based on centralized control can be used in an adaptive way.

3. Methods

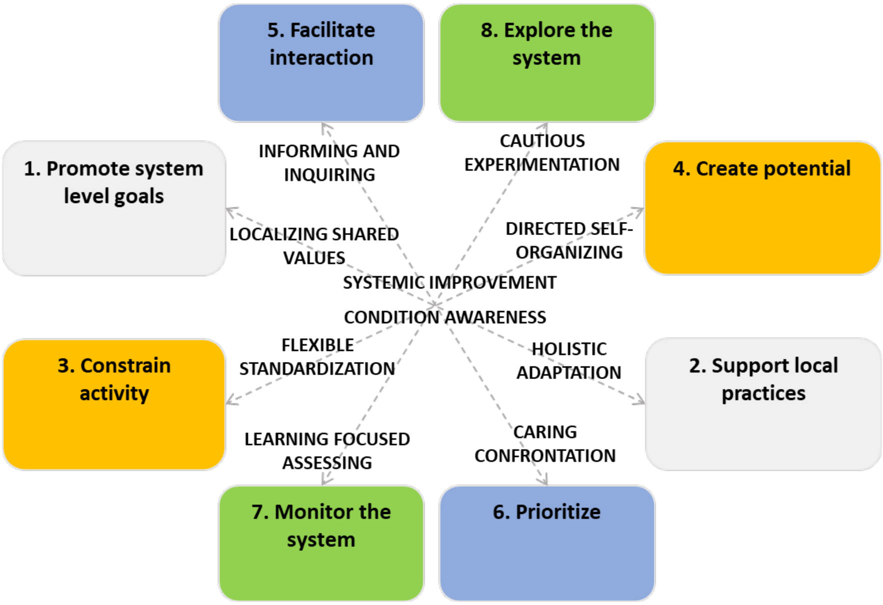
We define safety culture as the human and organizational characteristics of the system that allow it to give safety issues the attention warranted by their significance (IAEA 1991), and the work of safety culture specialists thus aims to improve the human and organizational capabilities to achieve safety.

There have been two major NPP construction projects in Finland during the last decade: Olkiluoto 3 NPP (OL3) and Hanhikivi 1 NPP (FH1). The construction of OL3 started in 2005. It has been in commercial operation since April 2023. The FH1 licensing process, basic design and site preparatory works started in 2014, and the project was terminated during Spring 2022. We have worked as safety culture specialists and contract researchers in these projects jointly for over 20 person years. The paper builds on lessons learned during the period from 2008-2022. We will build on the model of adaptive safety management by Reiman et al. (2015) and use it to elaborate the different roles of safety (culture) specialists. The eight safety management principles established by Reiman et al. (2015) are elaborated into eight main functions. Based on our experience, we propose ten integrating safety specialist working practices that promote resilience in the organization.

4. Main findings

We identified working practices based on all eight safety management functions. Our individual emphases differed, but jointly all functions were covered. The functions were revised to better illustrate the contradictory actions involved in them. Main results are summarized in Figure 1 and Table 1.

Figure 1. Safety management functions and working practices that balance the functions



The safety management functions in Figure 1 are based on Reiman et al. (2015). Adjustments have been made based on empirical evidence and other models such as Dekker (2018) and Provan et al. (2020).

4. Promote system level goals. There must be certain shared guiding principles according to which situational decisions are made. Safety must be one (but not the only one) of these guiding principles.
5. Support local practices. It also includes guiding the local adaptations.
6. Constrain activity. In safety critical environments some activities need to be constrained, e.g., by creating standard operating procedures and implementing safety barriers.
7. Create potential. In complex systems unanticipated events happen, and personnel need to react. This requires adaptive capacity.
8. Facilitate interaction. Employee involvement and good cooperation is needed both for commitment and information flow.
9. Prioritize. In complex systems attention needs to be divided into the most important issues. Means of prioritizing range from setting of objectives to giving commands and restrictions.

10. Monitor the system. The sociotechnical system needs to be monitored to have a realistic picture of the technical condition of equipment, the work conditions, and practices, and KSAs of the personnel.
11. Explore the system. Systems and their boundaries change. Exploration and learning are needed.

These functions can be fulfilled in different ways in practice. Figure 1 describes ten working practices. These working practices are presented as methods to balance the conflicting safety management functions. Table 1 gives examples of the eight working practices as they manifest in NPP construction

Table 1. Working practices with examples from NPP construction

Informing and inquiring Safety walks in the construction site to clarify the quality and nuclear requirements in the pre-operational phase of the project, and to discuss concerns with the contractors. Promoting open dialogue with personnel and senior management by being available for discussion, interacting regularly with both parties, and by reacting positively to people speaking up. Discussing safety culture status regularly with the senior management and arranging safety culture days together with senior management and personnel.
Caring confrontation Speaking up when observing unsafe practices at the construction site or leadership that was not in line with the safety culture principles. Explaining why certain actions or decisions are not recommended.
Learning focused assessing Safety culture self-assessments where corrective actions to both strengths and weaknesses were designed together with the senior management. Investigations with a focus on the organizational factors and how the management system contributed to the event.
Cautious experimentation Identifying units having an open climate for trying new practices and using these units as pilots, e.g. nominating safety culture ambassadors and attending unit meetings. Constructing risk scenarios to support senior management decision making based on personal and collected lessons from previous NPP construction projects as well as sociotechnical safety theories.
Holistic adaptation to local circumstances Reminding personnel about the safety culture principles in decision making points and conflict situations. Participating in early stages of contractor approval to ensure adequate coverage of safety culture issues. Using graded approach to prioritize issues having the highest safety significance.

<u>Localizing shared values</u> Defining safety culture principles jointly with management and personnel and regularly defining unit level concrete practices for each principle to localize them. Reminding line organization about their safety responsibilities, and personnel and management to remain mindful about risks
<u>Flexible standardization</u> Involving experts in writing the management system procedures. Building an integrated management system with regular reviewing and revising of the procedures.
<u>Directed self-organizing</u> Defining project specific guiding principles, including safety culture principles, that apply to all participating organizations and promoting them together. Promoting safety culture principles as guiding principles in uncertain situations.

Informing and inquiring means actively interacting with personnel and listening to their stories, worries and ideas, and taking heed. It also means gathering and sharing relevant information both horizontally and vertically. **Caring confrontation** refers to speaking up and gently confronting risky behavior or addressing risky conditions, and explaining why certain activities can be risky. It may also require stopping work in case of safety related uncertainties. These practices balance interaction with prioritization. The role requires enough authority in the organization to be able to speak up and not be silenced.

Learning focused assessing means audits, investigations, questionnaires that aim to learn about the system in addition to assuring compliance to requirements. However, compliance to requirements is easier to demonstrate (to regulators, senior management, and other organizations) than results from a learning focused assessment. The same assessment can be used for both, but the effectiveness may suffer. **Cautious experimentation** refers to micro-experiments in confined environments or organizational units (Boer 2021) and other safe-to-fail means of learning (e.g., simulators, virtual reality). Experiments can also be made totally theoretically, by using the understanding of current conditions to anticipate future conditions. It must be remembered that it is never possible to completely backtrack from a failed experiment, nor is it always possible to widen the application of a successful experiment.

Localizing shared values means first, jointly with personnel, formulating such values and principles that all employees can relate to them, and second facilitating the use of the principles as decision making guidance in uncertain situations. The challenge is that the espoused values and principles of an organization become easily too abstract to be of use in particular situations. **Holistic adaptation to**

local circumstances refers to advice given in the field that takes the organizational core task and the guiding principles into account and is vary of issues such as drift and normalization (Dekker 2011). To counter the risky adaptations in a field, the safety specialist needs a good understanding of the organizational core task and the technology involved.

Flexible standardization means creating rules and instructions that leave room for individual competence, and that are relatively easy to revise when evidence from their application is reviewed. Writing flexible procedures requires anticipating differ-rent contingencies, including scenarios where the rules do not apply. **Directed self-organizing** refers to giving guidance and advice to personnel that can be either technical or so-called soft skills but is generic enough to be usable in various situations yet based on safety principles and company main processes. However, some standardization is necessary to direct self-organizing. Standardization can also be conducted by shared values rather than strict rules.

In addition to the eight working practices described in Table 1, we identified two overarching practices that aid in balancing the different safety management functions: condition awareness and systemic improvement.

Condition awareness means generating and updating an awareness of the current way of handling risks, current work conditions and how they support safe work. Includes maintaining awareness of initial conditions. Awareness of work conditions is increased the more involved the safety specialist is in the daily work. However, to see clearly drift and normalization, some distance from the field is beneficial. Examples of condition awareness in NPP construction include continuous monitoring of organizational issues, such as observations, employee surveys, turnover and internal audits and regularly (quarterly or annually, depending on the pace of activities) summarizing the various data sources into safety culture status and reporting it to the management.

Systemic improvement refers to company-wide development of safety and safety culture based on realistic understanding of the current situation as well as on understanding of the various systems phenomena (such as drift and normalizing). Sufficient involvement in daily work and authority is needed to drive improvement. Examples of systemic improvement in NPP construction include establishing a program and a management system process for culture development and establishing a working group for facilitating safety culture development in the supply chain.

5. Conclusion

The paper aimed to demonstrate that complimentary working practices based on opposing principles (cf. Safety-I and Safety-II) are needed to manage safety in complex sociotechnical systems. It is important to realize the premises of the working practices as well as the trade-offs that safety professionals need to make to balance between the opposing requirements (see Figure 1). Further, the contextual requirements need to be considered when deciding what safety management functions to emphasize, and how, in any given moment.

The contextual requirements of NPP construction are varied. There are similarities to nuclear power production (regulation, nuclear safety, integrated management systems), construction (networks, high turnover of personnel, amount of manual work), as well as to any safety critical context. Nuclear context brings the long-term perspective, strong focus on rules and planning, and strong focus on control mechanisms (QC, QA, supervision etc.). Things need to be done in a correct pre-planned way in addition to the correct outcome. These show in increased resources devoted to different assurance functions, from safety and quality to safety culture. The abstract nature of nuclear safety (before the nuclear fuel is loaded) is a specific challenge to nuclear power plant construction.

The paper was based on experiences from the work of four safety culture professionals in two nuclear power plant construction projects. Further research is needed to elaborate the identified working practices and test their validity in other contexts. The following future research questions can be proposed: What is the applicability of the proposed framework and the working practices in other safety-critical contexts? Are there some practices that are specific to NPP construction and some that are generic to all safety critical contexts? What variables, e.g. type of safety, core task, culture, influence which function to emphasize and how to implement the function and the associated working practices? How does the work role of the professional and the division of labour between the given safety professional and other actors in the organization influence the working practices?

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Meaningful Learning: What can we learn from what actually happened and how can we become safer? The experience of one technical breakdown from a complex domain

Anthony Smoker & Tom Laursen

An event occurred in the afternoon at an Air Traffic Control Centre (ACC) in 2018. Three perturbations of the operational systems that provide flight data to ATC operational positions over a period of 4 hours.

Two views of the event were presented by Hollnagel et al (2022). One view represents the orthodox safety philosophy of learning from events through investigations. A second view was introduced, providing another perspective from the Air Traffic Control Officers (ATCOs) who were on duty at the time including their reflections after the breakdown.

The striking difference presented by Hollnagel et al (2022) between the two accounts illustrates the ambiguity of constructed formal investigation narratives in comparison with narratives and exploration of how operational actors handled the perturbation. ATCOs adapted to an unexpected situation that was characterised by uncertainty, ambiguity around technical system behaviour as well as the margins of performance. All contributing to complexity. The nature of the issues with the technical system were diagnosed: three system failures occurred until a technical solution was found.

This unusual episode was treated by the ATCOs (ATSEPs or Network managers will have other perspectives) within the compass of daily work. Adapting through adopting strategies that were developed partly from a different system state – stable and knowable, and partly innovative strategies. This episode introduced system instability, an unfamiliar system state and limited knowledge of the affordance of system behaviour. What is to be taken from this event? What will the organisation learn? What substantive interventions will follow the conventional mechanisms of 'learning'?

This paper argues that orthodox approaches to organisational learning will not provide a similar view to the transformative view that resilience engineering can potentially provide. Doing so through a prism of what proximal actors did, how they rationalised and made sense of a dynamic, uncertain and complex situation. Adaptations evolved reshaped their understanding of familiar system boundaries and margins of performance. The nature of these affected known views of adaptive capacity – how did this evolve? What local mechanisms facilitated the sustaining system performance through dynamic changes to the unknown or unfamiliar system state? Knowledge such as this transcends orthodox safety thinking because it is out with its scope or imagination.

Adapting to performance variability that confronts complex socio-technical systems is a norm for many practitioners working in complex safety critical domains. In this episode, complexity was introduced because the opacity of technical system (which if frequently the subject of upgrades and changes), its intractability, brought about through designs of technical systems that strive to optimise the potential opportunities, but in so doing hold the potential to introduce brittleness as well as changing the degrees of freedom to adapt. This episode is therefore illustrative of the nature of future system perturbations and the influence of increasing uncertainty and complexity upon resilient performance.

An ACC is a complex organism dependent upon a multiplicity of actors that shape the margins of performance and the system boundaries and thus influence adaptive capacity. One of these directly relates to organisational learning – the Safety Management System.

This episode is illustrative of the way that characteristics of complex adaptive social technical systems may change and provides. Data, in the form of formal investigation and ATCO interviews, to make assertions and draw conclusions on the nature of the changes as well as consider alternatives.

One example, identified from this episode concerns the boundaries of processes used and mandated to assure safety. Here, it is argued that an orthodox SMS limits the scale of the system boundaries and will, as a consequence, limit the scope as well as purpose of the SMS scope. Risk management therefore becomes an inappropriate means to learn about resilient performance from such episodes in complex systems.

Following from this, does the orthodox view of the SMS reduce the adaptive capacity of the system? In this episode the SMS response was that it was a technical problem that caused the problem and needed to be fixed. This confirmed the mechanistic view of the system that the SMS was using. The orthodox SMS was unable to 'see' the nature of adaptive capacity and thereby not able to support interventions that enhance this in the future. Over time, therefore, we stand to lose more and more adaptive capacity. Which, from analysis of the 2018 episode, to these questions?

- Is the orthodox SMS based on a mechanistic view capable of supporting adaptive capacity and resilience and resilient performance within its particular scope of system boundaries?
- Is it possible to revise the orthodox SMS to accommodate a perspective of resilient performance especially related to changing characteristics of complex socio-technical systems and the influence upon adaptive capacity? Or do we need a clean sheet? In which case, what alternative approaches could be useful?

This paper will examine, using the 2018 episode, pertinent questions around how the nature of boundaries influence what meaningful learning is, in a domain where the operational environment is anticipated to become increasingly complex through technical innovation, digitisation and radical change in operating concepts (SESAR, 2015).

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Conceptualizing resilience through a temporal lens: the role of interaction dynamics

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Systems working in complex, dynamic environments, are required to be resilient; not only withstand changes, but also find new means by which to deal with surprises and unexpected events. Resilience Engineering has developed a multitude of methods to investigate and map system properties or perform accident analyses after such events, but most of them adopt a reductionist, static approach to studying resilience. However, capturing the process by which systems stretch their boundaries to extend their adaptive capacity, or understanding the triggers of emergent system resources, requires a fine-grained analysis of moment-to-moment interactions that remains limited within RE. Interaction dynamics, referring to the behaviours that develop during an event, changing and forming different patterns of interaction as time unfolds, are a key means of mapping system resilience as graceful extensibility. In this paper we outline how interaction dynamics can be used in resilience research, and discuss how finite resources, responses, and system priorities can be extended and understood from within the emergence and adaptation of interaction dynamics. We also point out the advantages of researching interaction *dynamics not only during accidents that have led to collapse, but also during surprise events where systems have managed to stretch their adaptive capacity.*

Keywords: Interaction dynamics, graceful extensibility, boundaries, adaptive capacity, emergence, temporal processes

Introduction

Joint cognitive systems that comprise our societal, organizational, and political environments become increasingly more intertwined with complex interdependencies ranging from bridging individuals or teams, to bridging entire organizational structures. The highly dynamic, complex and uncertain task environments in which systems operate, such as those found in healthcare, aviation or aerospace, require constant adaptation and re-organisation of their processes, adjusting to the changing task demands, contexts, and constraints of each situation (Woods, 2018). To ensure safety and effectiveness in those closely intertwined systems, despite the complexity within which they operate, it is crucial to understand and map the *continuous nature* by which systems stretch the boundaries to handle surprises.

Researchers within the field of Resilience Engineering explore and develop ways to investigate, understand, and ensure that systems maintain safe operations in the face of disruptions and unforeseen events (Disconzi & Saurin, 2022). Yet, the process of extending adaptive capacity, that is, the ability, readiness, and potential to adjust and meet the demands of the situation (Woods, 2018), is studied predominantly through static, linear methods (Fiore et al., 2014; Gorman et al., 2019). In this way, resilience is conceptualised only as a property that systems may possess or lack. If we truly want to advance our understanding of how systems build resilience over time, the *temporal processes* that unfold need to be captured.

A temporal approach to studying interactions in natural work would enable researchers to capture not only what mechanisms underlie adaptive capacity, but also how these mechanisms emerge, change, or collapse at any given moment throughout operation. These insights can be used ultimately to design interventions for resilient performance, which helps systems maintain and improve their adaptive capacity. Yet, the adoption of a temporal, non-linear perspective with regard to researching adaptive capacity is a critical gap within the Resilience Engineering community that needs to be tackled (Fiore et al., 2014; Gorman et al., 2019).

In this paper, we aim to address this gap by offering a temporal approach to better understand, capture, and map a system's resilience. We conceptualise resilience as graceful extensibility, the practice of a system extending its capacity for adaptation, and explore the use of interaction dynamics, *a micro-level, temporal approach of studying moment-by-moment changes of interactions,* as a means to capture and map its emergence, triggers and progression as an event unravels. We conclude with ideas on how and in which settings interaction dynamics can mostly help to deepen our understanding of graceful extensibility.

State of the art in researching graceful extensibility

Every system possesses a basic adaptive capacity that forms its competence envelope; i.e., its area of safe operation, which includes the skills, strategies, and mechanisms that it can safely employ to deal with events and disruptions (Hollnagel et al., 2006). In the event of a surprise, systems are called to stretch the boundaries of their competence envelope, to find new resources and means to maintain operations. The process of successfully stretching those boundaries to ensure continuance of safe operations conceptualises system resilience as graceful extensibility, while inability to do results in brittleness.

Methods for researching resilience offer fine conceptual frameworks for safe system design (e.g. STAMP; Carayon et al., 2015) or prospective and retrospective accident analyses that outline system properties and potential systemic failures that hinder resilient performance (e.g. FRAM; see Patriarca et al., 2020 for full review). However, such analyses are based on static, reductionist perspectives, for example by using investigation reports instead of normal work processes, leading to omitting or overlooking important mechanisms with respect to maintaining operations and outmanoeuvring complexity. By adopting such approaches, resilience as graceful extensibility is conceptualized only as a static property of systems, instead of a temporal phenomenon including continuous processes that emerge and change. The unfolding mechanisms of graceful extensibility need to be captured with non-linear approaches that are fine-grained to time and agent interactions, in order to understand how graceful extensibility is manifested.

When a disruptive event in the system occurs, active coordination processes are triggered, developed, and continuously adjusted to cope with the situation at hand (Summers et al., 2012). Thus, a system's ability to gracefully extend is largely dependent on its ability to continuously adapt these coordination processes when boundaries are approached. We therefore argue that extensibility in adaptive capacity can be studied and understood by examining interaction dynamics, defined as moment-by-moment behaviours emerging and forming patterns that change and evolve as systems operate (David et al., 2022; Hoogeboom, 2019). In the following section we explore how the process of stretching boundaries can be studied and conceptualised through interaction dynamics.

Interaction dynamics: The hidden temporality of graceful extensibility

The process of *how* system boundaries stretch, or the triggers that lead to the emergence of this process, are crucial to understanding how a system re-organizes its processes to develop *new, emergent modus operandi (MO) of support;* i.e. changes in procedures and plans that emerge from within interactions despite of and accounting for the finite set of resources that the system processes. Below, we provide a brief description of interaction dynamics before moving on to incorporate them into the phenomenon of graceful extensibility. We present some exemplary studies that used interaction dynamics and temporal analysis techniques in domains outside of resilience, to propose how methodologies and results from such studies could translate into research on graceful extensibility. We then explore how our past and future work aims to aid our understanding and temporal conceptualisation of graceful extensibility.

Interaction dynamics entail different sequential combinations of behaviours exhibited by the agents comprising a system, which form patterns of interaction that continuously change, emerge, and evolve. Such behaviours may include events that are defined by their inherent features, such as speech acts (who talks to whom), physical proximity (changes in how close or far away from each other agents are), or even positioning in physical space (changes in positions of agents in the room). They may also include higher-level behaviours, reflecting events for which the content of information is needed to define it. For example, these might be verbal communication events or physical gestures reflecting actions such as 'suggesting' 'directing', or 'monitoring'.

By modelling such patterns over time and as an event unravels, we can see how various patterns change depending on environmental influences and internal or external disruptions. We can answer questions related to triggers of adaptation in exact moments were adaptation emerged, or even model the exact process by which it was promoted or hindered.

An exemplary research in healthcare by Kolbe et al (2014) used interaction dynamics of explicit and implicit coordination behaviours to understand drivers of high performance. The authors modelled behaviours of coordination observed during a general anaesthesia procedure. Using sequential analysis to analyse pattern formation, they found that patterns combining implicit coordination behaviours (e.g. monitoring), followed by explicit coordination behaviours (e.g. providing assistance, a type of back-up behaviour) were associated with higher performance. Backing-up behaviours have been found to both help and hinder performance depending on the context at which they are presented (Porter, 2005), so if we were to apply such a research to resilience during a surprise event, patterns of internal and external coordination could reveal at which points emergence of back-up behaviours emerged as MO system of support to the team's finite resources, as well as the patterns in which they developed (e.g. did they emerge after saturation of another team member).

A study by Rico et al. (2021) researched verbal and non-verbal interaction dynamics of coordination behaviours (e.g. giving instructions or commands, or providing assistance), and used T-pattern analysis technique, a technique of detecting complex patterns in interaction, to assess how different leadership style affect how coordination unfolds. Translating this into drivers for graceful extensibility, similar research could be used to assess which patterns of coordination would be beneficial when dealing with surprise and the mediating role of leadership patterns as an MO system of support for extending system boundaries.

Analysing patterns of interaction can also help us map phase transitions. For example, the analysis technique of Entropy is used to detect randomness, or uncertainty within a time series of events/behaviours (Pincus et al., 1991). Wiltshire et al., (2018) examined patterns of turn-taking behaviours reflecting problem solving processes (e.g. information provision, information request, solution evaluation) to spot phase transitions during a collaborative task using entropy. They found that teams with higher order in their interaction patterns throughout the task, and irrespective of the different phases they entered, performed better than teams with more disorder during transitions from one phase to another. Translating this research in resilience could be valuable to spot whether these patterns of order and disorder are related to teams entering the phase of extending their boundaries, and for modelling the exact process of deterioration, recovery, rebound to pre-existing patterns, or development of a new equilibrium in coordination throughout a surprise event.

A study that recently employed the analysis of temporal interaction dynamics to study adaptability on NASA's Apollo 13 incident (see van den Oever & Schraagen, 2021), showed that switching to less structured relationships between agents is a potential adaptive resource that helps the team to stretch their boundaries. More specifically, the authors researched patterns of actor switches before and during the surprise event using Relational Event Modelling and found that the system adjusted its responses, from adherence to command-control relationships to more loosely formed patterns. Interestingly, they also noted that the system adhered to institutional roles (command-control relationships) for as long as possible before switching their patterns of interaction. This is an example of how interaction dynamics can be used to map processes such as these discussed in the stress-strain model discussed by Woods and Wreathall (2008), reflecting the ability of teams to develop plans and procedures using their existing resources (Patterson et al., 2013), to be used as MO of systems of support for adaptation under new complex or unforeseen events.

Comparable findings were also noted in our research on a brittle system during a plane crash after an unexpected disturbance, indicating patterns that prohibit a system from extending its boundaries (David & Schraagen, 2018). Findings from comparing the patterns of actor switches before the unexpected disturbance to those that occurred afterwards, showed that patterns indicating reciprocity and initiative before were replaced by ad hoc responses of autocorrelation after the disturbance.

Future steps

In future steps in our research, we aim to expand our conceptualisation of graceful extensibility as a temporal phenomenon, by studying the resilient system of NASA's Mission Control room during the Apollo 13 'successful failure'. Studying a successful event as this was enacted moment-by-moment, can offer major insights of the solutions and drivers of resilience (Hollnagel et al., 2021). Research by van den Oever and Schraagen in the Apollo 13 incident, have initiated understanding of resilience as it unfolds, by focusing on comparing interaction dynamics before and after the surprise event. We now bring into the spotlight the critical event itself, to plot, the moment-by-moment changes in the coordination, and as new information was presented to the team. This research will plot interaction dynamics of coordination that regard not only the agents in the system, but also the information and actions exchanged (e.g. giving commands, requesting information etc) as these unfolded throughout the event. Emergent coordination patterns can be explored to investigate how a resilient system moves through different phases of coordination and how different MO system of support develop emerge and develop within these phases. We thus aim to conceptualise the temporality of graceful adaptability as this is translated in coordinative interaction dynamics of a highly complex joint cognitive system that managed to gracefully extend their boundaries of adaptive capacity.

Conclusions

We have introduced the idea of researching graceful extensibility through interaction dynamics, to understand how systems that operate under staining conditions and are limited by their finite set of resources, manage to continuously adapt their processes to meet current demands. Interaction dynamics can help frame and progress our exploration and understanding of resilience by exploring various internal or external triggers of extensibility, modelling different phases in interaction over short or long time-scales, or exploring the emergent systems of support that derive from changes in interaction.

We note that by studying what goe*s right*, such as investigating systems that have displayed graceful extensibility by managing to maintain safe operations despite perturbations, we can map mechanisms and processes of graceful extensibility that stem from within the system's interaction dynamics and stretch existing boundaries. Steps have begun being taken towards researching resilience and safety where it is present, with interesting findings on how dynamic changes in interaction can foster the development of MO systems of support (e.g. adherence to institutional roles followed by increasing flexibility during problem-solving). We aim to continue this research into interaction dynamics in systems that have managed to gracefully extend their boundaries, to understand how resilience develops and evolves from within system interactions. Mapping and understanding what goes right in these patterns of interaction can ultimately help in developing interventions and means for promoting system resilience and safety.

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Re-thinking a system's spatial and temporal boundaries through art

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The purpose of this case study was to explore how art images, as a data collection technique during a research interview process, can facilitate the re-imagination of system boundaries, adaptive capacities and strategies. Indeed, a central problem in the interpretation of system resilience is that of capturing the complexities of practitioners' lived experiences from working close to the boundaries of complex adaptive systems. Following on from a qualitative interview-based study of Swedish obstetricians' decision-making process, this case study attempts to suggest an innovative way of how to elicit knowledge of practitioners' lived experiences. A comparative narrative analysis of a two-parted interview, from before and after the introduction of art images, was performed. Firstly, reflecting freely on various aspects of obstetric emergencies, the interviewee constructed a narrative of a typical technical/operational reality. Secondly, following the reflection on two artworks by Salvador Dali, a new future-oriented reality involving ideas of family, motherhood and consequences for future generations was constructed. A distinct re-imagination was performed. This study illustrates how the introduction of a new medium during a research interview helped a practitioner working close to the boundaries of a complex adaptive system, such as an obstetric emergency, creatively redefine the boundaries of that system.

***Keywords*:** Obstetrics, Childbirth, Resilience Engineering, Resilience, Adaptivity, Qualitative Interview, Visual materials, Art, Method, Safety-Science.

How we think about our world and how we live in it are entwined. Our ontology and our practical engagements are woven together. This is true not only for philosophers. It is true for everyone. - Todd May, in *Gilles Deleuze: an introduction* (2005)

Introduction and background

A central problem in the interpretation of system resilience is that of capturing the complexities of practitioners' lived experiences from working close to the boundaries of complex adaptive systems [1-3]. As late Richard Cook said in a teaching session in Lund in January 2015: "A fundamental problem with doing research in our field is that people do not have access to their own cognition". This statement can be seen (and was much stated) as an appeal to avoid analytical frameworks attempting to study practitioners' cognitive constructs (i.e. mental workload or situational awareness) strategies, and rather focus on the analytical object of work. In this paper we attempt to take on this challenge and suggest a way to innovate how we elicit knowledge of practitioners' lived experiences in order to facilitate analysis of the boundaries, adaptive capacities, and dynamics of their systems. From the case study of a single interview, we argue that using art as associative support can help practitioners to re-think the spatial and temporal boundaries of their systems as well as their adaptive capacities in relation to such boundaries.

The setting of our case study is Swedish obstetric care, a medical discipline that, like many others, have undergone standardization and regulation of practice since the late 70's and 80's [4]. More recently however, how evidently standardized practices significantly improve obstetric outcomes has been debated, especially for situations that contain a great deal of uncertainty and risk, such as emergencies [5, 6]. Researchers have highlighted the inherent complexity of maternity care and obstetric emergencies as a possible explanation for why guidelines are just not enough [7-9]. Adding to this complexity is the well-known, within human factors and ergonomics, difference between work as prescribed and work as done, as well as other mismatches between various theoretical perspectives and actual practice [10, 11]. How well do practices actually reflect the dictates of practice? How congruent are the rules of what should be done with the pragmatism of every-day problem solving? What is practice like from the practitioners' perspective? A recent study attempted to gain some insights into this question in which art images were used as associative support (i.e., in order to widen the perspective and circumvent expected or rehearsed ideas on decision-making) [12]. The purpose of this present case study is to look more deeply into the results and effects of using art images in the research interview process to understand how such data collection techniques can facilitate the re-imagination of system boundaries, adaptive capacities and strategies.

2. Materials and methods

Study design

This case study is based on one of the transcripts of a previous interview-based study [12]. Individual qualitative interviews had been conducted in order to capture how obstetricians and gynecologists make sense of their decision-making process during childbirth-related emergencies [13]. During the course of the interview, art images were used halfway through as way to facilitate conversation [14, 15]. In this study a comparative narrative analysis of the two parts (i.e., before and after the introduction images) was used to illustrate the effects of art images in a qualitative research interview setting [16, 17]. Furthermore, representational and non-representational aspects of the results are later discussed hoping to expand the theoretical understanding in using such a medium/method.

Ethical considerations

Participation in the original interview-based study was voluntary and could be ended at any time. Written consent was given. The interviewees were assured of the strict confidentiality in handling their data. All interviews have subsequently gone through the Swedish National Data Service's review process and been anonymized for open access database publishing. No direct or indirect information can be traced back to a person, location, or event. The study was approved by the regional ethics review board of Lund (diary number LU 2018/198).

Sampling and study population

Out of the rich text material provided by the 17 in-depth interviews of the original study, and after discussion among the authors, one was eventually chosen for the purpose of this case study. The case was considered as being distinctively illustrative of the effect art images had on both the content and form of the interview.

Data collection

In the original study, all interviewing was conducted in a co-creative narrative way (i.e., how both parties jointly give meaning to the unfolding of the conversation in which they equally participate), and in two parts [18]. The first part of the interview developed from the retelling of a memorable obstetric emergency experience. The second part evolved from discussing art images (and a synthetized drawing of these) that spoke to interviewees about decision-making in the context of obstetric emergencies. Art images were used both as a tool for exploring new ways of expressing ideas related to the subject of interest [15, 19], and as a way to establish a common space in which the power imbalance between interviewee and interviewer could be redistributed [20]. The interviews had an open-ended character in order to give primacy to the narratives emerging in dialogue [21, 22].

Data analysis

The anonymized transcript of physician number 10, as well as the references to the art images that were chosen, were used for comparative narrative analysis [13, 16, 17]. Through a process of reading and re-reading, and working inductively through the transcript, intact narrative segments (i.e., bounded text sections) about decision- making were identified and labeled according to what ideas were expressed [16, 17]. Recurrent ideas were clustered into overarching themes. Subsequently a search for similarities and differences between the themes in the two parts of the interview was performed [16, 17]. The interpretative work was also developed in collaboration among the authors [16, 17]. Finally, the person described in the case presented is a non-gendered fictionalized character based on the first author's (GMR) experience with working as an obstetrician for many years, and referred to as *he/she*. However, the analysis and quotes are based on the transcript.

3. Results and analysis

Physician number 10 was a specialist in obstetrics and gynecology working predominantly in perinatology and having extensive experience in dealing with obstetric emergencies at both small and big maternity units in Sweden. *He/She* had expressed a keen interest in participating in an interview about decision-making since it had been a subject of much reflection for *him/her* over the years. A mutual professional respect and interest in each other's thoughts on the matter was the basis for an hour long, relaxed conversation between two colleagues. No specific case was mentioned during the conversation. The narratives that eventually developed during the interview were rather based on typical situations physician 10 regularly encountered in *his/her* work. During the interview physician 10 chronologically exposed three overarching themes. In the first half of the interview decision-making was described as essentially *communicative and relational*, and in the second half as *potentially harmful* and as *care for the future*. These are presented in order. Moreover, general aspects on changes in the mood of the conversation are also presented. Finally, in looking for the similarities in both parts and across the interview, two other overarching themes were constructed: *communication* and *responsibility*, presented at the end of this section.

Decision-making as communicative and relational

During the first half of the interview the conversation revolved around the idea of decision-making as being *communicative and relational.* More concretely physician number 10 stressed the importance of having a good relationship with midwives.

"Midwives, it's part of it... Just like the fetal heart monitoring or clinical examination and stuff ... Sometimes when you're thrown into a situation, you might not even have time... To read the patient's record... So, then you have to rely on what the midwife tells you in those twenty seconds... So, I think it's an important... Part of our job... To have a good relationship with them."

Indeed, in Swedish maternity care, midwives are the primary caregivers during pregnancies and childbirth. Physicians essentially only get involved when difficulties, complications and/or pathologies occur. And because of the way work is constructed and divided between the two professions, midwives spend the most time with the patients. Physicians are thus very much dependent on their relationships with the midwives, for getting information about pregnancy- or childbirth related processes, and for their decision-making, especially during emergencies. Knowing each other, even on a personal and informal level, and having worked together in various situations was also thought to be tremendously facilitating for collaborative aspects of work.

Reflecting further on *his/her* experience, physician 10 thought that the two professions (i.e., midwives and obstetricians) each have the tendency of interpreting childbirth through a different lens. Midwives see childbirth as a natural and positive process while physicians approach childbirth as a potentially dangerous event. For physician 10, this difference in perspective created a fundamental tension in the work-relationship, a tension that could easily develop into corrosive mistrust. For *him/her* it was therefore important to engage in an interested dialogue with each other about those differences, as a way to merge the perspectival gap. And, because physicians are higher up in the organizational hierarchy, they are the ones having the obligation to reach out to midwives and meet them on their premises first (i.e., that childbirth is natural and positive) while simultaneously keeping in mind risks of potential crises. *He/She* thought that this "balancing act" was essential for the tension to transform into a bonding trust between maternity care professions.

" You build up trust, a trust relationship. In which you know what the other can and in which you also listen... We can different things... But you need to listen".

Indeed, physician 10 was well aware that the two professions' different perspectives come from having almost oppositional domains of expertise. Nevertheless, *he/she* also believed that they did not need to be contradictory or even counterproductive. Provided there existed a mutually interested engagement with each other's differences, while simultaneously letting each other be within respective domain of expertise, there could be a trusting professional relationship, in turn enabling the full embrace of ones own professional responsibilities towards the patients and their partners/relatives.

Decision-making as potentially harmful and as care for the future

During the second half of the interview, physician 10 did not directly speak about the decision-making process itself but rather reflected on *his or her* feelings and perspective during that process. The reflection came about after choosing images representing two paintings by Salvador Dali (Table 1.), and having some of the paintings' elements fuel the conversation. The elements in *Venus and Amorini,* were the woman and the children, as well as the water. The elements from *Dream caused by the flight of a bee around a pomegranate, one second before awakening* were the jumping tigers and the rifle directed at the naked woman. Some of these were even synthetized into a drawing (Picture 1.).

Table 1. Artworks chosen by physician number 10

• Venus and Amorini (1925) by Salvador Dali
• Dream caused by the flight of a bee around a pomegranate, one second before awakening (1944) by Salvador Dali

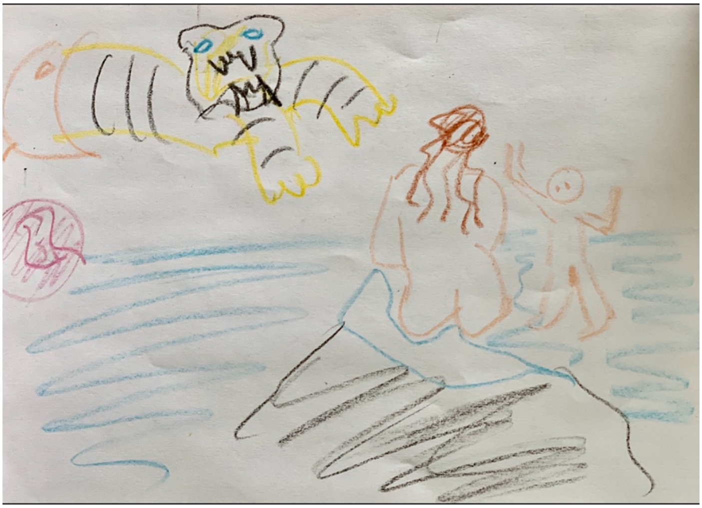

Figure 1.

Reflecting firstly on elements in *Venus and Amorini* feelings of warmth and security, but also fragility, were evoked. These were feelings *he/she* associated with the moment of birth and particularly with the dyad mother-child. Moreover, *he/she* talked about how *his/her* perspective on childbirth had evolved with experience, over the years. *His/Her* initial insecurity and self-centeredness from early years had eventually matured into an empathetic care and concern for the well being of the family-in-becoming. Having gotten a family of *his/her* own and having met many women/couples/families during complicated birthing situations added weight to this sense of care and responsibility built into the profession.

"What we are working with... What I feel is the important bit...the reason for our job is... To safeguard that birth will go well. To make sure that the child gets a good start in life. To make sure that the child is healthy, so that the family can get a good start"

Furthermore, using some elements from the *Dream caused by the flight of a bee around a pomegranate, one second before awakening* physician 10 reflected on the very special position obstetricians have to patients during emergencies. Indeed, the painting evoked feelings of aggression, brutality, and an idea of trauma. As a physician one gets involved to solve problematic situations during childbirth, not necessarily having the full picture beforehand, often only getting fragments of information from the assisting midwife and perhaps, in urgent circumstances, needing to act swiftly. Most commonly, the birthing patient implicitly allows the physician to act, especially when the stakes are as high as her or that of her child's survival. Here, physicians are granted particular privileges that are rarely seen elsewhere in healthcare.

"It sometimes feels like we throw ourselves literally on the woman, because of the emergency. In those moments you override all normal boundaries of what's allowed with a person. As physicians we've got this special permission to squeeze the womb between our fists for example... It's extreme."

For physician 10, needing to act in such a way during childbirth still felt difficult, almost abusive, even after many years of practice. One knows through experience that the trauma some women/couples/families carry with them after birth is not only related to a difficult outcome, or even a difficult birthing experience. It can also be from the consequences of actions needing to be performed by physicians, even when done with all the necessary care. Moreover, towards the end of the interview physician 10 eventually synthetized his/her reflections into an existential perspective of care for the future life of the birthing woman.

"I just think that it's important that we all the time, at the same time as we make good decisions, that we make sure... The woman, she has to live on with this for the rest of her life. And it's really a big thing for her. So even if it's some everyday routine for us, we have to be aware, that it's something very special for her."

Indeed, for physician 10 all that is said and done during a woman's/couple's/family's childbirth experience has a long-lasting impact, perhaps even for generations to come, through the stories of that birth. That is why, for physician 10, an obstetrician's actions and decisions should always be guided by empathy, particularly considering the responsibilities and the authority imbued with the role. For physician 10, empathy is oriented towards a future imaginary family, inclusive of the moment of birth in which midwives and physicians work together.

Changes in the interactional mood

A momentous shift in the mood of the conversation occurred during the interview when transitioning from its more classic part to the one using artwork as associative support. First of all, simply the fact of unloading a pile of books of artwork from a bag onto a table created a natural break and a slight bewilderment. As an interviewer, keeping a candid approach at this stage was very helpful in continuing to create a rapport with the interviewee. In terms of the research approach, the introduction of art images created a field in which neither interviewer nor interviewee had any of the "right" answers. As an interviewer it was impossible to have any idea of what would be expressed, and as an interviewee one was suddenly offered the possibility to express oneself more freely. This opened a field of exploration primarily for the interviewee, but in which the interviewer could be invited to participate. An atmosphere of ease and joy developed. Giggles and laughs started filling the room. There was genuine curiosity for the images (and drawings) and for what they meant to the interviewee. The general sense of the remainder of the interview was that of play.

The common themes of communication and responsibility

Two main themes/ideas could summarize physician 10's reflections on various aspects of obstetric emergencies including *his/her* decision-making process and *his/her* role in such circumstances, namely *communication* and *responsibility*. These ideas were expressed in both parts, however differently. *Communication*, in the way of connecting with others, is a tool purposefully used by physician 10. In the first part of the interview this was discussed primarily in relationship to midwives, as a way to be accepted and as a way of establishing trust between professions. In the second part, *communication* is essentially an expression of care for the patient. Indeed, through *communication* one can minimize or even avoid the harmful effects of hurtful but necessary decisions and actions performed during an obstetric emergency.

Similarly, *responsibility* is both a sentiment that is given by the obstetrician's role and a felt sense of care. R*esponsibility* as a given sentiment was mostly expressed in the first half of the interview, and in relationship to midwives. Indeed, a physician has the final medical responsibility for what is happening during a delivery in which *he/she* is involved. R*esponsibility* as a felt sense of care was discussed in relationship to the woman/couple/family giving birth, in the second part of the interview. Here *responsibility* is a genuine caring for, and involvement with the individuals and the perspective of their life after the delivery.

4. Discussion

Both *communication* and *responsibility* are fundamental aspects of practice for the medical professions. It was un- surprising that those ideas were brought up during the interview. However, what was rather unsuspected was what happened to those ideas at the introduction of art images.

Re-constructing the boundaries of complex systems

To complexity scholars system boundaries are always arbitrary, open for negotiation and interpretation. Fundamentally, boundaries are analytical choices by which we construct our systems and their functioning. As Heylighen, Cilliers and Geherson [23] note:

> *According to cybernetics, knowledge is intrinsically subjective; it is merely an imperfect tool used by an intelligent agent to help it achieve its personal goals (Heylighen & Joslyn, 2001; Maturana & Varela, 1992). Such an agent not only does not need an objective reflection of reality, it can never achieve one. (p. 8)*

In the case described above, and as largely expanded upon, it seems like the introduction of art images as knowledge elicitation-technique made the interviewee re-construct *his/her* reality. Indeed, the first constructed narrative was one of a typical technical/operational reality; constrained to a room, a woman in giving birth, a child to be delivered and a limited amount of colleagues to interact with during the limited time which bounds a birthing scenario. Eventually, following the reflection on elements depicted in Salvador Dali's two artworks *Venus and Amorini* and *Dream caused by the flight of a bee around a pomegranate, one second before awakening*, a new reality was constructed: one of a future family life involving the potential trauma from a childbirth emergency situation, a difficult start to family life, with long-lasting consequences. In this re-constructed narrative (of reality), the spatial boundaries shifted from the delivery suite to the (much more abstract) future family and the temporal boundaries from the birthing process ending with welcoming of a child to the entire future life of the woman and her family.

Aspects on the changes in the interactional mood

The changes in the mood of the conversation after the introduction of art images and the drawing are obviously difficult to factually render in this analysis. It is perhaps also difficult to subscribe any real value to this change of mood, at least for any outside looking observer. Nevertheless, by using our imagination as well as ourselves empathetically (i.e., by trying "to put ourselves in somebody else's shoes"), we can almost assume that a shift was actually felt by interviewer and interviewee in that interactional space and that that feeling had meaning to them [18, 21]. Furthermore, we invite readers of the original transcript to make their own interpretations [24]. We believe that the permissive and non-judgmental atmosphere, including the redistribution of power between interviewee and interviewer, allowed for the expansion of physician 10's reflections. This movement of expansion did, in turn, provide new insights into how the boundaries of the system and the boundaries between systems fluctuate. The techniques and media (i.e., art images and drawing) used, as well as the resulting atmosphere could even in themselves be understood to be an expression in action of a re-definition of boundaries.

Other aspects on the introduction of art images

Could it have been possible that the conversation and physician 10's reflections would have revolved around the same themes and ideas had not art images been used or had there simply been enough time or had the right questions been asked? Perhaps. However, such a question warrants carefulness in answering, as it is prone to the entertaining hindsight bias and counterfactual reasoning [25]. Art images were in fact introduced and the conversation did not happen any other way. A more substantial analysis of multiple interviews, with and without images might provide some relevant insights.

However, here also lays another, less obvious or subtler, assumption about our thoughts and how they might relate to the use of images. This often-unexamined assumption is that thinking is primarily/essentially representational; meaning that thoughts, ideas and concepts are some definable/identifiable "thing(s)" [26-29]. In reverse is the notion that a concrete image (e.g., an artwork) will reveal, or stands for, dormant thoughts and ideas otherwise not available to the person [30]. To subscribe to such a, rather psychoanalytical, view would be beyond our capacity as authors, as well as somewhat counter to our initial intent. Indeed, our starting point is that thinking is non-representational first; meaning that thinking is initially a process in time and that the movement of identification comes subsequently [26-29]. In other words, when considering thinking as non-representational the emphasis will be more on what the introduction of new medium, such as art images, brings about (i.e., what is created) in the conversation rather than on uncovering some secret meaning hidden within the person's thoughts [26-29]. In our approach we were more interested in the co-creative aspects of the interview and subsequent analysis rather than on the informational content of that interview [18, 31].

The re-construction of communication and responsibility, as well as that of temporal and spatial system boundaries in considering decision-making as potentially harmful and as care for the future shows the relative nature of boundaries in complex systems. It also shows the analytical strengths of interview techniques designed to facilitate the reinterpretation of our lived experiences. The complexity scholar Paul Cilliers [32] expressed his thoughts on the connection between appreciating various kinds of art and expanding our abilities to understand complex systems:

> The claim that our understanding of complex systems cannot be reduced to calculation means that there will always be some form of creativity involved when dealing with complexity. 'Creativity' should not (only) be understood in terms of flights of fancy or wild (postmodern) abandon, but also in terms of a careful and responsible development of the imagination. Imagining the future will involve risk, but the nature of this risk will be a function of the quality of our imagination. It is important that we start imagining better futures, and for that we need better imaginations. Reading books, listening to music, appreciating art and film is not a form of entertainment to be indulged in after we have done our serious work. These creative activities stimulate the imagination and thereby transform the frameworks we apply when apprehending the world. (p.264)

5. Conclusions

Trying to understand the complexities of practitioners' lived experiences from working close to the boundaries of complex adaptive systems is a challenging and still relevant issue for resilience engineering. From the case study of a single interview set within Swedish obstetric care, we have argued that the use of art images can help practitioners re-construct the boundaries of their systems and re-define their adaptive capacities in relation to such boundaries. We hope that this paper will be received as an invitation for researchers and practitioners alike to further explore the possibilities of using art images, as well as other creative avenues to help in re-imagining the frameworks for apprehending the reality of complexity in practice.

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Joint Performance Graphs (JPG): Visualizing Resilient Performance?

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When the Resilience Engineering Association (REA) challenged its members with the question, "Can we visualize resilience?", we attempted to answer that question with visual analytics. Although our ultimate creation is difficult to define as art, which is ultimately what the challenge was meant to produce, we feel that our method of translating critical aspects of resilience into visual media makes a valuable contribution to the conversation of what is resilience? We believe that our resultant Joint Performance Graphs (JPG) are a strong foundation from which we can depict graceful extensibility once additional aspects are encoded, and can serve to spur new conversations to further our ability to detect and measure the expression of and potential for resilience.

Keywords: Resilience, data visualization, joint performance, graceful extensibility, adaptive capacity

Joint Performance Graphs – rationale, methods and results

Defining resilient performance is a contentious endeavor, which makes visualizing it at least as provocative. Although there is strong consensus that resilient performance is what allows a system to maintain a stable state (Hollnagel et al., 2006), more detailed definitions quickly become fractious. Definitions range widely from describing individual attributes that allow certain people to manage and thrive amid challenges and hardships (Lo et al., 2016) to many definitions of resilient system performance. These include rebound: the ability to bounce back to a normal state after a shock (Nemeth & Olivier, 2017; Woods, 2015); robustness: the ability for the designed system to withstand known and well-modeled challenges (Woods, 2015); graceful extensibility: the system's ability to adapt and extend its capabilities to meet new challenges (Woods, 2015); sustained adaptability: a system's ability to adapt the manner in which it adapts to continually replenish sufficient adaptive capacity (Woods, 2015), thereby being able to sustain graceful extensibility. The resilience engineering community has more recently coalesced around these latter two concepts, updating the definition of resilience to be "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" (Hollnagel, 2013).

The visualizations that we designed, called Joint Performance Graphs (JPG's) (Morey et al., 2022) were primarily designed to compare performance of teams with different configurations of human and machine capabilities. Details are shown in Figure 1. The JPG's primary frame of reference (Woods, 1995) depicts system performance relative to the magnitude of system challenges. For each JPG, cases, probes, or periods of time that are associated with varying degrees of challenge are plotted (a). Then the system is tested, either experimentally or in an operational setting, with performance being charted relative each degree of challenge (b). Central tendency analysis is performed (c), the empirical performance curve is plotted (d), and performance is analyzed relative to a referent (e). This comparison to referent can be in the form of an A/B test of compared systems, or comparison to an agreed upon standard. Finally, a model is fitted to the observed performance, which is then plotted (f).

But are JPG's a visualization of resilience? Instead of answering that question directly, we instead seek to describe how aspects of the JPG are symbols that map to important aspects of resilience.

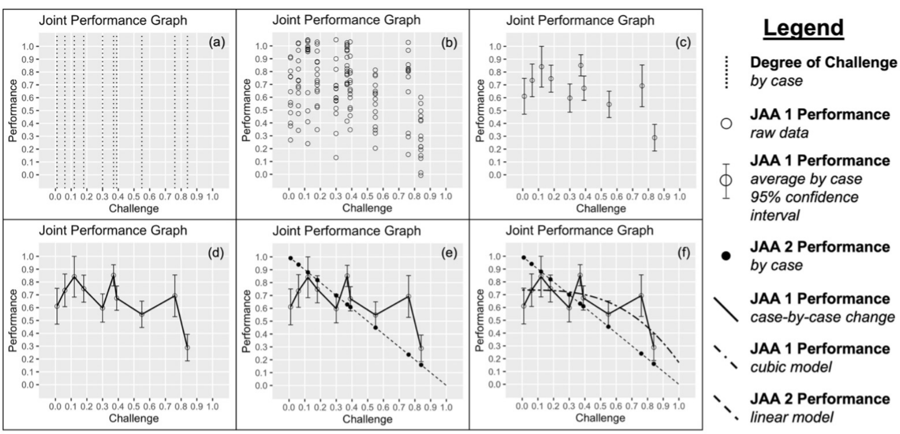

Figure 1.

Resilient performance symbols present in JPG's

Visualizing changes in performance. As mentioned above, the consensus definition of resilient performance is the ability to adapt behaviors to sustain performance in the face of increasing challenge (Hollnagel et al., 2006). JPG's clearly show both the observed and modeled system performance, implicitly directing attention to regions of stability, marked by relatively unwavering measured or modeled performance, and regions of brittleness, indicated by rapid performance decline (i.e., either largely negative first or second derivatives, or both) leading to failure (Woods et al., 2013).

Visualizing edges of competence envelope. Related to the performance changes mentioned above, the shape of the edge of the system's competency envelope is vital in understanding the extensibility of the system as it transitions between its base and extended adaptive capacity (Woods, 2018). However, it is difficult to know where those boundaries are unless they are crossed (Cook & Rasmussen, 2005). JPG's, however, are designed so that the location and shape of this boundary and transition zone can be directly perceived. Visual signatures of the shape of the boundary can represent that system will have sufficient time to deploy, mobilize, or generate resources when needed (Woods et al., 2013).

Visualizing support for anticipation. Because modeled performance can extend past the range of observed behavior, visual signatures can support anticipation of future system performance, which is a critical capability of resilient performance (Hollnagel, 2009). Extrapolated regions of the model outputs can be quickly scanned, either individually or collectively if multiple JPG's are displayed, to support discernment of potential hazards from irrelevant noise as challenges combine in combinations and magnitudes previously not experienced. The visual motifs of brittleness and extended boundaries described above can be used to interpret potential futures.

Resilient performance symbols NOT present in JPG's

Symbols of adaptation not present. Markers of adaptation and adaptive capacity are not currently present in JPG's. This is a notable shortcoming, as it is these markers that can are necessary to discern the difference between robust and extensible behavior (Woods, 2015), and provide valuable insights into potential future failure trajectories. In particular, this absence makes it ambiguous how flat (i.e., slope=0) regions of the JPG should be interpreted. Are these regions in which the challenge is sufficiently low that the system's latent robustness can address it, or is it the result of active adaptive processes successfully extending the system to meet it? Even though JPG's successfully prime observers to detect regions of brittleness, they are not well suited to unambiguously detect graceful extensibility.

Symbols representing stretching are needed. In this and in other visualizations seeking to depict resilient performance, visual symbols of system adaptation, or stretching, are needed. These visual depictions will need to symbolize both the kind and magnitude of the stretch. They will need to symbolize elastic stretch regions, in which the system is continuously diverging and returning to roughly the same state as it continuously sacrifices and resumes goals, structures and functions (Woods et al., 2013). They will also need to symbolize plastic stretch regions, in which these sacrifices forever deforms the system in ways that lead to meaningful system changes even after the system reforms after a challenge has been addressed (Woods et al., 2013). They will need to symbolize the magnitude of a stretch, potentially measured in the criticality of goals, structures and functions that were at least temporarily sacrificed. Stretch magnitude may also be depicted in terms of the rarity of a particular response, or way of stretching. Finally, they need to symbolize the cost of a given stretch or of a portfolio of stretches, giving insights of how tradeoffs will be negotiated to make a decision to stretch in a particular way (Hollnagel, 2017).

From Joint Performance Graphs to true Extensibility Plots

We are planning to extend our ability to collect data to determine the types, magnitudes, costs and sustainment of systems adaptations (i.e., stretches), relative to the types and magnitudes of observed challenges. We hope to be able to characterize and discriminate stretches that continue to replenish or bolster adaptive capacity from those that chronically deplete it. By understanding the multi-dimensional cost of these stretches, we can predict how urgent a perceived challenge would need to be to perform that stretch again. In these ways, we can more confidently assess a system's ability to gracefully extend and sustain its adaptability.

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Seeking Advantage in Video Games

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Fun and relaxing video games have been hijacked in recent years by the speed running community for a very different purpose: finding the fastest optimal path to completing games. Additional challenges and increases in difficulty require players to practice and perfect their skills to an extreme degree. They take advantage of affordances in the virtual world, intended and unintended by the game creators, to complete games in fractions of their typical playtime. As a community, speed runners share their recorded game runs including discovered glitches and new methods for shaving seconds and fractions of a second. The community also uses tools to assist in perfecting the theoretical limits of human ability. Those bounds are as flexible as the video game media and change as new discoveries are shared. Speed runners are unique players that take advantage of the brittle boundaries in video games to seek new frontiers of performance.

Keywords: video game, speed run, adaptation, brittleness, affordance, collaborative community.

Introduction

Most individuals play video games to enjoy the simulation or story of some realistic or fantasy scenario. The speed running community has a very different experience with games: the purpose is to complete a game in the shortest time possible. The definition of complete may change depending on the challenge, but the objective is the same. While this may seem like a strange usage or hijacking of games, it has become a popular competitive and collaborative pastime for a significant community across the internet. Speed running competitions raise millions every year for various charities (Gutelle, 2022; Paez, 2020) and are regularly a part of video streamers' repertoire. Players have taken advantage of gaming constraints to find innovative paths to completing games, adapting to their brittleness and creating new opportunities for themselves and the larger community.

Evolution of Gaming & Speed-Running

Video games have been a popular interactive media for decades, originating in university laboratories in the 1950s and 1960s (History.com Editors, 2017).

Simple renditions of tic-tac-toe and ping pong inspired other simulations extending beyond realistic settings. Adventure for Atari created the first adventure game with a medieval maze on incredibly limited hardware, while allowing for complex creature behaviors (East Coast Game Conference, 2019). As video games grew in length and complexity, players explored the boundaries and found new ways to "play". Racing games like "Drag Race" and "Dragster" (Carter, 2018) saw people competing against each other by posting pictures of their records on screen in the 1980s. It was not until the 1990s with the introduction of the video game "Doom" that speed-running grew in popularity to what it is today.

"Doom" allowed real-time capture of gameplay, which enabled players to share their playthroughs of the game. Players would then create challenges by setting self-imposed limitations, such as restricting what weapon choices they could use or without killing any enemies. Popular categories in the speed running community include any% (simply finishing the game without any stipulations), 100% (completing the game in full, usually by some achievement definition), and low% (finishing the game with the least number of achievements or progression). Some categories allow the exploitation of glitches, such as a player's character accidentally slipping behind game assets or falling through the floor. Challenges emphasize speed and/or added difficulty to the gameplay: for instance, "Super Mario Odyssey" speed runners were able to develop untaught mechanics to reach parts of the map and bypass the normal mechanisms of the game. Speed runners have played one of the hardest game series, Dark Souls, in many unintended ways like with a Guitar Hero controller and DDR mat, in addition to one challenge of a deathless multi-game speed run (must restart completely if the character dies) (Murray, 2022).

Speed running has kept many relatively older video games popular by setting records for completing games in under a fraction of their traditional playthrough time. For instance, "Super Mario Bros" has a current record under four minutes and 55 seconds (Orland, 2021) compared to the typical play time of 2 hours. The substantial record was achieved through glitch less and precise skill. The popular adventure game Pokémon Yellow any% world records are sub minute when the expected gameplay is measured in hours or days for the casual player (Wester, 2011). Speed runners play these video games in a fundamentally different way than the average player.

Skilful Opportunities in Games

Speed running focuses on finding the optimal path through a game, completing events and landmarks in a minimum amount of time (Omnigamer, 2014). This minimum may depend on physical constraints such as frame rate limitations (how fast the screen is outputting and updating the display), pixel perfect maneuvers and player reaction times. One example illustrates needing all three: players can save significant time in one level of "Super Mario Bros" by timing a frame-perfect time in between two specific blocks on a wall. The precision of the jump requires hours of practice and repetitive trials to achieve, especially on a consistent enough basis to record as most speed runs are continuously captured in one take. The game enables this optimization within the physical constraints of the virtual world itself.

Another example of seeking opportunity is utilizing the affordances of the game mechanics to unintended effect. Video games are entirely designed and built through computing with flexible boundaries on their capabilities. Designers may implement artificial boundaries such as invisible walls to prevent players from leaving certain areas or reduce the need to generate larger virtual worlds. Modern open world games can use procedurally generated content to reduce the limitations on the player's explorations. One example of an open world game is the "The Legend of Zelda: Breath of the Wild". This game has a particular mechanic that gives the player the ability to freeze objects in place and apply a delayed force to propel them in the direction of the user's action. While the game sets this ability up to complete various puzzles, many players have adapted it to propel their character across the large map instead by standing on the object before it unfreezes (Goldfire711, 2017). Even the life- simulator "Animal Crossing" gives players the opportunity to take advantage of certain object bounding boxes to funnel elusive balloon resources that appear at random into easier zones to catch (Crossing Channel, 2021).

Games can afford users other advantages through glitches, though these are generally unintended features or errors. Players can slip past the boundaries of the world to bypass normal obstacles. The brittleness of the system under certain conditions creates new opportunities and risks for the player seeking the fastest times. One instance, "The Legend of Zelda: The Wind Waker" had a blocked off final area that was eventually broken through by clipping past it (Alexandra, 2016). Bugs and glitches can save significant portions of time by maneuvering around barriers, but some can also endanger the save file, tracking the game's progress. Speed runs are generally completed in one continuous session, so the risk is often low for those taking advantage of the potential benefits.

A Community Seeking Continual Advantage

The various examples mentioned, from "The Legend of Zelda" to "Super Mario", were collaboratively discovered over time by members of the speed running community. Although there are multiple leaderboards ranking top players, speed runners openly share new exploits and advancements online. The community is based on transparency with members posting the captured video footage, controller input mapping and recording, hardware, and software specifications that were used to baseline results against others' performances. The game communities may take years of experimentation and tool-assisted trials to reduce the time on playthroughs (Brewster). Emulators can manipulate the time it takes to run through a game and achieve repeatable results (inverse). The replication of glitches and new affordances is the key to successfully building up the community's knowledge and extending the optimal performance over time.

Tool-assisted speed runs (TAS) also can give a theoretical limit on human performance as a standard for comparison. Going back to the "Super Mario Bros" world record example, the theoretical best time is calculated at 4:54:282 based on frame rate, reaction time, and allowable input action assumptions. Accounting for other shortcuts that the TAS incorporated, the world record was only nine frames off from the theoretical human limit (Orland, 2021). The mathematical limits are both a goal for speed runners and a way to corroborate reported times' validity. For example, one speed runner of "Trackmania", a racing game with user-built maps, was caught cheating because his world record's inputs were deemed impossible for a human to achieve (Wirtual, 2021). The theoretical limit becomes an achievable objective for speed runners, which dynamically changes as new methods are discovered. Speed runners live at the boundaries and continuously push them further as a community that sees games at the edges of performance.

Conclusion

Speed running is a nuanced, community-driven practice seeking new ways to optimize game completion. Taking advantage of intended and unintended affordances, as well as game-breaking glitches, pushes the bounds on human performance in these video game settings closer and closer to theoretical limits. Each time a new exploit is discovered, shared, and refined; the potential limit extends beyond what was previously thought possible. The speed running community has steadily grown over the past few decades to gather interest and momentum around adapting to the apparent brittleness of video games. As another interpretation, speed runners continuously seek advantage through the

constraints, dynamic flexibility, and opportunities of the virtual medium.

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Surviving in *The Martian*: resilience and imaginaries in extreme situation

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The Martian*, a film directed by Ridley Scott, recounts the survival experience of Mark Watney, a NASA astronaut, who is left to fend for himself on Mars following an accident. Confronted with an extreme situation, the character faces unprecedented difficulties, which test his capacities for resilience. The fact that Watney was selected and trained by NASA and his many scientific and technical skills partly explain his ability to adapt to a situation that no human has experienced before him. However, these criteria alone cannot explain the character's resistance.* The Martian *illustrates in this way the crucial role of imaginary meanings as human springs of the resilience in the face of an extreme situation. On the one hand, Watney gives a sublime purpose to his daily struggle, which is therefore filled with meaning. On the other hand, the thought and practices of the astronaut reflect an ideal of efficiency, a belief without which he could neither conceive his survival project nor implement it. This ideal also represents a determining element of its narrative identity, the maintenance of which constitutes a strategy for surviving in extreme situation.*

Keywords: space conquest, extreme situation, survival, resilience, engineering, imaginary, efficiency, identity.

1. Introduction

The Martian is a 2015 hard science fiction[1] film directed by Ridley Scott, based on the eponymous novel by Andy Weir (2014)[2]. The film chronicles the survival on Mars of astronaut Mark Watney, played by Matt Damon[3]. During an expedition to the Martian surface, Watney suffered an accident caused by a violent

[1] Science fiction genre in which the technologies described by the author and the situations he narrates are in accordance with the state of scientific knowledge at the time of the creation of the work.

[2] The film's screenwriter, Drew Goddard, has adapted Andy Weir's novel very faithfully. See "Signal Acquired. Writing and Direction", bonus on the Blu-Ray of *The Martian*, 9 min.

[3] See synopsis at the end of the article.

sandstorm. He is left for dead by his teammates, forced to take off in an emergency. The protagonist, however, survives and finds himself trapped on a distant and very hostile planet, with no way to contact Earth – the communication systems having been destroyed. Inspired by the character of Robinson Crusoe[4], Watney finds himself cut off from the world and confronted with unheard-of difficulties, straining his capacity for resilience. For two months, the astronaut manages to survive without benefiting from assistance, until NASA realises that he is still alive and implements all means to save him.

Ridley Scott wanted his film to be as realistic as possible. To do this, he carefully supervised designing the props, the making of the sets, and the development of the costumes (Couston, 2015). He also called on NASA experts as technical advisers during filming (Rouat, 2015). Delighted to participate in the project, the American space agency saw this collaboration with the director of *Alien*[5] and *Blade Runner*[6] as an excellent opportunity to reawaken the spectators' interest in exploring space (Le Point, 2015).

Upon its release, *The Martian* was a resounding commercial success and captivated a vast audience[7]. While recognising the artistic quality and the effort of realism of the film, the scientific community noted a certain number of inconsistencies. Alain Souchier[8] reminds us, for example, that the density of the atmosphere of Mars is 80 times lower than that of the Earth and that a wind of 300 km/h would exert the same pressure there as a wind of 30 km/h on our planet (Morin, 2015). In reality, a sandstorm could not constitute a threat comparable to that suffered by the astronaut team in *The Martian*. Scientists have also debated the possibility of surviving alone on Mars. Romain Charles[9] is surprised that Watney has no weaknesses and does not suffer from loneliness: "*Man is a social animal, and total isolation can hardly have any impact on his psychology*[10]" (Delesalle, 2015). François Forget[11], for his part, considers that Watney's resistance is far from implausible: "*I have seen presentations by NASA psychologists on the psychological risks specific to Mars travel. There are studies to define the best profiles, to*

[4] Hero of Daniel Defoe's novel, *The Life and Strange Adventures or Robinson Crusoe, of York, Mariner*, published in London in 1719. Following a shipwreck, Robinson Crusoe finds himself on a deserted island. He stays there for 28 years.
[5] Science fiction horror film directed by Ridley Scott in 1979.
[6] Science fiction film directed by Ridley Scott in 1982.
[7] It is the most important success of Ridley Scott's career.
[8] President of "Planète Mars", the French branch of the American Mars Society.
[9] Engineer from the Centre National d'Études Spatiales [National Center for Space Studies).
[10] Translated from French into English by the author of the article.
[11] Planetologist at the Centre National de la Recherche Scientifique [National Center for Scientific Research].

reduce the risk of depression, crisis, and tension. […] In my opinion, with well-selected astronauts, psychological issues will not be an obstacle[12]" (Zeitoun, 2016).

This point of view is in line with Andy Weir's vision of his character. For the novelist, Watney represents an idealised version of himself, having his character traits and most of his qualities but none of his faults: "*He has more resources but does not have my fears or my neuroses. I believe he is what I would like to become*[13]" (Première, 2016). Weir specifies that the astronaut is not tested by loneliness or stress because he was selected to go to Mars: "*So it is not just any random guy. To find himself in this situation, he had to be better than tens of thousands of other people*[14]" (Carroll, 2021).

A graduate of the University of Chicago, Watney is a botanist and mechanical engineer[15]. In the novel, a NASA psychologist maintains that besides being highly intelligent and resourceful, like all astronauts, he excels at problem-solving and has a strong sense of humour and self-mockery. By integrating the Mars exploration program, the character has also undergone comprehensive training and learned to deal with an emergency.

However, Watney's training, no more than his recruitment, expertise, ingenuity, or humorous traits, are not enough to explain that he survived on Mars; what is more, without any help from NASA teams for two months. In this, *The Martian* presents other narrative elements that play a crucial role in resilience, which we propose to examine through the prism of imaginary social meanings.

Following Cornélius Castoriadis (1998 [1975]), imaginary social meanings refer to norms, values, myths, representations, beliefs, projects, and traditions in which individuals of the same society participate. It is these imaginary meanings that hold the social edifice together. In return, the psychic existence of the individual only takes on meaning by referring to the imaginary meanings created by society. In this way, the two dimensions, one individual and the other collective, of the imaginary are connected. For Castoriadis (1996), the function of imaginary social meanings is threefold: they structure representations of the world in general, without which there would be no human being; they designate the aims of the action; finally, they establish the particular types of effects of society. These three

[12] Translated from French into English by the author of the article.
[13] Translated from French into English by the author of the article.
[14] Translated from French into English by the author of the article.
[15] As Watney explains in the novel: "*Everyone on the mission had two specialties. I'm a botanist and mechanical engineer. Basically, I was the mission's fix-it man who played with plants. The mechanical engineering might save my life if something breaks* », cf. Weir A., 2014: *The Martian*, *op. cit.*

functions materialise through the creation of institutions, considered the mediators of the imaginary.

Therefore, this study of *The Martian* proposes deciphering two particularly salient imaginary meanings, which correspond, on the one hand, to the sublimation of action and, on the other hand, to the ideal of efficiency. According to our hypothesis, these imaginary meanings constitute essential components of Watney's resilience in the face of his situation.

In an essay devoted to the powers of fiction, Vincent Jouve (2019) wonders what narrative reading, apart from the pleasure it provides, can bring to the reader or the viewer over the long term. In addition to compensating for the insufficiencies of reality, fiction allows the public to broaden their horizons and, in some cases, modify their vision of things. Fictional immersion opens up an exploration of possibilities, allowing access to the singular character of each experience and trying out situations. Fictions work like thought experiments to uncover what might happen if several conditions were met. They can confront the public with configurations they do not know or even do not imagine and constitute a way of learning. *The Martian* is, in this sense, a thought experiment, exposing the viewer to a survival situation that only science fiction allows us to envisage – the human exploration of Mars not being possible for the moment – and in able, in our view, to provide lessons on resilience in a context that we qualify as an "extreme situation".

2. Facing an extreme situation

For Bruno Bettelheim (1979), an individual finds himself in an extreme situation when he is suddenly catapulted into a set of living conditions that renders his defensive system inoperative, leading him to hit rock bottom. Gustave-Nicolas Fischer (1994) emphasises that individuals faced with an extreme situation reach the limits of what is acceptable and livable on a human level. Such an experience causes a break from a previous state of life, causing material and psychic changes for which the subject is unprepared.

Fischer uses the image of the spring to designate the multifaceted expressions of survival in extreme situation. This image illustrates the idea of human plasticity in the face of a situation deemed to be trying, the ability to act on these events (by absorbing shocks and bouncing back), and the individual's capacity for resistance, who must find in himself the strength to survive. Coping does not just mean mobilising resources to deal with a traumatic event. It also constitutes a struggle against death and its forces of destruction, which refers to a process through which the individual learns to live.

Survival mechanisms also reveal unsuspected resources and endurance in human beings. The question of survival is linked to the psychic work that the subject accomplishes on himself, identifying his reasons for living and referring to them to give meaning to his struggle. The individual must get out of the state of stupefaction into which the extreme situation plunges him and regain the power to act by deploying various resilience strategies.

Given this theoretical framework, we consider that the character of Watney is confronted with an extreme situation. Isolated in an environment unfit for life, with minimal resources, the astronaut must find the means not to collapse internally and to survive a situation that no human has experienced before him.

This collapse threatens Watney as soon as he regains consciousness following his accident. Injured, he joined the Habitat to heal before recording a video on a computer. His message expresses all his distress: "*I have no way to contact NASA. And even if I could, it's gonna be four years until a manned mission can reach me. And I'm in a Habitat designed to last thirty-one days. If the oxygenator breaks, I'm gonna suffocate. If the water reclaimer breaks, I'll die of thirst. Is the Habitat breaches, I'm just gonna, kind of… implode. And if by some miracle, none of that happens, eventually I'm gonna run out of food. So… Yeah*". Watney repeats this word before locking himself in a profound silence, which testifies to his stupefaction. It is then filmed from outside the Habitat. The wind blows strongly. Through a window, the spectator sees the astronaut seated in front of his screen. The composition of the plan illustrates the extreme vulnerability of the character. Completely distraught, he seems to have irretrievably hit rock bottom. The rest of the film, however, will demonstrate the opposite.

3. Project of survival and sublimation of the action

In the following shots, the astronaut examines the oxygen level indications, reflects, walks through the Habitat with a cup in his hand, and closes Commander Lewis' computer screen. He then places photographs left by the Commander in a bin. He closes the bin, places it in a storage area, and says, "*I'm not gonna die here*".

Watney then takes stock of his food supplies. The information collected allows him to determine the number of days he had before dying of malnutrition. This disastrous outcome refers to the concept of "temporality of the project" defined by Jean-Pierre Dupuy (1994; 2002), which is essential for studying the entry into resilience in the context of an extreme situation. In the temporality of the project, a point of reference is chosen on a future horizon to condition an action in the present to thwart the prophecy of annihilation. This concept leads the individual to order events sequentially and to give meaning to counterfactual reasoning. As Franck Guarnieri and Sébastien Travadel (2018) point out, the project's temporality allows the subject to consider innovative solutions, get out of the state of stupefaction and discover new means of action in action.

Watney inscribes the present in a trajectory leading to its annihilation, like a prophecy which must then be thwarted so that the present becomes habitable again. The astronaut sets himself the goal of mobilising all the means at his disposal to stay alive and hold out until the arrival on Mars of the next human mission, scheduled four years later. He then immerses himself in action, dealing with each of the difficulties he encounters sequentially, as he indicates: "*You just begin. You do the math. You solve one problem, then you solve the next one. And then the next. And if you solve enough problems, you get to come home*". Watney thus collects the excrement of the crew to fertilise the soil of Mars and manages to cultivate potatoes in the Habitat. To produce sufficient water, he uses the reserves of hydrazine contained in the Martian descent vehicle, which he transforms using a dangerous chemical process.

As a result, the character reduces the extreme situation to a series of problems, which he solves by being creative. However, he cannot exclude the possibility of an unfortunate error or the occurrence of an unforeseen event, the effects of which could lead to his death. In response to this eventuality, Watney will sublimate his action. He thus declares, in one of the videos he records to testify to his experience: "*if I die, I will die for a huge and magnificent project and bigger than me*". By removing death from its status as a failure, this imaginary meaning gives a grandiose significance to the struggle that the character leads. This proves to be all the less pointless in that it constitutes, whatever its outcome, an invaluable source of knowledge for NASA, thus serving the project of space conquest and the progress of humanity.

Watney idealises his daily struggle, thus filled with meaning. By sublimating his action, the character maintains at the same time his bond of belonging with his congeners, despite his distance from Earth and his isolation. In this way, he continues to make humanity and remain human, which for Bettelheim (1972), constitutes the whole point of the extreme situation.

4. Ideal of efficiency and narrative identity

The social utility that Watney attributes to his struggle also refers to the imaginary of the technique, which has several functions, according to Antoine Picon (2001). On the one hand, it gives the technique a purpose that justifies its use and distribution in societies. The imaginary, being based on images, consists, on the other hand, of making visible the invisible and making concepts, notions, or ideals that are difficult to represent concretely, such as the ideal of efficiency, almost tangible, which is at the heart of technical thinking and engineering methods. As Sébastien Travadel and Franck Guarnieri point out, "*The imaginary social meanings and the underlying principles of order condition the way an engineer formulates his questions and judges his results. Efficiency can indeed be defined as an evaluation of the functional properties of an object (typically, the solidity, the consumption, of particular resources of a collective) deduced from its adequacy to a principle of the natural order. The degree of rationalisation of a practice expresses the influence on this practice of an imaginary of efficiency*[16]" (Travadel and Guarnieri, 2021, 54-55).

Applied to our object of study, the modes of reasoning and practices used by Watney translate an ideal of efficiency without which the astronaut could neither conceive his survival project nor implement it. Faced with the extreme situation, the character bases his struggle on the unshakable belief in this ideal. Thus, he exposes in a video his plan to cultivate potatoes before exclaiming, not without an air of defiance: "*Mars will come to fear my botany powers!*". Armed with his imaginary, Watney faces danger and thwarts the traps set by the red planet, which he identifies here as the figure of the enemy.

The ideal of efficiency also plays a decisive role in the constitution of the character's identity. The values and beliefs of an individual and all of his representations of the world give his identity its coherence and stability (Fischer, 1994). The ideal of efficiency participates in the development of Watney's narrative identity, as evidenced by the account of his actions. According to Paul Ricœur (1985, 1990), identity can only be thought of in its relationship to human time. If narration is a means of structuring temporal experience, self-narrative can be interpreted as an attempt to inscribe an existence in time. The narrative activity, by plotting the facts that follow one another on a time frame, allows the individual to grasp the heterogeneity of his experience, to give it meaning and coherence, and to access understanding of his identity. In this, Watney's videos are not only a means of maintaining his morale or leaving a trace of his experience that NASA could exploit for scientific research. By making his videos, the character puts himself in narrative. He exposes the problems he faces, explains the technical solutions he develops, recounts his successes, and shares his concerns and setbacks without questioning the power of science or the effectiveness of engineering methods.

Watney gives meaning to his experience and defines his identity through his testimony, the maintenance of which is threatened by the extreme situation. In

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[16] Translated from French into English by the author of the article.

such a context, the individual sees his identity as subject to a risk of disintegration, as Fischer evokes: "*In the extreme situation, our identity markers lose their consistency, our frames of reference burst, our identity is torn apart*[17]". (Fischer, 1994, 27). Consequently, maintaining identity is a survival strategy in extreme situation (Bettelheim, 1972; Pollak, 2014). By becoming the narrator of his experience, Watney affirms his identity as a scientist and engineer whose constitutive elements refer as much to his actions as to the imaginary of the technique that it underlies. Thus, his self-narrative reveals the permanence of his system of beliefs and representations, which allows him to maintain the integrity of his narrative identity in the face of the forces of destruction at work in extreme situation.

5. Conclusion

This analysis of *The Martian* is not intended to exclude scripted elements such as the recruitment and training of astronauts or even Watney's professional skills and his unfailing humour in explaining the character's resistance. Nor is it a question of minimising the formidable means implemented by the NASA teams to bring the astronaut back to Earth safe and sound. These elements should be taken into account, but they do not in themselves shed light on how Watney makes sense of his experience and his relationship to the world to survive. This requires considering of the sublimation of action and the ideal of efficiency, which illustrate the crucial role of imaginary meanings as human springs of the resilience in the face of an extreme situation.

Moreover, the importance of this role, highlighted in Ridley Scott's film, can also be seen in very real cases of extreme situations, such as the Fukushima Daiichi nuclear disaster in Japan on 11 March 2011. Faced with existential risk, the plant operators felt they represented the only line of defence to protect their families, their region, and their country from annihilation (Guarnieri and Portelli, 2021). By idealising their action, they thus gave meaning to their efforts and sacrifices to regain a grip on the installations, which had become out of control.

Furthermore, viewing *The Martian* brings an additional lesson about the situation of isolation experienced by Watney. Indeed, despite an apparent paradox, the astronaut is never completely kept from the world during his stay on Mars. Of course, on a strictly physical level, he is forced to live alone on a distant and inhospitable planet; and even when he manages to re-establish contact with NASA, the distance between Mars and Earth remains abysmal and a source of dread. However, on the other hand, this cut becomes quite relative once related

[17] Translated from French into English by the author of the article.

to the psychic activity of the character. This is where the imaginary reveals its effective power. Watney places his fight at the service of the conquest of space and the future of humanity. His thought and his practices translate an ideal of efficiency which refers, in the same way as the social utility granted to his fight, to the imaginary of the technique. More precisely, this ideal and this social utility echo to the technicism aiming to privilege technique in all human activities. In this way, Watney continues to be immersed in technical society (Ellul, 2012) and the imaginaries that hold it together, thereby allowing the astronaut to continue to exist in the world that makes sense to him.

Synopsis

NASA's Ares III mission members were exploring Mars when they got caught in a high-intensity storm. Mark Watney, the team's botanist is hit by a torn antenna and disappears in the storm. The mission Commander, Melissa Lewis, is convinced that her colleague is dead. With the lives of the rest of the team threatened by the storm, Lewis orders them to abort the mission and take off immediately to join the *Hermes* spacecraft. The day after the accident, Watney regains consciousness and discovers that his teammates have left without him. Its food resources are minimal, and the communication systems with Earth have been destroyed. The next Ares IV mission is scheduled for four years. To survive, Watney must mobilise his scientific skills and demonstrate ingenuity. He thus manages to grow potatoes in the Habitat, a dome designed to ensure the survival of 6 astronauts for 30 days. The character also keeps a logbook in the form of videos in which he recounts his daily activities. Two months after the accident, NASA discovers, thanks to space imagery, that Watney is still alive. The agency director decides not to reveal this information to the crew of the *Hermes* back to Earth. Watney goes to the site of a space probe to recover his radio transceiver. He manages to reactivate it and re-establish contact with Earth. NASA decides to send a supply cargo ship to Mars. To save time, the engineers do not carry out the usual tests.

The launch date is approaching, and the NASA director informs Commander Lewis that Watney is still alive. The launch of the freighter takes place, but a failure causes its destruction during its flight phase. On Mars, a tear in the Habitat wall leads to the dome's decompression. Watney loses his entire harvest. The Chinese space agency offers NASA to send a rocket to Mars to refuel Watney. NASA agrees. An engineer from the American agency offers another solution. When the Hermes flies over Earth, the spacecraft could use its gravitational assistance to return to Mars and recover Watney. The director of NASA refuses this second scenario, as it is too risky for him. In disagreement with his boss, the mission flight director secretly submits the idea of the second scenario to the crew of the *Hermes*. The astronauts unanimously accept it, aware that this decision extends their stay in space by 533 days. They change their flight details without prior authorisation. NASA is forced to adapt its plan accordingly, and the Chinese rocket now has the mission of re-fuelling the *Hermes* during its flyby of Earth. Watney is made aware of the new rescue plan. He uses a rover to reach the site where the Ares IV return rocket has been prepositioned, allowing him to leave the Martian surface. However, the rocket must be more robust to place itself in orbit around Mars, and Watney must lighten the machine according to NASA's instructions.

After months of travel, the *Hermes* is approaching Mars. The rocket launches with Watney on board. However, the speed of the *Hermes* and the distance between the spacecraft and Watney remain too great. The crew manages to reduce the speed of the *Hermes* by triggering a controlled explosion on board. Lewis exits the ship to retrieve Watney, but he remains out of reach. He then pierces his suit at the arm's level and uses the air jet to propel himself into space. He manages to join Lewis, who recovers him *in extremis*. Back on Earth, Watney, now a NASA trainer, passes on his survival experience to aspiring astronauts.

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How Richard Cook Prepared Me to See the Impact of a New Technology on Complex Cognitive Nursing Work

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Conducting 'in situ' observations of complex, cognitive work in a specialized domain is a core competency of researchers in Naturalistic Decision Making and Resilience Engineering. A debated topic is how much to predict in advance findings from observations, given the trade-off of needing to pull findings from overwhelming and complex data and to remain open to discovering phenomena that are not predicted in advance. I discuss the role that formally documented predictions played in a series of observational studies of the impact of introducing Bar Code Medication Administration software to nurses throughout the hundreds of Veteran's Health Administration hospitals and long-term care facilities. These predictions were made by the late Dr. Richard I. Cook, and this paper is dedicated in honor of his memory and great legacy.

Keywords: Ethnography, Hospital Medication Systems, Software, Decision Making, Informatics, Human Factors

1. Introduction

In 1999, the eminent Dr. Richard Cook documented a set of predictions about how a new software technology being introduced throughout all of the hundreds of hospitals and long-term care facilities in the Veteran's Health Administration (VHA) would impact practitioner technical work. The software was Bar Code Medication Administration (BCMA), and the primary users were registered nurses in hospitals and long-term care settings. In his rationale, he referenced findings from the paper he co-authored with Dr. David Woods in 1996 in Human Factors, titled "Adapting to New Technology in the Operating Room."

2. Predictions by Dr. Cook on Impact of Bar Coding

Dr. Cook's ten predictions regarding the introduction of BCMA were numbered and are provided in this section. These are reproduced exactly as they were, in his words, in a memorandum on the letterhead of his Cognitive Technologies Laboratory at the University of Chicago with attention to Dr. Marta Render from Dr. Richard Cook on September 21, 1999. The memo was carbon copied to myself, Dr. David Woods, and a graduate student in Dr. Woods' Cognitive Systems Engineering Laboratory at The Ohio State University.

The predictions, followed by non-exhaustive proof-of-concept examples from our 'in situ' observations in hospitals and long-term care settings were:

1. Bar coding will impose new workload on users. Responses to this additional workload will vary but be directed at production while (apparently) maintaining robust performance.
2. Practitioner adaptations will include both system tailoring / task tailoring. System tailoring will be limited by the brittleness of the bar coding system itself. Task tailoring will dominate.
3. A variety of strategies will be tested, adopted, and discarded over a short period. Some of these will include

3.1. Efforts to maintain the old way of doing things;

3.2. Batching where bar code use is done en mass rather than at point of delivery for efficiency;

3.3. Workarounds such as development of bar code "cheat sheets" to allow manipulation of the system features using standins for the marked objects;

3.4. Off-the-record activities that bypass the bar coding system entirely, for example use of 'private stocks' of drugs and supplies with later replacement via the bar coded objects.

The viability of adaptations is not always immediately clear. People engage in a rapid development cycle of trying something, failing, trying something else, succeeding in the short run but producing undesired side effects, changing again, and so on. What is significant about this activity is the ways in which it is constrained by outside forces (e.g. resources, brittleness of the technology itself) and the speed with which people can test new approaches.

I would expect that the early adaptations will be heterogeneous across the various units and shifts but gradually coalesce into a coherent pattern that is highly optimized for the specific context of individual work settings.

4. Clumsy automation. Features expected by designers to reduce workload will actually have the characteristics of clumsy automation: they will increase workload at peak workload times. The savings that the automation produces will accrue at low workload times or to other people than those who bear the burdens of using the system. The designers will point out the global savings and minimize the local effects.

5. Less visibility of operations. The computer interposed in the process will hide features of the activity. These now-hidden features provided information about the process that people used to gauge effects, synchronize activities, and predict future events and consequences.
6. Limiting recovery from incipient failure
7. New forms of failure produced will be hard to predict
8. Apparent success of system and its cost will create perverse incentives to use it more and thus increase the workload of users
9. "Error" will be more easily lodged in sharp end practitioners because the only failures people will pay attention to are those the bar coding system points out.
10. Adaptations by practitioners will be partially successful; mainly in local settings

3. Relation of Findings to Predictions

Of the predicted findings, the following were confirmed during an observational study (Patterson et al., 2002) of BCMA in use in acute care and long-term care settings (Patterson et al., 2002):

1. **Bar coding imposed new workload on users.** This prediction was confirmed, for both the primary users (nurses) and secondary users (pharmacists). Nurses added steps of scanning the patient's wristband before preparing medications for administration, which invited additional interruptions while doing a cognitively challenging intensive task. Some medications had allergy flags, some prerequisites for administration or criteria to skip administration, some medications had to be given before others, some were given once a day and some twice a day, some had to be given in a manner that reduced the chance of choking, etc. When medications were administered outside the ordered administration times, nurses were required to enter something in a text box to explain the reason for each late medication. Pharmacists had to add barcodes to individual pills rather than allowing bar-coded ward medications to be administered. Nurses had to request and pharmacists had to replace individual barcoded pills that were dropped on the ground rather than substituting available pills that were of different dosages that could be multiplied to get the ordered dose. Nurses were not able to delegate getting narcotic medications for patients stored in a PYXIS machine to trainee nurses, because the same person who removed narcotics from the PYXIS had to scan the medication in the BCMA software. Nurses had to replace missing, wet, or otherwise damaged patient wristbands. Physicians had to ask nurses the time when medications were actually administered, because there were no longer paper records at the bedside for them to look at in case of a patient experiencing a fever or other adverse event.

2. **Practitioner adaptations will include both system tailoring / task tailoring.** This prediction was confirmed. System tailoring included adding thirty minutes to the allowed time to pass medications in long-term care settings and purchasing lightweight Computers on Wheels with space for a bar code scanner and a small number of medications for the acute care setting to make it easier to go in and out of rooms. Task tailoring included resident physicians no longer reviewing the Medication Administration History records for their patients on a regular basis, nurses no longer asking physicians to renew expired orders because there were no longer printouts of expired medications that served as a cue to do so (information stopped being shown on a display when an order expired). Unit clerks in some settings began printing reports of Missed Medications at the beginning of a work shift and handing it to nurses to cover the gap in administering medications that had already been removed from the display, such as when enough time had passed since it was ordered to trigger removal.

3. **A variety of strategies will be tested, adopted, and discarded over a short period.** These included:

3.1. Efforts to maintain the old way of doing things; This prediction was confirmed. 1) In many hospitals, decisions were made to require nurses to document both in the BCMA software that medications were administered by scanning as well as on the paper Medication Administration Record. In this way, all the people, and particularly the physicians, could continue to use their strategies that have developed around the paper-based MAR. 2) With the prior paper-based medication administration system, verbal orders were somewhat common where a physician verbally directed a nurse to administer a medication before a pharmacist verified the order which was electronically ordered first. With the implementation of BCMA, this was difficult to do because the medication order triggered the pharmacy to send the bar coded medication to the patient's drawer. In Intensive Care Units, ward stock with bar codes already printed on them, particularly for IV medications and normal saline, was stored to support the verbal order process in that setting, where delays are particularly important to avoid in many cases.

3.2. Batching where bar code use is done en mass rather than at point of delivery for efficiency; This prediction was confirmed. Nurses, particularly in long-term care settings where the medications were larger (and in some cases too large to get through the doorways of patient rooms), were observed to batch prepare all medications by scanning and opening the medications and putting the unlabeled unit dose medications into unlabeled paper cups for up to 32 patients at a time.

3.3. Workarounds such as development of bar code "cheat sheets" to allow manipulation of the system features using standins for the marked objects; This prediction was confirmed. Nurses were observed to print additional wristbands for patients and place them on the medication carts, carry them on metal rings or tape them to cardboard to have available for the shift. When preparing medications for the patient, the stand-in barcode for the patient would be scanned instead of the barcoded wristband on the patient.

3.4. Off-the-record activities that bypass the bar coding system entirely, for example use of 'private stocks' of drugs and supplies with later replacement via the bar coded objects. This prediction was confirmed. Nurses carried 'left-over' medications in pockets with barcodes on them that they then replaced with medications from the PYXIS after delivery to avoid having to interrupt a medication pass and walk to the PYXIS multiple times for multiple patients during a medication pass.

4. **Clumsy automation.** This prediction was partially observed. The role of automation with BCMA was problematic and certainly 'clumsy', but not quite in the manner predicted by Dr. Cook with relation to the dynamics of workload peaks. An automated feature of the software was decluttering the screens every four hours to remove IV medications in particular that were given without being scanned and documented as administered. Although the workload did not accrue at peak workload times, the loss of the ability to administer chemotherapy for a patient that was receiving treatment on an outpatient basis, but who did not yet have a suitable IV site, caused delays that were particularly problematic for the patient. With that case, the automated documentation of administration time after the order was added again to the BCMA software and the empty bag scanned required a significant amount of work to modify the administration time while the patient was being observed for side effects from the medication.

5. **Less visibility of operations.** This prediction was seen almost exactly as described. The previous paper-based Medication Administration Record (MAR) system had included a history of changes made. For example, if an administration time was delayed, it was marked on the page. If an order was discontinued, the order was crossed out. If an ordered was added, it was at the bottom of the list. This history was hidden with the BCMA design. More people (really anyone physically outside the patient room) had access to view the MAR. By providing logins initially only to nurses for BCMA, physicians could not see the electronic equivalent of the MAR.

6. **Limiting recovery from incipient failure.** This prediction was not confirmed.

7. **New forms of failure produced will be hard to predict.** This prediction was confirmed. An unexpected failure mode was that nurses increased using a dangerous strategy of pre-pouring medications (a nursing licensure violation) in order to have medications documented as administered within the on-time window, both to protect their reputation as well as to avoid documenting a reason that every medication was late. This failure mode was seen only in long-term care settings, and the comparatively poor fit of the BCMA software and hardware design with long-term care as compared to acute care was surprising. Many worried about the use of BCMA in intensive care units, as evidenced by strategically delaying implementation in that setting for a period of time, but that setting was not particularly problematic due to the low number of patients assigned to each nurse (1 or 2).

8. **Apparent success of system and its cost will create perverse incentives to use it more and thus increase the workload of users.** This prediction was not confirmed.

9. **"Error" will be more easily lodged in sharp end practitioners because the only failures people will pay attention to are those the bar coding system points out.** This prediction was not confirmed. In contrast, the BCMA software is relatively easily fooled by scanning barcoded wristbands and medications without involvement of a patient. There did not appear to be any staff allocated to reviewing timeliness of medication administration by nurse identifier or reasons for late medication administrations, so even though theoretically late medication administrations were highlighted by the system, the features did not appear to be used.

10. **Adaptations by practitioners will be partially successful, mainly in local settings.** This prediction is not necessarily confirmed nor disconfirmed. It is hard to assess "partial success" without being more specific about which stakeholder is being considered – the nurse, the pharmacist, the patient, the administrator, or the VHA nationally. For example, the BCMA software was adopted essentially throughout the VHA, so in this way it was a successful system for the VHA with common modifications to medication carts in acute care settings and batteries, outlets, and periodic replacement of patient wristbands in long-term care settings. The clear consensus was that it was an immature technology that needed to be modified, and many of the biggest issues were modified in future iterations, and this was done throughout the VHA. Local settings decided whether to continue the paper-based MAR in addition to BCMA. Some thresholds for late medication administration were changed locally. Some workarounds for found, such as by giving nurse administrators access to pharmacist scope of responsibility features in settings where no pharmacists worked on the weekends.

4. Conclusion

Most of Dr. Cook's predictions were revealed to be prescient, some additional findings emerged, particularly with respect to positive unintended consequences of introducing the software, and some need to be modified substantially, although generally being helpful in recognizing unintended consequences.

These predictions raise methodological questions about the nature of making and revealing expectations to guide 'in situ' observations, while remaining open to modifying expectations and learning new things. Others who observed the same system being introduced in a VHA hospital at approximately the same time did not generate findings that were as rich as our team, which I believe argues for seeding observations with a grounded understanding of the nature of how expert practitioners adopt and modify tools to meet their needs.

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Exploring the links between leadership and resilience – a middle managers' perspective

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Leadership as an antecedent for resilience has not been widely studied in the context of safety science, despite that healthy leadership and safety culture are crucial success factors for safety management. In this paper, we examine the links between leadership and resilience in the context of safety management. We use an empirical case study of nuclear power company middle management to identify leadership practices relating to resilience, focusing particularly on four adaptive safety management tensions.

Keywords: safety leadership, middle management, nuclear industry, adaptive safety management, resilience, tensions, safety culture

1. Introduction

Resilience is the ability of a system to sustain required operations under expected and unexpected conditions (Hollnagel et al., 2011). It is considered an essential part of ensuring safe operations. Building resilience involves four essential abilities: anticipation, monitoring, responding and learning; these are collectively referred to as the cornerstones of Resilience Engineering (RE, Hollnagel et al., 2011). Resilience and its relation to safety management has been characterized as paradoxical goals by Reiman et al. (2015) who proposed four primary tensions of adaptive safety management based on complex adaptive systems theory: Anticipating and responding to contingencies; disposition to variability; connections in the system; and goals at different system levels.

The primary research topics in RE have related to its need, definition, assessment and emergence, with for example the relationship between RE and safety culture being an identified research gap (Patriarca et al., 2018; Pillay, 2018). More importantly, leadership as an antecedent for RE has not been widely studied in the context of safety science (however, see Grote, 2019).

Healthy leadership and safety culture are crucial success factors for safety management. Specific safety leadership activities include safety-conscious decision-making, safety integrated into business strategy, nurturing safety culture by leading with example and communicating expectations, visible commitment to safety where actions match the words, clear accountability, management of potentially conflicting goals such as production, schedule, and safety, etc. Shortcomings in leadership have been contributory factors in many high-profile accidents, such as loss of Space Shuttle Columbia, Texas City oil refinery explosion, Boeing 737 MAX crashes and subsequent grounding, and Fukushima Daiichi nuclear power plant accident, just to name a few.

In this paper, we examine the links between leadership and resilience in the context of safety management. We use an empirical case study of nuclear power company middle management to identify leadership practices relating to resilience, focusing particularly on the four adaptive safety management tensions. Finally, we summarize the practical and academic implications of the paper.

2. Methods

The research strategy was to study middle managers that were perceived to be good leaders by their subordinates and identify what constitutes "good leadership". Leadership of middle managers were chosen as the research topic because they are in a crucial role in maintaining system performance under dynamic conditions – they must manage the complex demands coming from the top management and the experts. The case study company selected the interviewees based on ratings from a leadership survey where subordinates rated their supervisors' leadership activities. For the analysis presented in this paper, the focus was specifically on the practices of the leaders that may facilitate organizational resilience.

The middle managers were employed by a Nordic nuclear power company that was in progress of implementing a nuclear power plant construction project. Due to its complex and dynamic nature, we hypothesized that this context would be a rich source for identifying leadership practices that facilitate resilience. There were also situational factors in the company requiring resilience, including COVID-19 pandemic and an ongoing organizational change. The remote work resulting from the pandemic had implications on the possibility to perform leadership activities and it also affected working practices. The organizational change included changes in organizational structure, processes, and responsibilities. There were also changes in the top management.

Six semi-structured online interviews were conducted. Each interviewee had 3–10 immediate subordinates. Interview themes included interviewee's motive and approach to leadership, main activities as immediate supervisor, situations where the immediate supervisor has a significant role and how the situations are resolved, interactions with own team and various other groups, leadership during COVID-19, and relation to formal leadership development. Relevant management system documents were reviewed as a background information.

Interview recordings were transcribed and thematically analysed according to the adaptive safety management model. All themes emerged from the discussions concerning leadership activities; specific aspects of the adaptive safety management model were not systematically prompted during interviews.

3. Results and discussion

All interviewed middle managers indicated that they apply both production (setting goals and achieving tasks) and people-oriented (seeing leaders' role as enablers, supporters, and motivators) leadership styles. High focus on both production and people is considered as the goal for leadership according to Managerial Grid (Blake et al., 1962). In subsequent subchapters we summarize examples of how the interviewed middle managers manage each of the four safety management tensions. We include examples of both task-oriented and people-oriented leadership styles.

3.1 Anticipating and responding to contingencies

This tension involves both anticipation and response to expected (standard operating procedures, etc.) and unexpected (capability for self-organizing and adaptation) contingencies.

The interviewees found that dealing with various types of contingencies is a situation where they have an important role as leaders. Indeed, all had a generally similar approach to addressing challenging situations that emphasized **timely and clear approach to contingencies**. Immediate response, direct communication (instead of emails), and clear decision-making were commonly mentioned leadership practices during responding. Resource allocation (incl. formation of task forces) and warning staff before an upcoming problem were examples of leadership practices that related to anticipation.

"My experience is that one should react immediately. Things tend to escalate quickly. [...] If you have a critical issue at hand, you must deal with it right away – if you postpone it, it just

grows bigger. The challenge is to know which of the many small issues has the potential of becoming a big."

"If something is not done to agreed roles, you must immediately step in and take a decision. You need to tell your subordinates what he should do if it is out of organizational manual or if you are getting to the grey zone."

Some interviewees noted that in dynamic situations or when things do not go as planned, workers may become frustrated or lose optimism. To maintain the capability to anticipate and respond to the contingencies, the leader should also be able to maintain the **motivation** within the team. Some examples of ways to maintain motivation included directing the focus on how to proceed forward (rather than on ruminating on the issue itself), realistically anticipating upcoming issues to avoid disappointment, and nurturing a positive team atmosphere.

One of the leadership implications of these findings for the RE cornerstone "**responding**" is that the leader should provide the staff with a clarity of operational boundaries and expectations, through clear communication and decision-making. In situations where organizational turbulence is lengthy and discouraging, the leaders also need to be sensitive to motivational issues. The latter contributes to RE cornerstone "**monitoring**".

3.2 Disposition to variability

This tension relates to the extent to which variability is encouraged or constrained in the organization.

Several interviewees brought up the importance of providing the subordinates with sufficient **independence** and recognizing when the leader should be absent. This was associated with the following assumptions that emerged during the interviews: the leader should not interfere if things are going well, the group dynamics of meetings change if the manager is present potentially resulting in reduced communication, and that the managers do not always have the specific substance matter expertise as the experts.

"We have agreed that I will participate in [sub-team] meetings only if invited. I've been there 3-4 times this year to make a policy statement or if there has been uncertainty and they wanted confirmation. [...] I think ifthe manager interferes too much with details it's a bad thing. I have asked my team managers to notify me if I come too close to the practical work that they are trying to do."

"My role is not to handle the details, but to create possibilities for my team so that they can do their work as well as possible."

Many interviewees also expressed criticism towards micromanagement and characterised their leadership style as "coaching". The way in which the interviewees **oversaw** the activities of their subordinates emphasized trust and self-fulfilment rather than strict surveillance of completed tasks. However, some of the interviewees indicated that during "firefighting" mode, leaders may need to step in to intervene, which changes their control strategy. To perform in changing situations, many interviewees highlighted that it is important to know and "read" their staff well, including how they communicate, what are their competences, their personalities, etc. Observing the staff, leader field presence, reading their CVs, and arranging personnel development discussions and plans were examples of concrete leadership practices aiming to achieve this.

"I don't give tasks for their own sake. I hope they [subordinates] see their meaning and a culture would form in our team where the tasks are implemented and there is no need for strict controls."

"I already know my subordinates – how they would behave in such and such situation. So, I know if some person needs more support, or if another person doesn't."

These leadership approaches indicate that the interviewees have largely adopted the identity of a leader rather than just an expert. The confidence in subordinates relates to "**monitor**" cornerstone of RE, that is, knowing and appreciating the performance level of the system (i.e., capacity for resilient action of the subordinates) without having to manually interfere. "Deference to expertise" of High Reliability Organizations theory (Weick & Sutcliffe, 2015) recommends a similar general guiding principle. The implications of these findings are that the leaders should build teams that have the capacity to operate resiliently independently, and that the leaders should know when their direct involvement is or is not required to maintain optimal performance of the teams.

3.3 Connections in the system

This tension describes how interactions within the organization are managed. An approach emphasizing multiple weak ties builds upon participatory interactions and a bottom-up strategy, while an approach emphasizing few strong ties builds upon top-down strategy. The interactions can be within the team, or span to other parts of the organization vertically or horizontally.

All interviewees showed strong commitment and cohesion with their own team and subordinates, indicating their preference to bottom-up strategy for interactions. The most often-mentioned leadership objectives were **openness, trust, and shared understanding** within the team. Various types of meetings were used by the interviewees to achieve this, including team meetings on regular basis with joint discussions, roundtables, and one-to-one meetings with team members. In one team, a recurring "safety moment" was implemented as an open stage where subordinates were encouraged to highlight good practices or to raise concerns. The interviewees also valued good personal relationships with their subordinates and stressed the importance of empathy and confidentiality.

"I try to make room from my calendar for the subordinates. One-to- one meetings whenever possible and then team meetings. That's how we can openly communicate, I can speak my opinions and listen to any worries and ideas that the team has."

"It [presence] means that you can talk to everyone, and no-one is afraid to talk to you. The door is always open. You must be among the people and not isolate yourself."

These findings have leadership implications for "**anticipate**" and "**learning**" cornerstones of RE. They elaborate how leadership creates preconditions for resilient performance through interactions. The leaders should create a safe environment for their team that enables information-sharing, identification of potential issues, and formation of lessons learned for organizational learning.

3.4 Goals at different system levels

This tension includes both spatial (in organizational sense) and temporal aspects. Spatially differentiated goals refer to shared goals across the whole organization, and goals that optimize local efficiency (e.g., within teams). Temporally differentiated goals refer to short-term and acute goals (e.g., budget and schedule), and long-term strategic goals (e.g., safety). All interviewees highlighted the ability to solve short-term, acute issues while managing long-term goals as an important capability of a leader.

One perspective to this tension related to ensuring **work well-being**. The interviewees indicated that the stress level and energy required from the subordinates during the acute "firefighting" mode should be recognized and managed to ensure that it does not lead to exhaustion and decrease in performance. Immediate goals (e.g., schedule) may need to be sacrificed to ensure future long-term goals such as safety and performance. Some interviewees had also noticed that COVID-19 remote work made it more difficult to monitor well-being as they could not see people in person.

"Sometimes it's better to not deliver in time and pay the penalty that you delay something, but the work is done in quality way and the project manager feels he did it the right way and not under stress, because this program [...] will go for several years and if you already exhausted your project manager at the beginning [...] he will be little bit burnt."

This observation has implications concerning "**monitoring**" and "**responding**" cornerstones of RE. The leaders cannot expect the employees to adapt and respond to demanding variabilities indefinitely – especially if the working environment is highly dynamic and unstable – as this may eventually result in system migration towards unacceptable safety (or quality) performance when workload limits are exceeded (see Rasmussen, 1997). This means that the leaders should be mindful of the burden the variability sets for the workers and exercise their leadership accordingly.

One essential task of middle managers is serving as a **mediator between the demands of the larger organizations and own team** and solving any conflicting goals between them. Example situations raised by the interviewees included having unclear roles or differing opinions between own team and other disciplines or supplier organizations. In such cases, the interviewees felt that first a clear and shared understanding within one's own team should be established about the issue at hand. After this, the issue should be brought to the attention of top management. More generally, the interviewed middle managers expected top management to provide them support, mandate, and a clear policy for their activities. Documenting this effort into the management system was considered important to ensure continuity even in case of staff turnover.

Direct **access to top management** through regular meetings or one-to-one verbal communications was considered a success factor. Some interviewees provided negative counterexamples of top management interactions that did not support their work. They often involved too busy top managers that have no time for strategic discussions with them or who micromanage their activities, distant top managers that do not know or do not approach the middle managers, or top managers who put less importance on the middle manager's discipline.

"I appreciate it about my [top] manager that he listens, considers the messages I bring to him from our team, and of course also challenges me if he has a differing opinion."

"When the top management changed their decisions without sufficient clarification, it caused uncertainty to me. I didn't know the policy or my mandate, so I started to avoid making decisions."

Since the demands from different hierarchical levels of the organization affects the content of middle managers work significantly, these findings have leadership implications for all RE cornerstones. To retain resilient performance within teams, middle manager leaders should be provided with a clarity about the expectations and degrees from freedom for their operations, and a close, bidirectional, and collaborative relationship with top management is essential.

Conclusion

In this paper we have identified a variety of leadership practices of middle managers in a complex and dynamic safety-critical setting. They are examples of leadership as influencing resilient action of front-line workers, but also as building an organizational culture that cultivates resilience (cf. Grote, 2019).

Due to the low number of interviews, the results are not expected to be a definitive overview of all resilience-building leadership practices. Instead, they may serve as a starting point for more extensive research of the links between leadership activities, safety culture, and resilience. Potential future research questions could include: What characterises the (safety) culture of resilient organizations, and what are the effective leadership practices to achieve it? How to help leaders and managers be better aware of the consequences of too much or too little reliance on the resilient action of front-line workers, and how this affects their leadership activities?

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New Tricks for New Dogs: Using SCAD for Blunt End Work Insights

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With the vast majority of the resilience engineering tools, studies, and perspectives focused at the sharp end (i.e., frontline practitioners), it is unclear to what extent they can be useful when directly studying the blunt end. The blunt end is included in resilience engineering work largely to show that the results of blunt end work shapes and influences the work of the sharp end, and is not typically studied as work in its own right. We used the Systemic Contributors and Adaptations Diagramming (SCAD) method to study the adaptation patterns in the work of multiple roles in the U.S. Department of Defense (DoD) acquisition community, responsible for procuring, implementing and supporting the materials used by the sharp end DoD practitioners. We learned that a number of pressures and conflicts that greatly influenced the acquisition workforce's behaviors, and system attributes that fostered well-calibrated adaptation, which they call innovation. We found that SCAD and the underlying resilience concepts that it is built on are well-suited to describing, explaining, and improving blunt end work with little to no tailoring except for the typical contextual tailoring to new work domains. Directly affecting blunt end work is a high-impact opportunity that the resilience engineering rarely engages in, and represents an area for expansion that it is well-suited for.

Keywords: blunt end, proactive safety, system dynamics, pressure, conflict, adaptation.

1. Introduction

The resilience engineering literature contains a myriad of studies, methods, and findings pertaining to what Cook and Woods call *sharp end* work, but relatively little energy has been devoted to *blunt end* work. Sharp end practitioners are typically depicted as the set of actors that are directly interacting with the safety-critical or mission-critical processes of their organization (Woods et al., 2010), and include roles such as pilots, spacecraft controllers, surgeons, nurses, technicians, and intelligence analysts The blunt end is well documented as the set of actors that provide resources and exert organizational pressures on the sharp end. These actors include managers, administration, regulators, policy makers, and technology suppliers. In these ways, the blunt end shapes the conditions and substantially influences sharp end practitioners and their work (Woods et al., 2010). The resilience engineering literature, methods, and perspectives focus on how the blunt end (i.e., the results of blunt end work) shapes sharp end work and processes (Dekker, 2013; Woods et al., 2010), but does not provide details on the systems dynamics of the real-time work of the blunt end.

This is a non-trivial gap and a barrier to the effectiveness and reach of resilience engineering, as other competing and conflicting perspectives, including Lean Manufacturing and Six Sigma methodologies, have tailored their methods to explicitly study, describe and redesign blunt end work, or what they refer to as "back office" functions (Li et al., 2017; Mast et al., 2011). This work largely defines improvement as either reducing waste (Ohno, 1988), or reducing variation (Pepper & Spedding, 2010), or both. This is at odds with how resilience engineering conceptualizes performance of complex adaptive systems, which values creating an intentional balance between optimized, central control (i.e., the goal of Lean and Six Sigma) and a more polycentric, guided adaptability (Provan et al., 2020; Woods, 2019). This need for adaptation and adaptive capacity is especially important as systems near the edges of their performance envelope (Woods, 2018). This notion of how systems' needs change when they are far from or near to their boundaries is a unique contribution of resilience engineering. System redesigns that do not explicitly account for adaptive capacity inevitably erode it (Rayo & Saurin, 2019; Woods & Hollnagel, 2006), which greatly increases the risk of brittle collapse in the face of increasing or unforeseen challenges (Woods, 2018). Eliminating activities or resources that are deemed waste is likely reducing adaptive capacity, which is also described as slack in the resilience engineering literature. Reducing variation is also, by definition, reducing initiative, which can lead to organizational behaviors being slow and stale in the face of a novel challenge (Woods, 2019). This lack of resilience engineering focus on the blunt end likely results in an overall distortion of blunt end work towards these more linear perspectives.

However, it is likely that resilience engineering perspectives and at least a subset of its tools and practices are well-suited to studying blunt end work. A growing number of studies in multiple disciplines confirm that, as a rule, the laws that govern systems at one level of abstraction or scale are equally applicable at other levels or scales (Alderson & Doyle, 2010; Woods, 2019). Taken together, these studies further suggest that when looking at the real-time work of actors at the blunt end, it is actually sharp end work, which is shaped and influenced by the actions of other actors (i.e., the blunt end to their sharp end). Therefore, it stands to reason that the studies, methods, perspectives, and findings that study, describe and explain sharp end work in the system should be appropriate to study, describe, and explain blunt end work.

We chose to use the Systemic Contributors and Adaptations Diagramming (SCAD) interview and analysis method (Jefferies et al., 2022) to study the shaping factors in the work of the U.S. Department of Defense (DoD) acquisition communities, and specifically what is called *DoD acquisition innovation*. The acquisition community is responsible for procuring, designing and building all of the services and infrastructure needed to run the DoD, from managing facilities to procuring lawnmowing services to weapons design, implementation, and maintenance. Like any other massive bureaucracy, these acquisitions organizations are governed and guided by a set of intricate guidelines and regulations, mostly contained in the Federal Acquistion Regulations (FAR) system. These organizations are experiencing a unique juncture point, in which top-level administrators want their workforces to exercise adaptations, which they call innovations, both within and outside of the FAR, but there has been chronic reluctance in the acquisition workforce to embrace and utilize these adaptations, which they call innovations. The reported cause of this reluctance is the widely reported risk-averse nature of the acquisition culture (Eckerd & Girth, 2017; Girth & Lopez, 2019). However, the system dynamics underlying the observed behaviors have not been studied directly or modeled. SCAD was chosen for its abilities to be well-understood by practitioners outside of the research community and to provide rapid, systems-level insights that reach deeper than the surface-level behaviors of individual analysts (Jefferies et al., 2022). These types of insights are the hallmark of studying resilient systems performance (Dekker, 2013; Hollnagel, 2014; Woods et al., 2010; Woods & Cook, 1999).

In using SCAD to study the sharp end work of this blunt end setting, we asked the following questions:

1. What degree of tailoring must be made to the tool in adapting it to blunt end settings?
2. What types of insights will it produce, and how valuable will they be?
3. How much will insights about this blunt end analog of adaptation, innovation, be similar to other insights on adaptation from other settings and scales?

2. Methods

Research team selection

The SCAD interview method highly encourages that the core project team includes external experts and internal experts. The external experts' primary role is to bring in knowledge of how SCAD has been performed in other settings, train the internal experts, and bring in relevant systems patterns to influence how the resultant SCAD stories are interpreted, analyzed, and used to prime subsequent rounds of SCAD interviews. The internal experts' primary role is to contextualize the core of the SCAD interview technique and protocol to the language and culture of the target organization. They mitigate the risk of SCAD interviewees reverting into "teaching mode", and help to better guide the interviews into the more rich areas of adaptations, conflicts and pressures (Jefferies et al., 2022). The external experts for this project including one of the founders of the SCAD method and two graduate students who both had SCAD experience from multiple previous projects. The internal experts included an expert on acquisition policy outside of the target acquisition organization, and a leader in the target organization's research organization who was officially given reserved time on the project by the target organization's leadership.

Protocol design

The core question of the SCAD interview is *"tell me a time where you did something different than you otherwise would, or what the textbook dictates that you should"*. This core question was adapted in this project to: *"Tell me about a time where you did something a little differently than normal when reviewing or applying a given acquisition strategy"* (Jefferies et al., 2022). The interview guide was set up to allow interviewees to select the acquisition process steps that they wanted to talk about, and the entire acquisition process lifecycle was presented to them as a map to facilitate their thinking. The standard SCAD semi-structured approach of guiding the conversations from (1) adaptations to (2) the set of perceived or real conflicts that resulted in the adaptation to (3) the set of pressures that created that conflict were used.

Interview participants data collection and analysis

Fourteen SCAD interviews were completed with 15 participants across six areas of the target organization.. Anonymity was guaranteed as a condition of the interview. Participant characteristics are found in Table 1. SCAD interviews were approximately one hour in length, conducted via Zoom or MS Teams, and were recorded and transcribed. Thematic pattern analysis was used to categorize a set of patterns focused on (1) the system attributes that support innovative behaviors, (2) the set of often conflicting pressures that foster and degrade these systems attributes, and (3) how a set of "compound pressures" can up-regulate and down-regulate the observed pressures.

Table 1: SCAD interview participant employment characteristics

Positions	Ranks	Functions
Leadership (5)	Military (1): Maj Gen Civilian (4): SES, NH-04 (2), GS-15	Contracting (3) Program Management (2)
Staff/Frontline (10)	Military (5): Maj, Capt, 1st Lt, TSgt, SrA Civilian (5): GS-14 (2), GS-12(2), NH-03	Contracting (10)

3. Results

Interview data revealed innovation efforts, even within formalized "innovation-supported settings", are driven largely by the voluntary effort of the participants, and nearly exclusively performed in addition to other duties. Pockets of innovative behavior exist at multiple levels of the hierarchy and at multiple locations geographically, but information regarding innovative developments, either successes or failures, is rarely shared beyond the wing-level. Innovative behaviors were also more likely to emerge in response to acute and temporary circumstances such as a high-profile or time-sensitive requirement or a project that needs "saving" (e.g., time, cost, quality). Figure 1 illustrates the evolution of ingraining a new acquisition process from initiating innovation (occurs or not), to sustaining (used once, or adopted by the unit), to spreading (replicating throughout the enterprise). At each transition stage, we found that there are unique obstacles that prevent new, innovative acquisition ideas from flourishing across the enterprise.

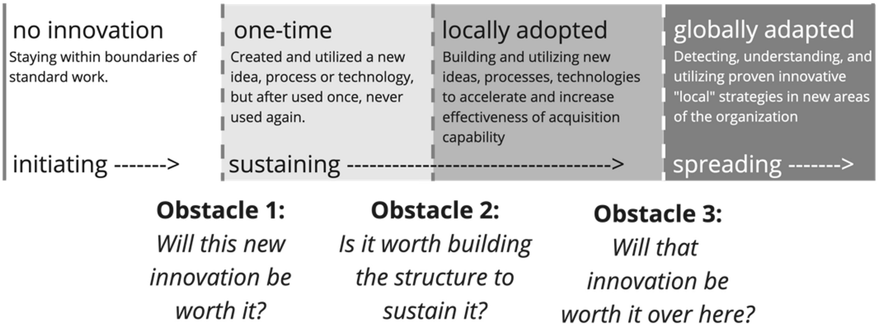

Figure 1

Our initial study data revealed a small number (of likely a larger set) of systems attributes that are reliably associated with innovative acquisition behaviors that can overcome these obstacles. The most frequently cited system attributes supporting innovative behavior include:

1. **Making room for failure and risk-taking:** Encouraging risks and creative solutions without fear of punishment for trying something new, accepting that failure is a part of the innovation process.
2. **Fostering organizational learning:** Supporting institutional learning by keeping people up to date on new tools and methods, and using past efforts at innovative thinking and innovation-centered behaviors to guide future action.
3. **Aligning team goals:** Ensuring people horizontally and vertically within the organization share common goals and understand their integral role in reaching goals.
4. **Collaborating internally and externally:** Facilitating collaboration with stakeholders within the organization, externally with relevant units, and industry partners.
5. **Autonomy:** Allowing people to have flexibility and freedom to complete work through their own means, less supervisor involvement and more personal authority over work.

This work also exposed patterns of how systemic pressures (also likely part of a larger set) either strengthened or eroded the system attributes linked to innovation. Interview participants indicated the following pressures most often influenced innovative behavior:

1. **Procedure:** Policy, process, rules, and regulation emerged as the most cited pressure on system attributes. It can both encourage

change (if it is not prohibited, we can try it), and stymy it (rote adherence without creative thinking).

2. **Time:** The default is to go fast to complete tasks quickly, in part, due to workload, which encourages status quo and slows adoption. Time can also accelerate change when there is a crisis or acute need to solve complex problem creatively or new approaches must be tried.

3. **Innovation prioritization:** Emphasizing the organization's desire to innovate through resource allocation, messaging, policies, and/or structures put in place to support innovation.

4. **Workload:** There is a mismatch between work requirements and availability of necessary resources (staff, expertise, etc.). Peers have little capacity to assist whether due to unclear or unsynchronized priorities; this is, in part, because the acquisition workforce has not kept pace given the growth in requirements.

5. **Budget constraint:** Limited resources to attract the right vendors to develop and/or execute creative solutions can hinder new approaches.

6. **Turnover:** A particularly salient issue for military personnel with frequent reassignment and/or deployment, and new leadership assignments. Personnel change can disrupt or terminate momentum, but also lead to staff slow-rolling adoption to "wait it out" for new leadership.

7. **Reliance on routines:** Preference for status quo work routines and resisting adoption of new practices. This can be reflected by tenure, with younger/newer employees more likely to pursue change.

Notably, some of these pressures both strengthened and eroded one or more attributes, depending on the magnitude of the pressure.

Finally, our work revealed how management-led interventions simultaneously upregulated and down-regulated the reported pressures, ultimately contributing to the strengthening and erosion of innovation systems attributes. Each of these management-led efforts, which we have dubbed "compound pressures," modulated the more primitive, discrete system pressures in both intended and unintended ways. Staff/frontline interviews unanimously reported leadership support was a critical ingredient to innovation efforts. Weak leadership support facilitated (or did not hinder) experimentation, allowing staff more discretion and thus creative solutions occurred. Supervisors exhibiting strong leadership commitment would not only encourage local adoption but provide support and resources. Two such examples were the were the creation of a staffed innovation cell and a new acquisition innovation pipeline process called "firestarter". We synthesized pilot SCAD interview findings in Figure 2, which models the influence of compound and system pressures on the systemic attributes that foster innovation behaviors.

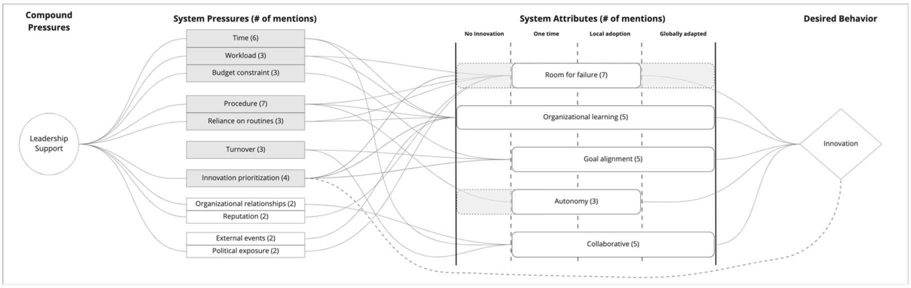

Figure 2.

4. Discussion and Conclusions

This work with SCAD to reveal systemic insights about work at the blunt end demonstrated that, at least for this resilience engineering method, it can reliably be applied to blunt end work with only contextual tailoring to the target institution. It was found to be very valuable to the target organization, and plans are moving forward to expand this SCAD program throughout the U.S. Department of Defense. Perhaps not surprisingly, the results of our analysis reveal that the analysts' hesitation to consider acquisition strategies increasing outside of the boundaries of the FAR is not simply due to risk-aversion. These behaviors are better explained and predicted by a set of pressures and conflicts that are consistent and enduring throughout the organization, even though they express themselves differently as they are experienced vertically and horizontally throughout the organization.

The pressures that were revealed in the final analysis are largely identical to those found to be outsized contributors in other frontline settings. The revealed systems attributes necessary for innovation are also highly aligned with those most critical to resilient frontline performance. Initiative and reciprocity, which are critically important ingredients for resilient front line performance (Woods, 2019), were deemed as some of the most important contributors to innovative acquisition performance (in the Autonomy and Room for failure themes). Two other revealed systems attributes for innovation, Goal alignment and being increasingly Collaborative across larger organizational scopings, are also hallmarks of resilient front line performance (Woods, 2018).

Studying and influencing the blunt end portions of organizations represents an opportunity to make a large, sustainable impact in the resilient performance of the overall organization. The methods and perspectives of resilience engineering are well-suited to describe, explain and improve the drivers of blunt end work, and reveal that these drivers are consistent with other forms of sharp end work.

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Learning from Hassles, Big and Small

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Organizations tend to investigate large-scale, high-impact incidents to correct problems in their system. Those rare cases provide useful insights but are infrequent and can drive toward solution-oriented single-loop learning. As a small business, we have engaged in double-loop learning by questioning the assumptions and changing mindset with investigations into small-scale, hassle events. These events occur frequently and have low consequences, which makes them less likely to be investigated. A case study presented here describes the comprehensive view of the interdependencies and misalignments discovered by investigating a frustrating yet successful proposal submission. Production pressures and ill-defined consequences make it difficult for organizations to invest in lower stakes investigations. However, organizations at any scale can become more resilient by increasing their capacity to do double-loop learning and dedicating resources to analysis for all scopes of incidents.

Keywords: incident analysis, organizational resilience, double-loop learning, non-high-risk organization, hassles, case study.

Introduction

Much of the available literature on organizational resilience focuses on larger organizations and critical accidents, such as NASA's Columbia explosion or the Knight Capital software-induced bankruptcy (United States of America Securities and Exchange Commission, 2013; Woods, 2005). Indeed, resilience is often discussed in the wake of accidents–the need for organizational change is evident after a large-scale accident, although the lessons learned do not always generate lasting change.

This paper / presentation discusses steps toward developing a resilient organization and learning culture at a small organization handling non-safety-critical operations. We will discuss differences in creating resilience initiatives in a non-safety-critical environment, where consequences studied were small difficulties and hassles, not large-scale accidents or loss of life. A sample initiative is presented, as well as the lessons learned for the organization. In the end, production pressures chip away at resilience initiatives where the consequences are not well defined, even though learning from hassles can often provide a thorough understanding of how the system works. Organizations of any size can take inspiration from the lessons and difficulties of analyzing hassle "incidents" (Hollnagel et al., 2013; Sujan et al., 2017).

Creating Resilient Organizations

Resilience is not a static quality of organizations. They struggle, grow, and adapt to internal and external pressures in their domain. Resilience is concerned not only with anticipated pressures but also with unexpected pressures that fall outside the model of competence and require shifts in strategy to meet new demands (Woods, 2006a). The capacity to adapt in anticipation to and in response to changes in a system's environment is paradoxically only known when presented with these challenges (Kirschner & Gerhart, 2005; Woods, 2018). Large scale incidents, for instance, reveal previously hidden interdependencies between functional units. Such information is critical for effectively responding to anomalies in those units and further developing the system.

Organizations who do not work in high-risk, safety-critical industries are at less risk of large-scale, highly salient incidents with negative outcomes that necessitate investigation. This can mean they are less likely to uncover complexities and interdependencies in their operations because they are less likely to have in-depth investigations, which in turn makes them less likely to actively pursue learning from incidents. When the consequence is a late business proposal and not a deadly accident, it can be more difficult to justify sacrificing production needs to pursue an internal investigation.

However, organizations should not wait, and do not need to wait, for a large-scale incident in order to drive change. There is a perception that learning correlates with the severity of the incident studied, which means we can save resources and maximize efficiency by focusing on those incidents. This is not true (Hollnagel et al., 2013). Effective learning and organizational change can occur by studying everyday hassles, defined as incidents that create problems during daily work but ultimately have no or low consequences. These hassles provide opportunities to understand the system as it generally works and creates success (Sujan et al., 2017). The model of single-loop and double-loop learning provides a way of looking at the cognitive requirements of learning from incidents.

Argyris and Schön introduced the concept of single-loop and double-loop learning to the organizational learning domain, which was developed from a thermostat example by Ashby. In single-loop learning, the thermostat would act to achieve a desired temperature by turning the heat on or off (Putnam, 2014). Many organizations practice single-loop learning in the actions of planning, acting, assessing results, and replanning to achieve desired results. Correcting errors in single-loops is quite possible, but over time the situation can deteriorate and system boundaries will be tested as more and more actions are required to compensate for errors in order to reach the desired results (Argyris, 1977).

Double-loop learning involves more comprehensive questioning of system behavior. Instead of correcting for an outcome, the system must question why it is doing what it is doing. In the thermostat example, the thermostat might consider if the temperature can be reached in a better way or if the temperature is even optimal (Argyris, 1977). If we consider an accident investigation technique like root cause analysis, where a "bad" action or actor is identified and removed to achieve desired results, that is not enough to consider the "why" of what occurred and create double-loop learning. This means that lasting behavioral changes and insights stimulated by double-loop learning will not occur.

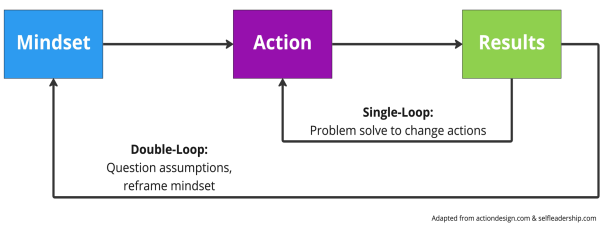

Figure 1. adapted from: (Andrew Bryant, 2020; Robert W. Putnam, n.d.)

This creates the question of how double-loop learning occurs, and what we can do to create it. Putnam (2014) describes three stages to double-loop learning that creates behavioral change. These are 1) discovering how current policies and frames for understanding the world are not producing good outcomes, and what changes could lead to more desirable outcomes, 2) honing the ability to use the new behavior in real-world situations, and 3) integrating the new behavior into policy and norms. Of these, number 1, reframing, is a good focus and also difficult. Reframing occurs when someone discovers that information is not as expected, and the frame through which they are interpreting data must be discarded (Klein et al., 2007). The difficulty is discovering that the frame through which data is being viewed is inadequate, especially when it seems that some behavior could be simply and easily corrected to get good results.

The removal of some object or behavior does not protect the system from future incidents. Incidents result from multiple factors–each necessary but only jointly sufficient (Woods & Hollnagel, 2006). Systemic accident analysis techniques go beyond root causes to uncover the complex interactions within the system, and recognizing this complexity drives double-loop learning because basic assumptions about how the system functions are challenged. Systemic techniques are as useful for small hassle events as they are for large incidents, especially because a large sample of deviations can provide a more thorough representation of the system than just one analysis of a large incident.

While larger incidents in terms of scope or impact may draw the most attention, organizations will find value in studying lesser consequence incidents to provide opportunities to learn about and reflect on the system as it generally works and creates success. We studied one such example in our organization, described here.

Case Study: Disjointed Proposal Delivery

Many organizations, particularly in consulting, routinely write proposals as a vehicle for new projects. Some groups have a single individual compose the entirety of the prose. In this case, a diverse group was organized to respond to a particular call given their unique backgrounds and our organization's tendency to emphasize the value of collaboration across multiple perspectives. The team had a couple of technical experts and business professionals, each with varied levels of experience with different types of proposals. Leadership bypassed the usual review process for evaluating business opportunities to bring the group together quickly.

Initially, the most experienced proposal writers shared their expectations on the formatting and schedule for completing the proposal by the deadline. The other members of the team responsible for the technical writing had trouble aligning their previous experiences with these new expectations. Unconfirmed drops in communication also contributed to some team members not being aware of deadlines or access to key documents (i.e., overall schedule, updated versions) until much later. Several review meetings did not give all members of the team confidence they were on the right track to meet the deadline, though it was unclear how to adjust course. With the finish line looming, leadership decided to intervene, and additional resources were called in to help. The final weekend saw large reworks of several sections by a few team members before submission.

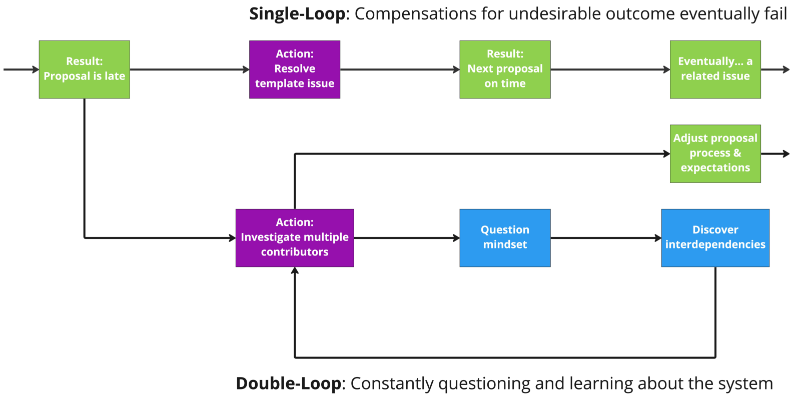

Figure 2.

Over the course of nearly two months, the hidden costs of coordination and repairing broken common ground culminated in a stressful, last-minute submission that was sufficient but not overly satisfactory. The result was a successful submission, but the process itself was far from smooth. Analyzing the case retrospectively revealed areas of misalignment throughout the timeline that often had lasting effects. The hassle points showed friction in the team's workflow and communications, though no significant safety- or business- critical impact. Frustration was high after the proposal submission, which prompted the investigation and analysis. Beyond the emotional impact, it was not immediately clear what value analyzing the incident would present to those individuals or the larger organization. The resulting findings were surprising to the team and valuable to prompt deliberate change in the proposal writing workflow, though the learning process itself was the bigger takeaway.

Resilience and Learning with Hassle Events

Because the consequences of the event were not well defined (the proposal was still submitted before the deadline, albeit without the formal reviews and not when it was intended to be submitted) there were some difficulties in creating systemic learning from the incident. The hassles that came up had less tangible impacts–lost time, some frustrations. Other hassle event investigations were seen as "nice to haves" rather than necessary. Without the need to review a critical incident, production pressures ate away at the ability to conduct more incident analyses. Both key incident review facilitators were required for other projects, and it was hard to justify losing paid project time for subsequent evaluations of low-consequence incidents. The low numbers of incidents reviewed thus far meant that fewer connections were made between projects and less was revealed about the system overall, though there are several sources to inspire organizational change.

Organizations like Indeed, an American employee hiring platform, and others in the Learning from Incidents community have found ways to drive internal incident evaluations. Many of the companies in the Learning from Incidents community are larger, and some have high-risk, safety-critical operations. Larger, high-consequence accidents often inspired them to join the community. The incidents have higher visibility, and it is often easier to justify the time and expense for an investigation than it is for a small, low-consequence hassle incident. Still, there are plenty of opportunities for big and small, high-risk and low-risk companies to learn from each other. Smaller and low-risk organizations can benefit from developing an emphasis on incident analysis. Larger and high-risk organizations can benefit from seeking out and funding investigations for hassle incidents, rather than focusing all their time and money on one larger event.

It is easier for smaller, low-risk organizations to focus on hassle events, because there are usually no large-scale events to take up resources. Hassles reveal interdependencies, misalignments, and assumptions about the system. A number of small deviations (negative and even positive) across the organization and over time will provide a better representation of organizational performance than looking at a sample size of one large incident. Therefore, it is essential for organizations to continue to pursue accident analysis and resilience programs even when the need is not obvious.

Our organization has begun to embrace the importance of multiple incident analyses and hassles such as the case study above. In this case, a more systemic analysis was performed. The analysis went beyond action-feedback and enabled the team to have reflective double-loop learning. The small group could have easily fixated on solving the acute problem of having a singular proposal template, but it was the (mis)assumptions and context that they found most valuable after the incident review. The combined timeline presentation of events from individual perspectives reframed the situation, breaking down and updating the mental models of the people involved. Moving beyond problem solving to reflection helped us to uncover more factors behind the hassle.

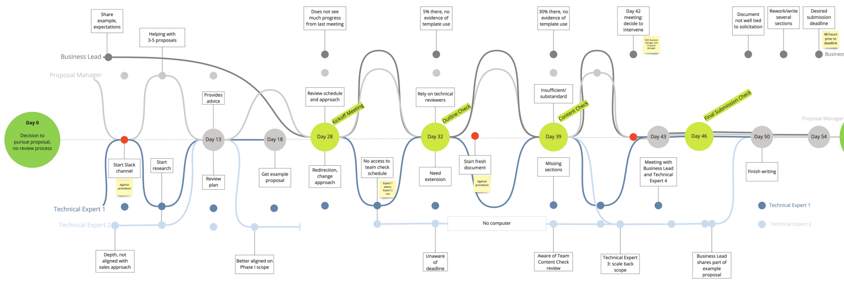

Figure 3.

It is still easy to slip into single-loop learning even with a focus on systemic analysis and discovering complexity within the organization. An organization may make continuous corrections with the goal of achieving resilience, but resilience is not a state to be reached. The single-loop corrections fall most frequently on individuals in the system, who make up for the problems with "heroic" late hours and actions, or who must devise workarounds to keep everything going. It is not simple to learn how to be resilient. Resilience is a dynamic process managed by monitoring and balancing the tradeoff between production pressures and risk (Woods, 2006b). Double-loop learning helps to maintain this balance not only by uncovering interdependencies but by constantly calling into question why the system is working as it is, and whether or not that is optimal to achieve the desired balance of production and safety.

Conclusion, For Now

Our organization is still taking steps toward having a more resilient, learning culture. The program is a work in progress, but we have been able to learn from what makes developing a resilient organization difficult. This includes sacrificing some production pressures to increase the likelihood of conducting incident reviews. We have been able to get cooperation and buy-in from the highest levels of the organization, which has allowed us to investigate incidents like the one above and begin to implement lessons from those investigations.

Recently, the company has begun conducting investigations into past healthy, neutral, and unhealthy projects in order to determine common themes and dependencies between them. The initiative supports double-loop learning for the organization as a whole, questioning our assumptions about what made successful projects actually successful and with other outcomes. This effort shows senior leadership's commitment to going beyond isolated, reactive incident investigations: it is an investment toward discovering system boundaries and becoming a more resilient organization. Groups of all sizes can invest in double-loop learning from hassle events up through the scale to catastrophic incidents and everywhere in between.

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Facilitated Debriefs in Trauma Health Care Simulations Enable Resilience

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Establishing resilience when working with trauma patients involves the ability to perform a valid assessment of the situation to allow sufficient flexibility and adaptive capacity. Resilience provides options in the face of various pressures and constraints to prevent being solely reactive in an emergency. Recognizing perceptual cues and relating those to next steps such as diagnosis and treatment plan generation supports resilience. One way to encourage this is through using remote augmented reality and prompting participants (medical students) to perform a self-assessment of their debrief compared to a physician coach's debrief. In our study, participants gave an overall debrief of a virtual trauma patient focusing on the diagnosis, treatment plan, and thoughts on next steps. Participants were then provided with an audio-recorded physician coach's debrief and asked to compare theirs with the physician coach's, focusing on what was similar and different. The physician coach debrief contained relationships between perceptual cues and patient experiences, commentary on the progression of the case, and general patient status, covering the entire scenario. Participants increased their resilience through exposure to expertise and complex medical scenarios, and via comparison of their debrief to the physician coach debrief.

Keywords: Health care, resilience, facilitated debrief, simulation, medical education, trauma cases, virtual patient.

1. Introduction

A between-subjects study was conducted to evaluate whether the addition of prompts and physician coach commentary allowed participants to better recognize perceptual cues of a virtual trauma patient and to determine the correct diagnosis and treatment plans for three different trauma cases. Trauma case complexities can be due to myriad stressors, which include time pressures, dynamic patient cues, quickly escalating situations, no deliberate practice, and a lack of previous encounters (Pruchnicki, 2018). Resilience training has been shown to protect individuals from the adverse impacts of stressors (Robertson et al., 2015). Certainly, trauma cases are inherently complex, and during this study we provided the participants with exposure to cases they may not otherwise experience, while aiding in the enhancement of their resilience.

While medical students can learn about perceptual cues via textbooks, seeing the cues expressed on a virtual patient can provide a more immersive and engaging experience (Hernandez et al., 2020). In addition, by using a virtual patient, students can learn and develop in a low-risk and low-consequence environment, where taking time to perform self-reflection does not impact an actual patient's health care. Performing collaborative cross-checking is not "free," in that it causes increased complexity due to changes in plans (Patterson et al., 2007) and can cause interruptions in real-world scenarios. Here we correlate collaborative cross-checking with facilitated debriefs based on self-assessment. However, as the cross-checking is done as a part of the training in our study with the physician coach, the amount of interruption is substantially less, and has fewer potentially negative outcomes (no actual patients at risk).

Those in the experimental condition generated a debrief after each of the patient cases and those in the control condition only gave a debrief after the final case. In addition, the physician coach provided a debrief after the participant's debrief for all three trauma cases (gunshot wound, superheated airway, and tension pneumothorax) for the experimental condition only.

2. Facilitated Debriefs

Debriefing is often thought of as bidirectional, however, debriefing is a reflective conversation (Sawyer et al., 2016). Facilitated debriefs do not need to be led by another person, having a participant self-reflect is adequate (Pruchnicki, 2018). They go on to note that regardless of the simulator-training outcome, sessions can be more useful when a facilitated debrief is utilized afterward. Thus, even good performance can be enhanced using self-reflection.

For this study, though the physician coach debriefs used were canned (pre-recorded) and not customized to the participants' prior commentary or performance, we still see that the prompts plus physician coaching which made up the experimental condition led to significantly better performance on perceptual cue recognition (p-value $< .001$ for all cases combined) and treatment planning (p-value $< .05$ for all cases combined). However, for diagnosis correct the experimental condition was significantly better only for the second case (p-value $< .001$), which may have been due to the physician coach commentary. By having the participant compare their debrief to the physician coach's, a sort of internal cross-checking can be done for the detection of inaccuracies, which can stop erroneous assessments from resulting in negative outcomes (e.g., patient harm). Fresh perspectives governed by experience and knowledge can help to correct mis-assessments of scenarios (Patterson et al., 2007). Here, this is provided by the physician coach.

Some say professionals may be required to facilitate a debrief for cases involving complex decision-making (Dismukes et al., 2006). However, this study demonstrated that canned physician coach debriefs paired with remote augmented reality and prompting did produce significant participant improvement in perceptual cue recognition and treatment planning over the control condition. Debriefing has been noted as one of the most important components of health care simulations, which enables continuous learning through deliberate reflection on one's experience (Sawyer et al., 2016). This neatly aligns with our aim for active learning with immersive and engaging content, particularly during the self-reflection when comparing one's debrief to the physician coach debrief.

3. Facets of Resilience

Medical students need to be able to recognize and adapt to variations, changes, and surprises (Patterson et al., 2007). To do this, medical students should be able to recognize and interpret perceptual cues, find gaps in information and take steps to fill them, perhaps via labs or other types of tests, or by bringing in others with relevant expertise. They should possess self-awareness and calibration of their knowledge and skills. Treatment plans must be updated as needed if new information comes from tests, new perceptual cues develop or existing cues change, or as additional individuals are brought in to aid with patient care applying their own skillsets, perspectives, and experience.

The awareness of information needs of others can enable coordination (Patterson et al., 2007). By developing shared understanding, a participant can begin to acknowledge the perspectives of those with more experience, enhancing their own skills. From their self-assessment of their debrief compared to the physician coach's, participants benefit from not only reflecting on what was similar between their debrief and the physician coach debrief (what was "right"), but also what was different, which now becomes a learning opportunity.

The self-assessments can allow participants to become more active in their own learning experience. Participants learn how to assess their own performance through their comparison with the physician coach and develop the skill of critically assessing their interpretations and comprehension. Resilience training has been found to improve workplace performance and productivity (Robertson et al., 2015). Some benefits of debriefing can include the transfer of knowledge across perspectives (Patterson et al., 2007). The skills of determining how and why a situation occurred in complex real-world areas are valuable to aid in building resilience and developing knowledge. The debriefing allows the participants to perform more than just regurgitation of memorized facts (Dismukes et al., 2006). Participants learned not only new information but also how to summarize that information in a debrief, and the most meaningful perceptual cues in different trauma cases. Thoughtfully evaluating the situation and applying relevant knowledge and information to the case at hand can allow medical students to learn how to think and work. A debrief "formula" can be developed which can be further enriched as the participants grow in their careers. To meet the overall goals of patient health care, there are often tradeoffs, triage requirements, or reprioritizations. These can either be temporary or permanent, depending on the progression of a scenario. Goal trade-offs are an important consideration for health care in general. One must be able to deal with dynamic situations to give rise to resilience. The ability to absorb disturbances can aid in the formation of resilience (Patterson et al., 2007). Health care is dynamic in nature, and medical students need to become accustomed to this environment.

4. Educational Considerations

Patterson et al. (2007) note that collaborative cross-checks can produce increased awareness of the information needs of others. The physician coach's exemplars can allow medical students to learn what concepts or pieces of information are most relevant and salient to include in a debrief, and how to consider what next steps to take in different scenarios. Thus, the study provides both an expert example and an opportunity to self-assess via reflection and comparison.

By teaching medical students how perceptual cues look on virtual patients we allow them to translate this experience more directly into their own practice. This can help them to recognize if prior knowledge applies to the current situation and with recalling the details of that information. Knowing what to look for can help them assess a patient with increased speed and accuracy, which can lead to enhanced resilience by providing more proactive trauma health care. An organization has levels of adaptive capacity that can face a range of challenging situations (Patterson et al., 2007). Even with built-in levels of organizational adaptive capacity, humans are still providing resilience in abnormal and high-demand situations (Pruchnicki, 2018). Poorly designed processes can lead to adverse events and a decrease in resilience (Patterson et al., 2007). Therefore, training medical students to be a stopgap between the design of health care systems and the real world creates resilience in health care.

Patient safety is a key component of health care and one that is challenging to establish. Resilience fosters patient safety in that providers are able to persist even when the situation is dynamic and can adapt as needed (Patterson et al., 2007). Shared understanding can be built and maintained by knowing what information needs to be shared during a debrief.

5. Conclusion

Canned debriefs from a physician coach can enhance resilience when used with a self-reflection model. Self-assessments can be considered facilitated debriefs. By comparing their own debrief to that of the physician coach, participants can realize things they missed, and understand why those aspects were important to the case and their relevance to the patient. Not only did participants get to apply and build their own knowledge related to the patient's conditions, but they also received training on the key aspects of a debrief. The physician coach debriefs helped to indicate what information is the most relevant and useful to communicate in various trauma scenarios.

Simulation training with virtual trauma patients allows medical students to see perceptual cues and learn how those cues feed into a treatment plan. It also allows them to experience complex and time-sensitive scenarios without risk to an actual patient. Resilience is developed through recognizing perceptual cues and adapting plans as needed during the self-assessment with the physician coach's debrief. Shared understanding is developed, and trade-offs can then be considered with the overall goal of patient health and safety at the forefront.

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Handling the Multi-Party Dilemma

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Since the Second World War, the concept of "outsourcing" has increasingly seen organizational boundaries redrawn as both manufacturing and services were carried out by external companies. With the rise of information technologies and the nascent days of the public Internet, IT outsourcing also emerged as a practice(Lacity et al, 2009). Recently, there has been a marked shift towards outsourcing operational responsibilities of business-critical services to third-party vendors. Examples of this include source code management (e.g., GitHub), cloud computing (e.g., Amazon AWS), and business productivity (e.g., Zoom). This shift allows companies to focus on core competencies and relies on the expertise of others for non-core areas. As these parties enter into business agreements, the result is new dependencies and ways of working. This "multi-party dilemma" is a dynamic that describes challenges at the boundary between interdependent parties, especially during anomaly response. Characteristics of the multi-party dilemma can include information asymmetry, higher costs of coordination, and goal misalignment. It becomes a new form of brittleness and introduces new forms of failure into complex adaptive systems. This paper describes results from a thematic analysis across a corpus of cases conducted by large-scale technology companies and discusses key findings and challenges of the multi-party dilemma in distributed software systems. Some promising directions for embracing the multi-party dilemma across external boundaries conclude this paper.

Keywords: resilience engineering, coordination, distributed systems, technology transformation, boundaries, anomaly response.

1. Introduction

For much of the 20th century, increasing globalization of markets and the introduction of new technologies accelerated the scale, speed, and distance at which organizations operate. Strategies such as subcontracting were used in attempts to increase operational efficiency (such as production speeds and customer response times), manage risk by transferring it to third parties, and access larger markets. Smaller, more specialized companies took on core business functions such as customer service, payroll, and shipping, reducing the need for in-house expertise. In software specifically, the 1990s saw a form of outsourcing called off-shoring, which focused on the global distribution of IT capabilities to trained workers in countries with lower operating costs.

This form of reorganization shifted “the work” involved. One factor motivating this reorganization is the opportunity for the business to tighten focus on core competencies while leaving non-core competencies as prime candidates for outsourcing to third-party vendors. In the rapidly evolving software development landscape, third-party vendors may be faster and better positioned to develop and maintain certain core functions. Some examples of core functions outsourced to third parties that software engineering companies commonly use include source code management (e.g., GitHub), cloud computing (e.g., Amazon AWS), and business productivity (e.g., Zoom).

Technical aspects of operations cannot be moved outside the organizational boundary without generating new forms of failures and transforming work for the engineers. Therefore, the shift away from technical work involves a concurrent level of coordinative work. Smooth coordinative work involves a specialized set of skills and preconditions to be successful (Maguire, 2020). The requirements for inter-organizational (within a company) coordination and intra-organizational (external to a company) coordination are similar but further research is needed to understand the full implications of extensive and hidden interdependencies (Woods, 2014) in software engineering.

This paper examines the "multi-party dilemma" (MPD), which describes challenges at the boundary between interdependent parties. This analysis focuses on the MPD during anomaly response - when highly reliable software services are degraded or unavailable for use- and the implications for resilience.

2. Analysis

Background

The MPD describes a general problem that emerges across many different domains. The consequence of this problem is seen in complex adaptive systems involving human agents that engage in joint activity during anomaly response. Pointing to this consequence in the distributed software domain requires a case study analysis of the anomalies where this problem potentially appears. The intricate dynamics of how the MPD plays out in an anomaly response to large-scale software incidents are difficult to observe by watching the response play out or engaging with lasting artifacts such as chat transcripts or trouble tickets. The pressures, fears, and judgments that responders experience during the anomaly are locked from view inside their internal cognition. The decisions they make and the knowledge they rely upon are often not readily available for analysis without a systematic methodology for doing so.

Methods

The techniques used to collect the data and conduct the analysis include process tracing (Woods, 1993), knowledge elicitation, critical incident technique (Flanagan, 1954), and case study method (Schoch, 2020). The main goals were thematic analysis to uncover common themes from the data. Themes are a description of the organization at the time that they are uncovered (Allspaw, 2021). The analyst does not construct a theme, rather, it is discovered. A theme should be supported through the collection and analysis of the data.

Finding the MPD in themes

Using this methodology, a large-scale technology company conducted case studies across a corpus of cases in 2021. A recurring theme pointed to the challenges of seeking emergency support from third-party vendors during anomaly responses involving critical or vital business functions. The key findings and challenges pointed to by the theme are a direct consequence of the MPD. The way these key findings and challenges manifested in the cases varied.

Another series of cases identifying patterns of the multi-party dilemma involved several organizations of varying scales.

Case 1

A professional services vendor for a popular open-source database technology compelled their customer to delay stabilizing measures to gather additional diagnostic data. This misalignment of goals that extended from their respective corporate missions led to both parties working at cross purposes.

Case 2

A vendor of a distributed message bus was recruited by their customer to bring their expertise to bear on a severe anomaly. The customer's expectations were dashed when one of the first requests from the vendor after joining the response was for the customer to turn the verbosity of diagnostic logging to the highest level. This request from the vendor betrayed the customer’s faith in their competence. In turn, the vendor became suspicious of the competence of the customer when they learned of the specific configuration parameters that had been used to tune their product. Information sharing in the anomaly response shifted toward proving that the other party had the problem on their side rather than working together to understand the problem. The aftermath of that case revealed that the problem was shared on both sides of the boundary. It became clear that the vendor needed more context before successfully bringing their expertise to bear on the anomaly.

Case 3

A source code repository was experiencing degraded performance issues around critical functions. The on-call engineers recognized they needed sufficient information to diagnose the issue properly and contacted the vendor. The vendor had a rigid ticketing process, which delayed access to their expertise and led to mistrust and frustration. The loss of common ground resulted in the vendor asking the on-call engineers to perform diagnostic tests, further exacerbating the performance issues and increasing frustration. The team could not overcome the difficulties faced in the MPD, and it was only through fortuitous findings from one of the on-call engineers that the issue was resolved.

Case 4

Low cross-boundary context and difficulties coordinating during recovery meant a routine upgrade to improve performance issues had cascading effects when corrupted backups were coupled with an undisclosed change from a vendor. Contractual issues delayed information sharing and restricted access to needed expertise, resulting in mistrust and a multi-day incident with catastrophic data loss.

3. Key findings and challenges

Several key findings emerged from the analysis focusing on the additional cognitive work challenges that occur from the distribution of anomaly response efforts across organizational boundaries. They are 1) difficulties in bringing expertise to bear, 2) increases in coordination costs, 3) barriers to preparing to have incidents with third-party vendors, 4) mission misalignment, 5) inhibited flow of information.

Bringing expertise to bear

Large-scale software systems distributed across organizational boundaries present a particularly challenging context for recruiting needed resources and enabling them to be helpful to the response quickly. There are several reasons for this. First, prearranged contractual agreements may not guarantee acceptable response times for the escalating nature of the consequences of the anomaly. Second, expertise in a given aspect of a company's service delivery is typically not readily available. Maguire (2020) showed that escalation systems from lower-level troubleshooting to more sophisticated levels of expertise allow the vendor to manage the competing demands on their experts but often impoverish handoffs between each level of responders. As a result, each new level orients to the problem by repeating some of the previous steps. Even in cases where this is not happening, an incoming responder must come up to speed on an incident that is underway and rapidly orient to a system they may not have familiarity with. They are likely working with client responders with whom they have not established common ground (Klein et al., 2006). As discussed in the next section, this increases the coordination costs.

Incident response teams across organizational boundaries are necessarily ad hoc and emergent - with responders coming in and going out as the incident progresses. Using this expertise efficiently requires shared frames of reference and often shared access to systems. Friction develops when responders must work through the frustration of not having readily available information and, in some cases, not trusting other participants' skills, capabilities, or intentions. Establishing and maintaining common ground in these conditions is exceptionally difficult. Woods & Patterns (2001) show that escalating cognition and coordinative demands exacerbate novel or exceptional problem handling.

Increasing coordination costs

A second finding looking at cross-boundaries work came in recognizing the increased cognitive costs of coordination. Incident handling across organizations has increased friction because of accessibility or lack of accessibility to the right knowledge resources or shared tooling, the variability of available information, and difficulties in working on complex problems with participants unfamiliar with one another.

Experts with deep knowledge are typically scarce resources and therefore have multiple demands on their attention. Responding to incidents is just one of many job responsibilities. In addition, privileged access to create and view support cases in the vendor’s ticket system might be unevenly distributed among potential responders. Joining a video chat may be simple, but given that it requires substantial attention to participate in, it represents a high attentional cost to the responder. Lower bandwidth tooling, such as chat platforms, allow the responder to task switch across other demands and defer responding to a moment of lower tempo.

In addition, the lack of established common ground (the shared knowledge, beliefs, and assumptions) can increase the amount of communication and cognitive effort to identify what information is needed to be shared and to recognize when there are discrepancies in assumed vs. actual knowledge, beliefs, or assumptions. This is relevant in the hypothesis generation phase of anomaly response (Maguire, 2019).

Barriers to preparing to have incidents with third-party vendors

Sharing information between companies (especially between incidents occurring) often involves logistical challenges and concerns around topics such as legal culpability, contract law, financial impact, and privacy violations. Some of these concerns may be driven by regulatory requirements (HIPAA, FedRAMP, PCI), while others may be based on the requirements and preferences of individual companies.

Tensions occur when these legal, financial, and privacy concerns interfere with the free flow of information between parties, often becoming a struggle between the desire to be transparent and the regulations or rules in play. This is particularly true in the middle of a high-tempo anomaly response where information changes rapidly and sharing information between parties may unknowingly involve sharing information that will later be proved incorrect.

Mission misalignment

Teams and organizations on each side of the boundary are often driven by their respective organizations' goals, missions, and values. In a multi-party dilemma with multiple companies involved, the motivations and objectives often differ and can occasionally lead to goal misalignment, which can lead to working at cross purposes. This dynamic is called the "mission misalignment" (Elman, forthcoming).

When bringing two organizations together to work in a unified way on a common problem, a transient and ad-hoc organization may emerge to deal with the dynamics of collaborating within the existing organizational bureaucracies. The transient organization can span the boundaries between the bureaucracies of the customer and the third-party vendor. Teams may temporarily "redraw" the boundary to include representatives from both companies. Authority is held by subject-matter experts who form multi-disciplinary teams oriented around a shared goal. Mission misalignment can become a crucial challenge in this approach as misalignment occurs around topics such as goal orientation, decision-making authority, and information sharing.

Inhibited flow of information

A fundamental component of the multi-party dilemma is information asymmetry between parties. One of the ways to overcome information asymmetry is through reciprocity in sharing information across the boundary. Reciprocity involves information transparency and mutual trust, generally in the context of previously agreed-upon sharing conventions or guide rails governing both content and logistics of information sharing.

During anomaly response, poor information flow poses several risks. Among them is stale or out-of-date information that is no longer accurate and the risk of oversimplification as information is passed between parties. These challenges are particularly present in high-tempo distributed response activities.

Bi-directional information flow

In many anomaly response environments, information may flow from one side to the other (e.g., from the customer logging a case to the vendor, from the vendor putting out status updates via a status page to the customer) without meaningfully flowing in both directions.

Strong bi-directional information flow across the boundary is particularly important in anomaly response where incidents have certain characteristics. These characteristics include novel or poorly understood incidents, situations with many unknowns where a path to stabilization is not clearly understood, systems with tightly coupled integration across the boundary, and situations where both parties need more information from the other side to make progress.

In some cases, sharing information bi-directionally across the boundary and collaborating across the boundary can meaningfully impact the response of both parties to an anomaly and provide solutions and insight that neither party could do alone.

There is significant nuance involved and potential for further research and analysis in the area of bi-directional information flow across the boundary.

The novelty inequality

Single-party anomaly response typically becomes a multi-party affair because the first party is dealing with a completely novel problem. The first party senses that they are ill-equipped to deal with the incident and are facing intense time pressure to stabilize. They escalate to the vendor in order to recruit their expertise and bring it to bear on the incident. The diagnostic search of the novel situation starts broad (Grayson, 2018). Often there is a higher consequence of ambiguity on one side of the boundary leading to an information inequality. This is the "novelty inequality" (D Woods 2022; Personal Communication, 1 December). Addressing the novelty inequality requires agents on both sides to work together to share information and form a new shared understanding in order to shrink the task of diagnostic search. Each side is motivated by different goals that derive from their respective corporate missions.

4. Handling the multi-party dilemma

Asking "what went right"?

The multi-party dilemma is a durable feature of many systems and environments, and it is best viewed as something to be handled and managed rather than something to be fixed or resolved. As every company, system, and situation is unique, attempting to solve the multi-party dilemma in an overly prescriptive way would be ineffective. When looking at the cross-case analysis to determine factors that helped systems respond and adapt to the multi-party dilemma well, the following were common components of success:

Communication and information flow

Managing the flow of information is a crucial component of handling multi-party dynamics, particularly during anomaly responses involving high-tempo work. Allowing for technical, transparent, and timely information across the boundary can significantly improve anomaly response outcomes and help manage the unique dynamics of the MPD. During this type of response, bi-directional communication allows the necessary information to reach the appropriate responders on both sides of the boundary without becoming oversimplified or significantly delayed. Ensuring the socio-technical response system has sufficient capacity to allow for clear communication in a high-throughput manner can aid in anomaly response. Some potential considerations for managing information flow include using dedicated staffing to facilitate this information exchange and the ability to asynchronously provide information in a way that does not interfere with or constrain other investigation efforts or parallel workstreams.

Informal networks of expertise

Leveraging the collective expertise of the broader organization can help provide unique resilience to socio-technical systems navigating the MPD. Informal networks of expertise may include employees who previously worked for the third party in question or experts from a different part of the organization who hold deep expertise in areas such as the operation or integration of systems in question across the boundary. During anomaly response, these individuals may naturally gravitate towards the incident to offer their assistance or may be known through primary responders and recruited to join the response in an "out of band" capacity. Informal networks of expertise can provide insight, resources, privilege, and escalation support beyond what may be available to the company via more traditional channels.

The power of partnerships

Creating robust partnerships ahead of an acute event dramatically improves the success and speed of response during the event. The STELLA report (Woods, 2017) found that "[T]o be immediately productive in anomaly response, experts may need to be regularly in touch with the underlying processes so that they have sufficient context to be effective quickly." Through planning and partnerships ahead of an anomaly, responders on both sides of the boundary can establish new norms of collaboration. In addition, agreeing ahead of time on the type of information each side needs to exchange during the initial stages of anomaly response (particularly as it relates to proprietary or confidential information with the vendor) will help the responders to jointly build a new understanding of the problem and address potential legal or privacy issues. Examples of this can include specific version numbers(s) of the vendor's product currently in use, how the vendor's product is situated within the customer's architecture or samples of data stored in or flowing through the vendor's product. If possible, the customer may want to grant the vendor privileged or elevated access to internal systems or knowledge bases.

Challenging assumptions

Many of the challenges of the multi-party dilemma stem from the existing norms around vendor relationships. Due to privacy and legal protection concerns, vendors may be uncomfortable or unwilling to share information. Both sides may be reluctant to fully and transparently collaborate or relay information due to concerns of financial repercussions. However, inviting the participation of relevant vendors to design reviews and incident retrospectives involving their product(s) would be a bold new approach. Engaging in work with the vendor between incidents that is comprehensive enough to reveal more context on how the vendor's product is situated within the complex adaptive system improves outcomes during incidents.

5. Conclusion

The multi-party dilemma is a pattern so prevalent in organizations that it can be considered "law-like" (D Woods 2022; Personal Communication, 1 December). It describes challenges at the boundary between interdependent parties. It becomes a new form of brittleness and introduces new forms of failure and new ways of working into a complex adaptive system. Analyzing the multi-party dilemma in complex software systems uncovers key challenges, including increased coordination costs, information asymmetry, and mission misalignment. The multi-party dilemma is a durable feature of many organizations in today's "as a service" environment and is best thought of as being handled instead of eradicated. Managing this new form of work will require challenging established norms and conventions, including changing how companies share information. Continuing research will continue to discover new ways to handle the multi-party dilemma.

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Command-and-Control Policy Implications for the TRUSTS Resilience Framework

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The TRUSTS Framework of Work System Resilience specifies capabilities and features of work systems that enable resilient performance in the face of unpredictable dynamic demands and high-demand and nonroutine conditions and events. These capabilities and features, which we refer to as resilience requirements, were drawn from resilience engineering, naturalistic decision making, and complex systems science bodies of research and theory. We are iteratively refining them through the evaluation of case studies and conduct of interviews with complex systems experts. In this paper, we use a case study of military command-and-control (C2) policy to assess the applicability and refine the work system resilience requirements specified in the TRUSTS Framework. Specifically, we compared the requirements with C2 policy changes recommended for the purpose of taking better advantage of the F-35 fighter jet's ability to improve flexibility and resilience in Royal Norwegian Air Force (RNoAF) operations. The case study provided evidence of the framework's generalizability, revealed a new resilience requirement to potentially add to the framework, and shed light on three other work system features that had been previously considered, but not retained.

Keywords: Command and control, multi-domain operations, resilience, adaptivity, work system, TRUSTS Framework

Introduction

Command-and-control (C2) policy guides orchestration of the elements, capabilities, and resources of military operations to prepare for and respond to demanding, unpredictable, and dynamic operating conditions. Military C2 policy in the United States and Europe has been informed by centuries of theory, thought, and lessons learned about how to succeed when faced with great uncertainty, complexity, and the constant potential for unexpected situations. We assert that military C2 policy is therefore a valuable and valid source of information about general system capabilities and features that enable resilience in the performance of complex, dynamic systems.

In their 2022 article, Bjerke and Valaker describe an evaluation of command-and-control (C2) policy in the Royal Norwegian Air Force (RNoAF) and recommend policy changes that could enable better use of F-35 Lightning capabilities. The F-35 is a single-seat, multi-role jet. Its capabilities, depending on how employed, have the potential to increase RNoAF agility in rapidly changing combat conditions. The authors' evaluation focused on C2 policy affecting F-35 benefits to interconnectedness and flexibility of coordination in multi- domain operations.

In multi-domain operations, military problems ranging from combat operations to humanitarian missions are viewed without regard for Service ownership of the response (Odom & Hayes, 2014). The goal is to flexibly combine assets and capabilities from any of the ground, sea, air, cyber, and space domains and across US forces, allies, and other partners. The cooperative and strategic use of assets, capabilities, and tactics from across the military enterprise can increase the resourcefulness and resilience of operations and the ability to overload and outmaneuver the adversary. An underlying premise is that establishing superiority in any domain of the complex modern battlespace is no longer a probable outcome; instead, capabilities of two or more domains can be combined to break through adversary tactics and achieve effects for limited periods of time (Atkins, 2018).

Based on their evaluation, which draws on interdependency and coordination theory, Bjerke and Valaker make recommendations to reinforce and adapt aspects of current RNoAF C2 policy. Although not framed as such by the authors, we assert that Bjerke and Valaker's work is a study of work-system resilience. We use the term *work system* to refer to a combination of interacting elements organized to achieve one or more stated purposes within a domain of work; elements include technology, people, policies, protocols, procedures, and more (based on NIST SP 800-37 Rev. 2 from ISO/IEC 15288). Elements working together toward a military objective can thus be considered a military work system. By *resilience*, we mean "the intrinsic ability of a system to [adaptively] adjust its functioning prior to, during, or following changes," events, disturbances, and opportunities, and thereby sustain operations required to achieve the system's goals and mission" (Nemeth et al., 2011, p. 1).

When new technology is introduced into a complex work system and its operations, that technology has the potential to both contribute to and interfere with the work system's resilience. In the case of the F-35 entering into RNoAF operations, the jet's diverse capabilities and capability employment options have the potential to improve the resilience of operations in a number of ways. These include building situation awareness across a multi-domain operation, lending its strengths to whatever mission is most critical at any given moment, and, if necessary, assuming decision authority and operate independently and without communications, a mode Bjerke and Valaker refer to as *autonomous*. For that improvement to happen, C2 must be flexible, possibly more flexible than existing C2 policy supports.

The TRUSTS Framework of Work System Resilience specifies the characteristics and features of complex work systems that enable them to respond to diverse situations and challenges with resilience (Neville et al., 2022; Neville et al., 2021). Figure 1 depicts the framework's "Big Five" resilience factors and subfactors. Not shown in the figure are the two to eight "resilience requirements" that contribute to each resilience subfactor.

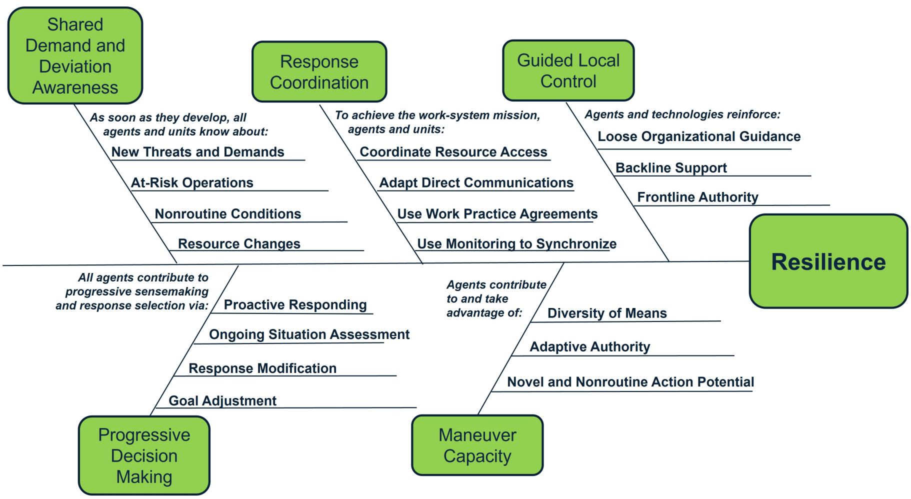

Figure 1. A High-Level View of the TRUSTS Framework of Work System Resilience©

The framework describes sources of resilience for all high-stakes and complex work systems. It is based on research and theory that crosses disciplines and domains, and includes resilience engineering, complex systems science, and naturalistic decision making bodies of work. It has been iteratively adapted over time to incorporate insights from case study evaluations and interviews with experts in complex work systems and in a particular complex work system's operation. Of particular note are:

- Hollnagel's (2011) cornerstones of resilience,
- Woods and his colleagues' writings and research about system dynamics associated with competing goals and associated tradeoffs, adaptive capacity, graceful extensibility, initiative, and reciprocity (e.g., Hoffman & Woods, 2011; Hollnagel & Woods, 2005; Woods, 2018, 2015),
- Studies of system dynamics in "work as done" (Hollnagel et al. , 2013) such as workarounds in healthcare (Patterson 2018, Ash et al., 2004), and
- Klein's (1997; Klein et al., 2007) study and models of sensemaking and decision making in complex, dynamic, high-stakes situations, along with
- Complex systems science writings on emergence, self-organization, and co-evolution (e.g., Bar-Yam, 2004; Benbya & McKelvey, 2006; Heylighen, 2008; Kitano, 2004; Paries, 2006).

Comparison of C2 Policy Recommendations with TRUSTS Resilience Requirements

Bjerke and Valaker's evaluation focuses on coordination flexibility and adaptivity required to benefit from the range of F-35 capabilities. Flexibility and adaptivity are at the core of resilience, and we have reframed Bjerke and Valaker's work as a case study of C2 policy effects on operational resilience. Viewed through this lens, the case study's C2 policy recommendations are aimed at taking advantage of the F-35 to improve operational resilience of the RNoAF. Recommendations additionally include mitigations of risks that may follow from the introduction of greater coordination flexibility and autonomy (ability to act as an independent agent). In the section that follows, we present a comparison of Bjerke and Valaker's recommendations for RNoAF C2 policy with TRUSTS Framework factors and requirements for work system resilience.

Bjerke and Valaker identified fourteen C2 policy recommendations. We compared the recommendations and their rationale, inferred from the authors' discussion, with work system resilience requirements specified in the TRUSTS Framework. The comparison involved one author's mapping of resilience requirements to recommendations and rationale followed by the second author's critique of the mappings. The authors in turn considered comparisons that revealed differences to determine if any differences reflected gaps in the TRUSTS Framework.

Findings and Discussion

Our comparison of the TRUSTS Framework with Bjerke and Valaker's (2020) recommendations supports the generalizability of a number of TRUSTS resilience requirements, revealed candidate resilience requirements that are absent from the framework, and contributed to a clearer understanding and description of candidate requirements. They did not call into question framework factors or requirements.

We assessed the rationale of all fourteen C2 policy recommendations as consistent with high-level TRUSTS resilience factors. We assessed seven of the recommendations as directly mapping to resilience requirements of the TRUSTS Framework and seven as absent from the detailed requirements level of the framework. We discuss each set in turn below.

Table 1 presents the seven C2 policy recommendations that mapped directly to TRUSTS requirements and their rationale. Due to space constraints, we present only the TRUSTS factors and subfactors, not the detailed requirements, they mapped to.

Seven recommendations mapped to TRUSTS resilience factors but not to specific TRUSTS resilience requirements. With one exception (in the first row of table 3), these recommendations were for strategies to achieve C2 outcomes that TRUSTS proposes to achieve using other means. Three of the seven unmapped recommendations were assessed in the context of operations as inferior to TRUSTS resilience requirements as a means to address the associated C2 goal.

Table 1. C2 Recommendations Assessed as Consistent with TRUSTS Resilience Requirements

C2 Recommendation	Rationale Underlying C2 Recommendation	Mapped Resilience Requirements' Factors (Resilience Factor: Subfactor)
Be prepared to enable autonomous (independent) F-35 operations by delegating decision authority to the F-35 flight lead	Respond quickly to changing and unpredictable circumstances	- Guided Local Control: Frontline Authority - Maneuver Capacity: Adaptive Authority - Progressive Responding: Proactive Response
In keeping with common military wisdom and policy (e.g., Mulgund, 2021), retain	Avoid possible risks of decentralized planning: tendencies for increased risk taking and passive leadership and cultural	- Response Coordination: Know Work Practice Agreements - Guided Local Control: Backline Support (to enable Frontline Authority)

centralized planning (Note: All units often give inputs into the planning process)	differences across groups that contribute to tribalism	
Develop flexible procedures for rapidly delegating authority: Permit the skipping of one or more C2 levels in time critical situations.	Maintain control in strategically sensitive missions while being poised to quickly pass control to the F-35 (and other tactical assets)	- Maneuver Capacity: Novel and Non-Routine Action Potential - Progressive Responding: Proactive Response
Standardize and ensure interoperability of data and other inputs into cross-group activities and products	Minimize the effort of information exchange	The TRUSTS Framework supports this recommendation partially through: - Response Coordination: Know Work Practice Agreements The framework assumes imperfect communications and interoperability and a requirement for: - Maneuver Capacity: Diversity of Means to Accomplish Goals
Communication and information systems (CIS) need to be continually available, horizontally and vertically.	Share situational awareness to enable well- informed decisions	The requirement for bilateral horizontal and vertical communications contributes to: - Response Coordination: Adapt Direct Communications to Conditions The framework assumes that imperfect communications and system shutdowns will occur and so requires: - Maneuver Capacity: Diversity of Means to Accomplish Goals
CIS need to support an increased rate of information updates during conflicts and crises.	Keep pace with operational demands when a conflict or crisis increases operational complexity	- Progressive Responding: Ongoing Situation Assessment - Shared Demand and Deviation Awareness: New Threats and Demands (demand rate, complexity, and time sensitivity)
Permit teams with different specialties to operate interchangeably	Improve flexibility of multi-domain operations	- Maneuver Capacity: Diversity of Means to Accomplish Goals - Response Coordination : Coordinate Resource Access

As shown in Table 2, Bjerke and Valaker recommend analysis work to support pre-specification of procedures and protocols that might minimize coordination breakdowns. The TRUSTS framework factors and requirements, especially those related to Response Coordination, Shared Demand and Deviation Awareness, and Guided Local Control, operate together to minimize the likelihood of coordination breakdowns while providing means to recover from them. Bjerke and Valaker also recommend training to ensure efficient and effective information distribution. An assumption of TRUSTS is a high level of human proficiency is required for work system resilience.

Table 2. C2 Design Objectives Recommendations Proposed TRUSTS Requirements

Shared C2 Objectives	Bjerke and Valaker's Recommendation	Related TRUSTS Resilience Requirements
- Avoid coordination breakdowns due to hidden and unacknowledged dependencies.	- Map F-35 interdependencies with above and horizonal actors and units - Conduct simulation-based and other types of experimentation to surface interdependencies	- Response Coordination requirements to allow eavesdropping and embedded liaisons from other groups - Shared Demand and Deviation Awareness requirements for the sharing of information types that are key to avoiding coordination breakdowns
Have procedures for sharing a limited high- value resource, the F-35s	- Conduct simulation-based and other types of experimentation to surface interdependencies	The Response Coordination factor includes requirements for ways to obtain and negotiate resources
- Be able to translate F-35 ISR data into timely, precise, and relevant decisions; make it available to the right people at the right time	- Train people to facilitate the movement and processing of the ISR data made available via the F-35	*TRUSTS assumes proficient personnel.*

Four unmapped recommendations, listed in Table 3, suggest new TRUSTS resilience requirements. One requirement had not been identified based on our work to date. Three suggested work system features we had observed in at least one prior case study and considered for inclusion. The example of their role in supporting RNoAF operations in the present case study together with the prior example helped generate a general resilience requirement for each.

The unmapped recommendation we assessed as new called for educating all enterprise units about F-35 abilities across multi-domain operation participants. We generalized this to a candidate resilience requirement for baseline knowledge of work system resource capabilities and grouped it in the Coordinate Resource Access subfactor of the Response Coordination factor.

The three other unmapped recommendations are for:

- A formal work practice agreement delineating when F-35s should switch from networked to autonomous operations. We generalized this to a candidate requirement for an entire work system to have awareness of when changed conditions necessitate loosening control to permit more flexible and adaptive, i.e., resilient, responding.
- The use of liaisons and groups with cross-unit membership as a means to help ensure that within multi- domain operations, decisions of any given team or unit take into account competing goals, activities, protocols, resource needs, and resource availability across the different domains (i.e., cyber, air, ground, sea, space, and cognitive domains). We generalized this recommendation to a candidate requirement for direct access to one or more members of other teams, human or machine, with liaisons and groups formed across teams as examples.
- Access by all echelons and units of a work system to situation awareness views fed by all enterprise units and domains and thus benefitting from their differing information collection opportunities. Whereas the other three additions were mapped to the Response Coordination factor, this recommendation was translated to a candidate requirement for Guided Local Control because of the important role awareness plays in empowering decision making at all levels, including frontline operations.

Table 3. Recommendations that Revealed a Potential Gap in the TRUSTS Framework

C2 Recommendation	Rationale Underlying C2 Recommendation	Proposed Candidate Resilience Requirement
Educate all enterprise units in the multi-domain operation about F-35 abilities across multi-domain operation participants.	Minimize the risk of breakdowns in the coordination of a limited and high value resource (the F-35)	To make resources available where and when needed, resource-users...

		- Have accurate, up-to-date knowledge about resource capabilities
Develop a strong framework that specifies the circumstances when a team will switch to independent and autonomous operation and can or should stop sharing information.	Minimize higher echelon resistance to delegating decision authority even when it makes sense due to: - A feeling of a loss of control - Dependence on F-35-provided ISR data Temptation to use rich F-35- provided SA to reach down and control at the front lines	Work-practice agreements enable coordinated adaptation by providing a shared understanding of... - Conditions under which work operations will switch from a centralized or high efficiency mode to a decentralized or flexible mode
Establish core cross-domain groups and liaisons to build multi-domain knowledge and culture.	Avoid potential adverse effects of centralized planning (e.g., tribalism tendencies) and ensure effective use of resources, including the F-35, across the work system	Anticipation and coordination are enabled by gents that know about other work system units or groups and how to coordinate by... - Having direct access to a unit or group representative
Enterprise-wide situation awareness is fed, via interconnectivity, by the differentiated views of all participating units and domains	Well-informed decisions all the way down to the F-35	Frontline units and agents have authority and associated permissions to... - Access situation awareness views fed by all enterprise units and domains

Conclusion

Efforts to improve C2 focus heavily on technology advances. And while technologies do have an important role, the F-35 serving as a case in point, Bjerke and Valaker's work reminds us that technology advances are only a part of the answer for improving a work system's performance. The art of C2 must also advance. As noted by Swift (2018):

In the increasingly hyper-technological age in which the U.S. military may be called on to fight, too much time, attention, and resources are being devoted to the science of warfare, rather than the art of it. That is as grave a mistake today as it ever was, because the most important skill a warfighter needs to master is the art of C2 (para. 1).

On their own and without complementary C2 advances, technology advances will never achieve the hoped- for impact. Considerable effort and thought must be invested in the deliberate integration of new technology into its work system. The integration plan, much like the C2 policy Bjerke and Valaker evaluated, determines how the technology will participate in the work system, and, importantly, how it will coordinate with work system elements, share resources, and contribute to the work system's resilience to nonroutine and challenging performance conditions. Ideally, this integration work would begin in an early stage of a technology's development. At this early stage, it could take the form of what-iffing discussions with work- system stakeholders, tabletop exercises, or the wargaming of potential capability sets. These activities could be conducted periodically and might transition to higher fidelity human-in-the-loop simulations and evaluations conducted in situ.

Our primary goal in developing the TRUSTS Framework is to make sure a new technology's impacts on work system resilience are taken into account as it is developed. To integrate the TRUSTS resilience requirements into technology development, we developed Resilience-Readiness Risk Assessment (R3A) and Resilience-Aware Development (RAD) methods. If Bjerke and Valaker had used the TRUSTS Framework or the R3A method to guide their evaluation of C2 policy, they might have considered F-35 implications more comprehensively and systematically. As examples, they might have considered factors such as resource management and brokering mechanisms, backline support mechanisms that allow F-35s and other frontline assets to stay focused on the dynamic challenges facing them, shared awareness of new demands and deviations, and resilience requirements of Progressive Responding that may become possible to meet as a result of an increased potential for fluid goal and response modification.

The TRUSTS framework together with R3A and RAD provide means to advance technology development and employment into high stakes and complex work systems. The goals of our future work are to both continue refining the Framework and iteratively employing and evolving framework-based technology development, employment, and evaluation methods such as R3A and RAD.

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RE-working rules: supporting resilience through collaborative rule-making

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Resilience requires adaptive capacity, which depends on flexibility and autonomy to carry out the different activities in safety-critical industries. Therefore, rules, standards and other prescriptive safety measures are often seen as opposite to resilience, and little research has attempted to bridge the boundaries between standardization and resilience. This paper reports on two qualitative studies examining the standards making process in the railway industry in the UK. Based on recommendations to create environments that support resilience in complex sociotechnical systems proposed in prior literature, this paper shows how a collaborative approach to rule-making may serve as a ground to promote resilience.

Keywords: Resilience, safety, collaborative rule-making, standardization, railways, sociotechnical systems, ultrasafe industries, uncertainty.

1. Introduction

Ultrasafe industries such as the European railway system (Amalberti, 2001) operate safety within a paradigm of risk avoidance (Amalberti, 2013). This safety model relies on standardization, automation and operators with high levels of skills mainly directed to a correct execution of routines to manage normal and degraded situations (Vincent and Amalberti, 2016).

Resilience Engineering (RE) emphasizes the problematic of managing safety based on prescriptive artefacts such as rules and standards. One of the arguments is that prescribed work emerges from work-as-imagined, which represents how work is supposed to be, rather than how it really is. To cope with the situational realities of everyday operations, frontline operators rely on flexible, adaptive behaviors. This work-as-done is fundamental to maintaining safety (Hollnagel, 2014). This boundary between work-as-imagined and work-as-done makes rules and standards, which represent an anticipatory approach and typically tend to constrain action, to appear at odds with the here-and-now adaptability seen as the base of resilience (Macrae, 2013).

The apparent contradiction between standardization and adaptability means these concepts are often regarded as "hopeless opposites" (Oyri and Wiig, 2022). However, there are examples in the safety literature that contradict this understanding and point out ways in which standardization may assist resilience. For example, Grote (2020) put forward that adaptive behaviors can be promoted using flexible rules (Hale and Swuste, 1998; Grote, 2015). These rules do not prescribe the exact course of action, they are goal oriented, giving little or no guidance on how to achieve the prescribed goal. Macrae (2013) suggests that standardizing basic processes can support resilience because it frees up workers' cognitive resources, allowing them to focus their attention and intellect on those processes that require adaptations. Despite some research exploring this perspective, most studies about prescriptions and regulations focus on the management of deviation and noncompliance, not on how rules may contribute to resilience (Oyri at al., 2021).

This paper describes the rules and standards making process in the rail industry in Great Britain (GB), looking at connections between standardization and resilience through the rule-making process.

2. Research method

This paper draws on two qualitative studies exploring stability and flexibility in the railway system focusing on mechanisms for control and stability typically used in the rail industry, such as standards, rules, and regulations. The first study consisted of a document review and analysis of publicly available documentation published on websites by the GB railway industry, the UK government, and European institutions. The railway regulatory context outlined in section 3 reports on findings from this study. The second (ongoing) study interviewed rail experts involved in the development of rules and standards from various organizations such as regulators, infrastructure managers, freight and passenger train operators, and trade unions. The semi-structured interviews were set to explore their understanding of the role of rules and standards in rail operations. The rule-making process outlined in section 4 is informed by five of those interviews with members of the Rail Safety Standards Board (RSSB) (n=4), and a train operating company (n=1).

3. The GB railway regulatory context.

The infrastructure manager in GB provides passenger and freight train operating companies with the track and stations to run the trains on. These train operating companies are known as rail undertakings. They buy or lease the trains from manufacturers and rolling stock owners. They all are supported by a vast supply chain of plant and component manufacturers and suppliers, maintainers, consultants, assessment bodies, and specialists (RSSB, 2021). Each of these organizations has its own specific safety responsibilities. Companies with defined safety duties are referred to as 'duty holders'.

Core to the development of rail industry rules are the standards committees. There are seven committees covering all parts of the system. Central to operational safety is the Traffic Operation and Management (TOM) Standards Committee. It is formed of members and observers from passenger, freight and other non-passenger train operators, rolling stock companies, infrastructure managers, owners and contractors, suppliers and rolling stock manufacturers, the Rail Safety and Standards Board (RSSB), the Office of Rail and Road (ORR), Trades Unions and the Department for Transport (RSSB, 2022). The standards committees, the RSSB and industry stakeholders (the duty holders) are the main actors involved in developing industry standards through a process summarized in the next section.

4. The rule-making process

In this paper, the word 'rule' includes rules and standards, and 'new rule' refers to the rule being made or developed. Rule-making refers to the process of either developing a new rule to fill an existing gap or changing an existing rule, which is the most common process of rule-making in the industry. Contrary to the intuitive idea of industry rules being developed in a top-down fashion, rail industry rules follow a transversal pathway in which the different actors that form the rail system participate. Figure 1 represents a summary of the main steps in the rule-making process.

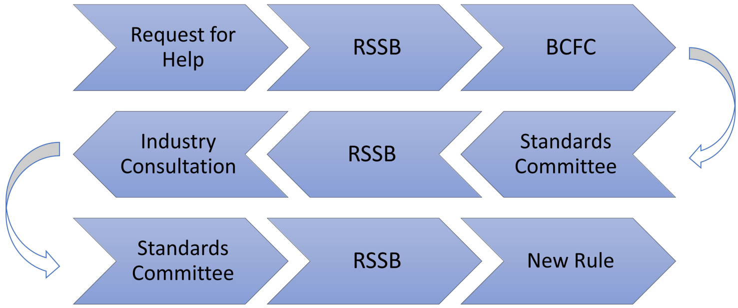

Figure 1. *GB rail industry standards making process. RSSB (Rail Safety Standards Board); BCFC (Business Case for Change). Caption: Own source.*

1. Anyone in the industry can contact the RSSB and apply for a rule change. This is called 'a request for help'.
2. The RSSB assesses the request and decides if the change has merits to be pursued.
3. If the request has merits, they elaborate a 'business case for the change' (BCFC), explaining why the change should be made, the cost-benefit analysis or who will be impacted by the change. Different experts such as human factors specialists, technical specialists, and risk assessors participate in building the business case.
4. The business case is presented to the Standards Committee for assessment, which makes the decision on whether the rule change project progresses.
5. If the Committee decides to progress, the RSSB will draft the new rule and send it back to the Committee, which will approve it for consultation.
6. Although minor changes can be consulted and approved among the Committee members, most rule drafts with wider impact will be sent back to the RSSB to start an industry consultation.
7. The RSSB has a consultation stakeholder register of about 300 organizations registered. They will receive the rule draft and have a period to respond and send comments. The RSSB must respond to every comment received.
8. The Committee examines the consultation process, and the changes made to the draft. If they are satisfied, they will approve the draft for publication.

9. The RSSB does the final drafting, printing, and distributing of the new rule.

New rules must be approved by consensus, not by majority, which means everyone must agree. Although achieving consensus is the main challenge mentioned by the interviewees, it ensures that the rules produced work for everyone in the system.

This description illustrates that rule-making in the GB rail industry is a process a) in which all the different system's stakeholders – i.e., duty holders, industry bodies, regulators, and Trade Unions – are represented and collaborate to produce rules that work for everyone; b) different professional perspectives and skills (at a senior level) are part of, and c) that is dynamic and moves back and forth rather than top-down.

Organizations also make their company standards tailored to their needs based on the risk assessment of their activities. Organizations are not obliged to follow a standardized consultation or employee involvement process when writing their company and project standards. For this reason, the level of staff participation in the rule-making process varies among organizations. The next section considers how an inclusive, collaborative rule-making process may support engineering resilience in processes and performance in complex socio-technical systems.

5. Supporting resilience in complex sociotechnical systems

The railway has been described as a complex sociotechnical system (CSTS) (Ryan et al., 2021); that is, an open system with a wide diversity of connected elements interacting with their environment (Saurin and Sosa, 2013). According to Saurin et al. (2013), resilience is an intrinsic capability of complex systems that can be either supported or hindered by systems design. They put forward six recommendations for the management of CSTS, suggesting that the use of the first five recommendations is a means to achieve the last recommendation; that is, to *create an environment that supports resilience*. Table 1 summarizes the key aspect of Saurin et al. (2013) five recommendations to create such an environment and their relationship with the GB rail collaborative approach to rule-making.

Table 1. Saurin et al. (2013) recommendations for creating environments that support resilience and their relationship with the GB rail standards making process

Recommendation	Key aspects	Relationship with rail standards making process
Give visibility to processes and outcomes	Make visible abnormalities and informal work practices that are part of normal work, and the context that promotes them, as they often contribute to producing expected outcomes.	The rule-making process starts by putting forward rules that are not fit for purpose or informal work practices that contribute more efficiently to desirable outcomes, giving visibility to these practices and the context in which they occur.
Encourage diversity of perspectives when making decisions	Including the diversity of agents that work the system helps deal with uncertainty and complexity. This requires high levels of trust, identification of the most suitable decision-makers, and the reduction of power imbalance.	The rule-making process in GB rail exemplifies the diversity of agents that can be involved in rules development. Trust and good relationships may be preconditions for including such a diversity of agents, but they are also a product of the agreement process.
Anticipate and monitor the impact of small changes	In complex systems, local optimizations may result in undesired global outcomes. While significant changes are carefully planned, that may not be the case for small changes, which impact might be underestimated.	Since the RSSB and the Committee must approve small changes, the impact of the changes on other parts of the system is anticipated

Design slack	Introducing slack in the design reduces tight couplings, helping to absorb the effects of variability	Tight coupling can be reduced through flexible rules, but allowing autonomy brings accountability concerns and requires high levels of trust. A collaborative rule-making process may offer the space to discuss these issues
Monitor and understand the gap between prescription and practice	Standardized procedures reduce complexity by reducing unanticipated variability. Yet, they cannot cover all possible situations, creating the need to fill in the gaps.	Including frontline staff in the rule-making process promotes monitoring the gap between prescription and practice as work-as-done to fill the gaps is exposed. This requires a culture of trust in which staff can feel confident to openly talk about informal practices, and top management trusts staff to manage the uncovered situations in the first place

Reworking rules is a process that aims to make the system safer or more efficient and involves monitoring such a system. In collaborative rule-making, monitoring happens at all system levels since anyone can initiate the process. This helps to tackle uncertainty because decisions are made by people with complementary skills and different knowledge about the system (Saurin et al., 2013). It also gives a holistic view of the system as the different parts in which the system interfaces are represented by the agents that operate them. During the rule-making process, they assess how shifts in processes or responsibilities in other parts of the system may impact their activities, which helps to monitor (although perhaps not always to anticipate) the effects of changes across the system. Including frontline staff in rule-making is essential to give visibility to informal practices, monitor the prescription-practice gap, and discuss issues surrounding control, autonomy and the different degrees of prescription that may be embedded in rules.

6. Conclusion

This paper has presented the collaborative approach to making rail industry standards in GB. It has suggested how this rule-making approach may help to engineer resilience in complex sociotechnical systems. Bringing together agents from across the system with different roles, responsibilities, knowledge and skills to agree on their operational standards helps to deal with uncertainty and to interface the boundaries between a) the different parts of the system and b) how work is imagined and done.

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Perturbation Training: Insights for Training Design in the Resilience Engineering Approach

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The Resilience Engineering (RE) approach is conceptually strongly developed, but practitioners sometimes struggle operationalize its principles because of the strong focus on the system. This also applies to training. We argue that although the system is the unit of analysis in RE, individuals and teams should be the departure point to design effective training interventions. Perturbation training is a form of training that enhances actors' flexibility and performance, and thus seems to contribute to resilience. We elaborate five perturbation dimensions (uncertainty, urgency, high-intensity, long duration, and scarcity) for the design of resilience training. We argue that this type of training can provide insights to the beginnings of what can be called 'Safety II training'.

Keywords: training design, perturbation training, degraded and critical situations, resilience training, Safety II training

Introduction

Degraded or critical situations can be a considerable challenge for organizations concerned by safety (e.g., industrial, nuclear, naval or healthcare organizations), or security (e.g., emergency response or military organizations, police or firefighters). Both types of organizations can be confronted with contingencies and critical situations compromising safety and/or security, as well as the organization's ability to respond to degraded or critical situations. In safety-related and crisis management literature, it is now generally acknowledged that enhancing resilience in and of organizations is a promising way to support, converge, and improve the professional's capability to face and manage degraded or critical situations (Bergström et al., 2015; Hollnagel, 2017). However, concrete means to operationalize resilience remain underdeveloped (Adini et al., 2017; Herrera et al., 2017), especially in training (Righi et al., 2015). Nevertheless, professionalisation and skills development through training are considered as important factors to enhance the capability of professionals to manage critical situations (Bergström et al., 2017; Rankin et al., 2013; Righi et al., 2015). To this end, the identification of resilience training principles is essential. This contribution proposes a reflection along five dimensions for the design of resilience training, elaborated from the principle of perturbation training (Gorman et al., 2010).

Point of Departure

In an RE perspective, "the unit of analysis for designing and assessing training should be the joint cognitive system" (Righi et al., 2015, p. 148) rather than the individual worker. Consequently, training individuals with the prospect to increase their ability to cope with degraded situations ('resilience training') is an underexplored research area in the RE approach (ibid). Moreover, professionals' capability to face up to degraded or critical situations is considered through a collective adaptive scheme (Hollnagel, 2017), that is not always well defined, or pertains to non-technical or transversal skills (e.g., Wachs et al., 2012). Our analysis is that resilience training still lacks a conceptual basis. In this communication, we present the design principle of perturbation as a promising avenue for resilience training for both individuals and teams, and we develop it along five tentative perturbation dimensions.

Training Resilience: The Principle of Perturbation Training

Perturbation is a training principle adopted from the dynamic systems literature that consists in disrupting standard workflow with the introduction of relevant events. A perturbation is "an extrinsic application of force that briefly disrupts a dynamic process, forcing the reacquisition of a new stable trajectory, and is typically used to probe the stability of that process" (Gorman et al., 2010, p. 297). The rationale behind this type of training is that by introducing perturbations, teams are forced to coordinate in novel ways to achieve their objective, leading to more flexibility. This flexibility is manifested in augmented team performance and reduced response time to novel events in comparison to teams trained differently (cross-training and procedural training, Gorman et al., 2010). Perturbations can be created by introducing disruptions regarding team organization (role distribution, communication), by depriving the team from resources (lack of expected information, equipment malfunction, induced understaffing), or by putting strain on the team through information overload, or by accelerating events. Through perturbation training, it is possible to work on two elements of resilience: robustness and reorganization (Woods, 2015).

Perturbation-based resilience training: five design dimensions

We present five perturbation dimensions that were empirically defined by studying actors' experiences in real or simulated work situations. They have a descriptive value but can also be used to derive principles for the design of resilience training. The dimensions are separately presented for the purpose of conceptual ordering but are in no way mutually exclusive: in reality they display overlap.

Uncertainty

This dimension refers to different degrees of uncertainty in degraded situations. It ranges from the simply unexpected (regular or irregular situations, Westrum, 2006) presenting a risk of surprise, to the unthought-of event with a risk of collapse of sensemaking (Weick, 1993). An example to prepare professionals to face up to situations characterized by uncertainty is a safety training observed on a gas storage site, where the death of two on-call agents was simulated (Flandin & Poizat, 2018). This event was not figuring in the organization's safety analysis. In the exercise, the watch officer in charge received an alert and sent two on-call agents outside for removal of doubt. He then heard an explosion and called the fire brigade, while trying to reach the on-call agents, who never answered. The watch officer, after 10 minutes of confusion, not understanding why the on-call agents did not reply, deviated from the procedure as he realized that it had become insufficient to overcome the problem, and finally succeeded in finding new ways to unblock the situation. It was observed how he went from an initial state of perplexity to a collapse of meaning to an acceptance of the uncertainty and the construction of new resources. This requires - and so, tends to develop - a capability for uncertainty tolerance and invention.

Urgency

Urgency refers to the management of rapidly evolving episodes. It involves an acceleration of events (or escalation), time pressure, stress, and a risk of overwhelming decision-making and operational capacity. It requires a high reaction speed. For example, a crisis unit in a French nuclear expertise institute (Institute for radiation protection and nuclear safety) must be able to produce a diagnosis within one hour after an accident/incident. Fast evolving scenarios are used during crisis exercises, to perturb participants in a very complex activity that must be carried out in high-speed in the case of an emergency (Drakos et al., 2022). This puts a strain on individual participants regarding cognitive load, but on the system as well, and training it is susceptible to develop a higher level of responsiveness.

High Intensity

High intensity is an individual and/or collective, physical and/or mental 'over-solicitation'. It concerns actors operating in extremely demanding contexts and subject to critical disturbances. An example is a training that prepares leaders (officer cadets for civil and military security professionals: firefighters, police officers, and soldiers) " (the equatorial forest). It explicitly breaks with training interventions preparing participants to apply the prescribed norms, and with those that create protected environments. Participants are challenged to preserve their resources in a program that confronts them with a multiplicity of disruptive demands. These perturbations can be long orientation walks (night and day), crossing wet cuts, or carrying team members for long periods. The goal is to engage participants in a training program that does "not encourage their activity, but on the contrary hinders it" (ibid). This faces participants with a double challenge: "even though they are immersed in an environment where everything distracts, interrupts, and diverts them from what they have to do, they must still ensure that their overriding action remains focused on successfully completing their mission. Yet they must also find ways to preserve both the individual and group resources that are necessary for this." (p. 244). This requires a capability for resistance to different forms of adversity, on the part of actors and teams.

So, the constant introduction of novel events creates an unstable environment which forces participants to coordinate themselves in such a way that the collapse of the system (in this case the team) is avoided as long as possible. In the case of this specific high-intensity training, the point of collapse is actively sought. This, however, aims at enhancing individual and team robustness, which should expand "the set of disturbances the system can respond to effectively" (Woods, 2015, p. 6).

Long duration

This dimension is characterized by a large number of events to be managed successively. It implies the need to maintain an operational capacity over a long period of time requiring the endurance of professionals and systems. An example are firefighter USAR teams (Urban Search and Rescue) training to be accredited by the UN INSARAG (International Search and Rescue Advisory Group). This certification allows them to internationally intervene in the event of large earthquakes. An USAR team is a self-contained team with logistics for at least 7-10 days of operation in the full number of 36-68 members. The training for the certification lasts three days, presenting challenges on rest, lucidity, food, and hygiene that must be managed in such a way that the team succeeds its missions, while also preserving its own security and safety. This long duration component is perturbing for fire fighters who are used to intervening in shorter missions most of the time. Training in these conditions is therefore susceptible to develop the actors' endurance.

Scarcity

Scarcity is the critical stage of the mismatch between ends and means. It forces professionals to make intensive use of themselves and available resources, to divert the use of some, and to obtain or create new ones. The COVID-19 pandemic faced health workers with the consequences of scarcity of personal protection equipment (PPE), medical equipment or medication. This led to the emergence of resource allocation dilemmas, such as in the case of humanitarian first responders who had to deal with overloaded capacity in other hospitals, limited patient transfer capacity, lack of coordination between hospitals, and pressure of patients and family. One of the dilemmas observed in this context characterized by scarcity was "ensuring the right to impartial access to medical assistance for all in need whilst providing medical care that is within the competency and capacity of the service offered" (Scannell et al., 2021).

Creating scarcity is an effective way to put strain on a team in simulated situations, scenarizing for example loss of electricity, or the unavailability of other resources. Training in conditions characterized by scarcity is susceptible to develop the actors' capability for adaptation (adjustment, or even subsidiarity) and productive imagination.

Discussion

Simulation training seems particularly suitable to confront actors in an effective way with these perturbation dimensions. Rather than searching for high fidelity on all aspects of degraded or critical situations, which is a criticized ambition in terms of training efficacy (e.g., Dieckmann et al., 2007), these perturbation dimensions specify certain aspects of them. This allows to create pedagogically rich activities (Billett & Noble, 2020) that depend more on the 'quality' of the fidelity of the perturbation dimensions, than on their 'quantity'.

Further development of the conceptual basis of perturbation training

So, we argue that confronting professionals with these perturbation dimensions is susceptible to contribute to individual and team resilience and/or robustness. Building on Gorman (2010), i) a deeper analysis of how the nature of perturbations contributes to the development of professionals' capability to face up to attractors, and ii) a finer-grained qualification of what type of capability is developed by which perturbation would be a useful contribution to the resilience training literature. To this end, we propose two reflections for further studies. The first one is a distinction that could be made between 'positive' and 'negative' capabilities. Positive capabilities (adaptation, improvisation, innovation) are often (i) conscious and intentional for the actor, (ii) transform of the environment, and (iii) are identifiable by manifest occurrences for the researcher (Scannell et al., 2021). Negative capabilities (Flandin, Salini, Drakos, & Poizat, 2021; French, 2001; Simpson, French, & Harvey, 2002), are often (i) neither conceptualized by the actors (ii) nor finalized by transformations of the environment, but by resistance to the disturbances that emanate from it, (iii) nor locatable by manifest occurrences, but inferred from the analysis (ibid). A second next step would be to identify the most promising combinations in terms of perturbation (e.g., does long duration also transform responsiveness to other perturbations?), and their relevance to specific fields (high-risk industry versus population protection).

Perturbation-based Training to Develop Safety II

As stated before, in safety-related literature the system is mainly thought of at the organizational level. This often leads to the idea that a technical system requires certain tasks from operators, which are translated into a set of procedures or rules, and which are transmitted to the people in a top-down, prescriptive way (Bourrier, 2017). Generally, training in this top-down approach is thought of like a transmission. This still resonates quite strongly with a Safety I vision of training (Hollnagel et al., 2015). However, based on an ergonomics perspective, it is known that actors 'produce' functioning and safety through modalities of practice that are not contained in prescriptions (Hollnagel, 2017).

Actors, safety experts, and trainers in safety and security concerned organizations are all familiar with top-down training. So much, that it is difficult to imagine what 'bottom-up training' would look like. We argue that that training in safety/security-concerned organizations can be a lever that is particularly interesting to enhance resilience, because of its imminently socio-technical-organizational character, if we succeed in seeing training beyond a top-down perspective. On the one hand, it is what will allow operators to effectively implement the procedures necessary for the proper functioning of the system. On the other hand, it provides the opportunity to verify if these procedures are applicable, considering that prescriptions must be appropriated by operators not only as rules, but also as resources. Training environments can also constitute a space to understand when prescriptions do not suffice anymore, such as in degraded and critical situations. This approach to training seems in line with a Safety II perspective (Hollnagel et al., 2015), focusing on how actors collectively work and train to make things go right, even when their work is strongly perturbed on different levels.

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Proactive Organizational Learning Toward Adaptive Capacity Building, Leveraging Data Analytics and Machine Learning

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Incident reporting systems (IRS) are widely prevalent in hospitals as a way of learning about safety-related events based on self-reports by employees. They represent a narrow approach of learning about work through the lens of negative outcomes or potential harm, whereas the majority of the time, outcomes may be considered positive or not harmful. The Resilience Engineering Tool to Improve Patient Safety (RETIPS) is a semi-structured tool designed for hospital staff to share narratives of adaptations in everyday work that contribute to effective care. The work applies natural language processing (NLP) techniques, including topic modeling and sentiment analysis, to capture of high-level patterns and themes in the reports. This will support the aggregate analysis of reports. The reports will be analyzed to identify areas of synergy (and lack of) between organizational levels that enabled successful adaptation around safety and quality issues by operational teams and caregivers.

Keywords: Proactive learning, adaptive capacity, machine learning, artificial intelligence, incident reports, natural language processing.

1. Introduction

An important driver of an organization's adaptive capacity and resilient performance is its ability to learn proactively (Hollnagel, 2014; Woods et al., 2015). This includes learning about pressures, trade-offs, adaptive strategies, coordination, monitoring and anticipatory mechanisms across multiple levels of scale. One of the challenges to learning, however, is the cross-flow of information and lessons across organizational layers, i.e. between the sharp-end and blunt-end. Various approaches have been described to help transmit key information across these boundaries (e.g., Bergström & Dekker, 2014). However, specific tools and mechanisms for implementation at scale are largely missing or still being explored. Recent advances in data analytics and artificial intelligence (AI) offer potential pathways for organizations to support proactive learning at scale.

Data Analytics and Artificial Intelligence

Data analytics and artificial intelligence (AI) are increasingly in use for learning in organizations and to support decision-making at various levels. Whether it be through sensors or human-input, data is both generated and consumed, converted to information, and readily translated into insights. Large-scale trends, such as customer behavior, traffic flow patterns, errors, are analyzed for patterns and for prediction (Boukerche et al., 2020; Li et al., 2019; Shen et al., 2019). However, these techniques do not currently focus on supporting patterns of drift, brittleness or adaptive capacity in organizations.

Incident Reporting Systems

Incident reporting systems (IRS) are widely prevalent in hospitals as a way of learning about safety-related events. These systems are designed for self-reporting of adverse events and near-misses by staff and caregivers involved in the incident. At large multi-specialty hospitals, several thousand reports are generated each year with a majority of respondents being nurses. However, IRS have largely been ineffective in improving care quality and patient safety (Anderson et al., 2013; Sujan et al., 2017; Waring, 2005). Reasons for failure include the lack of prompt and thorough analysis and follow up, lack of evidence of positive impact of reporting, and the fact that reporting is mostly compliance-driven and impeded by fear of blame and retribution. Additionally, they represent a narrow approach of learning about work through the lens of negative outcomes or potential harm, whereas the majority of the time, outcomes may be considered positive or at least, not harmful. Remedial actions and organizational changes implemented based solely on such a reactive approach are known to be limited in their effectiveness and sustainability over time (Hettinger et al., 2013). This is in part because improvement efforts to address identified hazards may inadvertently dismantle the adaptive capacities that may be preventing the occurrence of even more incidents (Hegde et al., 2013). Further, the natural variability of everyday work calls for a continual and proactive learning approach to inform care quality & safety improvement efforts.

Use of Machine Learning for Analysis of IRS Databases

In recent years, there has been an increasing use of machine learning techniques, particularly in the category of natural language processing (NLP), to analyze free-text data from incident reports (Evans et al., 2020; A. Fong & Ratwani, 2015; Allan Fong et al., 2019, 2021; Syed et al., 2020; Young et al., 2019). NLP algorithms can potentially help scale analysis of reports through automation. Most work using NLP has focused on classification of specific elements of the reports, such as incident type, type of medication error etc. (Young et al., 2019). However, progress on the application of NLP to extract more semantic patterns in the data has been slow. A combination of techniques, including topic modeling, sentiment/emotion analysis, and named entity recognition (NER) can help improve the semantic interpretability of free-text data. However, as artefacts of the Safety-I paradigm, incident reports primarily comprise narratives of error, blame, defensiveness, and a general bias toward negative outcomes and causes.

Resilience Engineering and AI: Paths for Synergy

While the capabilities of AI are growing rapidly, as is the enthusiasm for their use, drawing from decades of research on the fallout of automation for human control of (or lack of) systems, there is need for caution. That said, AI and data analytics are already becoming a part of work-as-done as these technologies have proliferated work systems across domains. This presents, both a challenge and an opportunity for the resilience engineering (RE) community, in terms of coping with the pace of change in the nature of work. Machine learning based analytics of IRS data is a case in point. The tracking of topics, sentiments, and other relationships in the reports over time could help identify emerging patterns, which could be correlated (or not) with organizational decisions or other factors. Such analysis can trigger or support detailed investigations by quality improvement teams.

The Resilience Engineering Tool to Improve Patient Safety (RETIPS)

RETIPS has previously been demonstrated as a tool to elicit narratives of adaptation from frontline healthcare workers (Hegde et al., 2020). While it is structured similar to a typical incident reporting tool, the questions focus on aspects relating to resilience and adaptive capacity, such as workarounds and coping mechanisms, resources used, organizational enabling factors, and challenges. RETIPS has previously been implemented within large healthcare organizations with specific groups, such as anesthesia and radiology. As a tool designed to generate data from the frontlines for proactive learning, RETIPS could be integrated within the organizational learning framework to complement the IRS, while also leveraging NLP capabilities for analytics.

The work described here represents the application of a resilience engineering lens to a machine learning based approach toward improving organizational adaptive capacity. Specifically, NLP was used to analyze themes and trends relating to adaptive capacity, based on RETIPS reports.

2. Method

The RETIPS tool was implemented in the radiology department at a large pediatric hospital in the United States to help the organization learn how their employees were coping during the beginning of the COVID-19 pandemic. The details of the implementation and findings were presented at the previous REA symposium, and will therefore not be repeated here. The reports (58) obtained were used to train a variety of NLP algorithms with the goal of identifying topics and patterns that could have implications for learning about adaptive capacity. This ongoing work involves techniques briefly described below.

Topic modeling: Identify topics emphasized in the free-form survey responses, corresponding to the radiology-specific issues surrounding patient safety and care quality. Toward this end we performed Latent Dirichlet Allocation (LDA) for topic modeling. Hospital stakeholders will be engaged with in an iterative process to refine the algorithm to increase its ability to identify topics of particular interest for those stakeholders.

Sentiment analysis: Provide metadata for each such topic area, in the form of sentiment and emotion analysis, to achieve a “sentiment profile” of each topic, consisting of a numerical score for each of six emotions (joy, sadness, anger, love, fear, and surprise) as well as an overall sentiment score (representing to what extent the overall sentiment of the text is positive or negative). This serves to enhance topics’ interpretability, making it easier for stakeholders to understand the nature and content of the topics discussed in the survey responses. Sentiment metadata also serve to highlight topic areas with unexpected or unusual content, which can help focus downstream efforts in analyzing the data. For instance, if a topic related to patient handling scores high on anger, this should probably prompt a detailed inquiry into the process.

Named entity recognition (NER): Perform a named entity recognition analysis of the data, extracting as metadata for each survey response a list of the departments, persons and organizations and staff mentioned in the response. We will apply a pre-trained model, engaging with hospital stakeholders to iteratively tune the data preprocessing and the model algorithm in order to produce NER outputs of maximal utility and interest with respect to stakeholder priorities.

Document embedding: Produce an AI-driven numerical document embedding (Sanh et al., 2019) for each survey response, to allow for a variety of downstream analyses, including: a) Similarity analysis, measuring the degree to which responses within that topic are similar in meaning to one another (allowing one to distinguish between topics that constitute relatively homogenous responses and topics that comprise a wide variety of responses); b) Similarity search, through which a researcher can find documents close to a particular, pre-defined area of interest (allowing one to easily search for all responses relevant to, e.g., patient positioning).

3. Results

Preliminary results from the algorithms thus far indicate potential directions for improvement in accuracy.

Latent Dirichlet Allocation (LDA) Topic Modeling

Based on the initial LDA, 3 topic clusters were found. Each topic was associated with a specific distribution of weights across relevant terms, such as “work”, “staff”, “home”, “change”, and “time” (Figure 1).

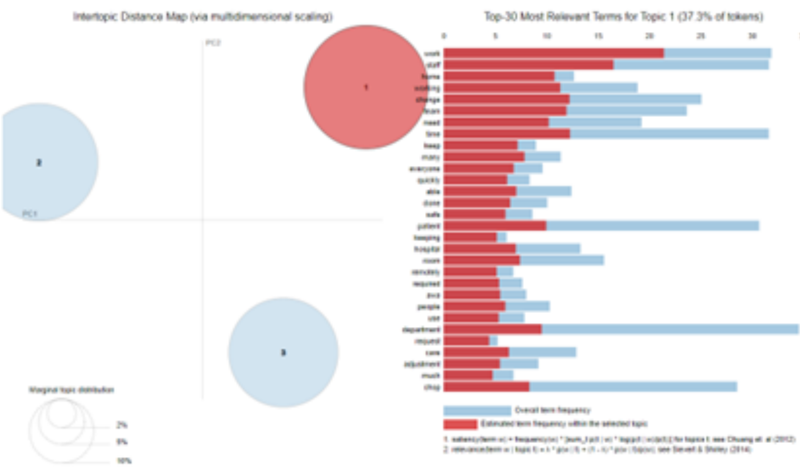

Figure 1: Initial results from topic modeling

Sentiment Analysis

Sentiment scores were obtained for overall sentiment, and for specific emotions. While the overall sentiment score was high, only anger, joy and fear had scores distributed across the scale (indicating varying levels of these emotions), whereas, surprise, love and sadness were close to non-existent (Figure 2).

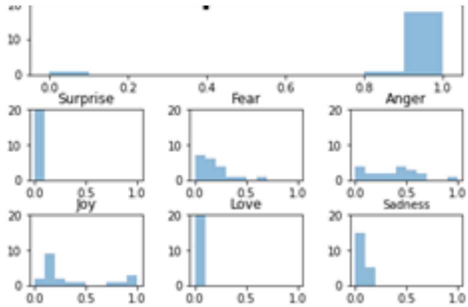

Figure 2: Sentiment analysis scores based on RETIPS data.

Named Entity Recognition

A RoBERTa-large model pre-trained on English NER was used for identifying entities such as people, places, and organizations in the RETIPS data. Additionally, the BERT pre trained model was used to create numerical embeddings from free text data. Analysis wa then performed to identify the occurrence of each identity in the data. This serves as a crucial data point when identifying trends in user-reported text data. These embeddings are also used to search for different key terms or themes within the RETIPS responses and have a wide variety of other modelling applications that can be explored. Figure 3 shows the “PPE” and “CHOP” (the hospital) being the predominantly named entities the reports.

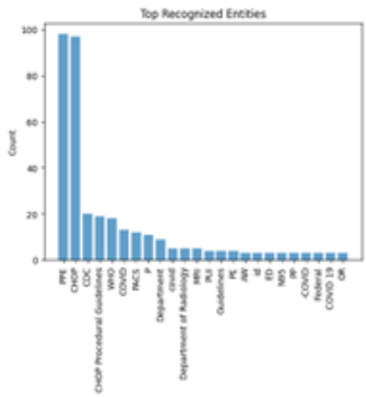

Figure 3: Top recognized entities from the NER applied to the RETIPS reports

4. Discussion

Boundaries are more than the just those that delineate formal layers, such as levels of hierarchy. They become boundaries in the real sense when information flows across the layers are impeded, leading to mental models becoming misaligned with each other.

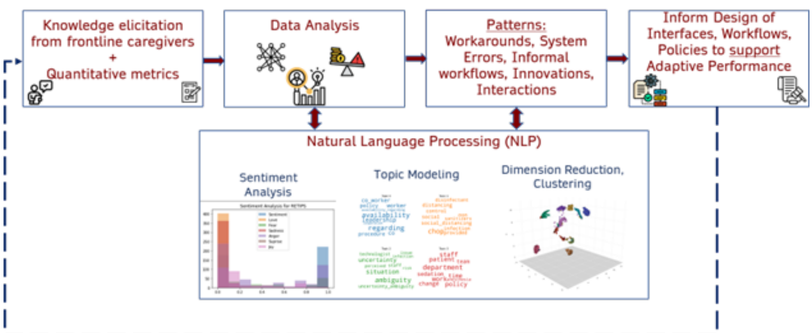

Figure 4: Framework for continual learning supported by AI

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The Resilience of Resilience Engineering: Extending resilient design methodologies with a regenerative design approach

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Keywords: resilience, regeneration, aviation, systems diagnostics, engineering design methodology

Resilience engineering is a relatively new concept in safety thinking that has gained support particularly in socio-organizational networked systems, such as health care. The introduction of two new essential foundations of resilience - initiative and reciprocity – are showcasing further refinements and improved applicability of resilience engineering (Woods, 2019). At the same time, there are also still reservations of the applicability of resilience engineering in socio-technical domains which can feature a technology-dominant engineering culture, such as the transport industry (Zimmerman, 2011; ESReDA, 2020). This contribution targets a further maturation and applicability of resilience engineering by exploring the boundaries of resilience engineering as we know it now, and proposing a new design methodology – regenerative engineering - that would allow those boundaries to be extended indefinitely.

Introduction

This contribution elaborates on the analysis of system architecture, technological concepts, functional configuration and operational context of legacy systems with a high level of technology and complexity, in particular in the commercial aviation domain. While legacy systems in this domain may feature the ability to demonstrate resilience to (limited) changes in their operational context, they also demonstrate an undesired rigidity toward accommodating new (short-term) policy shifts, as well as long-term transformations in social values, economic climates and technical innovations. The concept of "graceful extensibility" (Woods, 2019) has often been (both explicitly and implicitly) a design strategy applied in the concept of shifting performance requirements. In recent years, as a plethora of new requirements are added with respect to sustainability and circular economy (e.g., Horizon 2050 and EU Green Deal demands). Domains such as IT, human-machine teaming, propulsion and mechanical (composite) structures all feature examples of derivative evolutions of legacy systems being "gracefully extended".

While the concept of graceful extensibility has its merits, the analysis of several (transport) systems has also identified that there is a limit to this extensibility. This is particularly the case when attempting to integrate externally-driven and/or higher-order changes in performance requirements (e.g., climate goals, new global economic playing fields), requiring systems to transition well beyond their originally defined system state space boundaries and associated predominant solution concepts. In such cases, the extensibility of these systems can be either limited due to their maturity, legacy and fundamental design assumptions, or be exhausted by complexity, ability to be modelled and existing knowledge deficiencies. Unfortunately, due to the lack of stop rules, such resilience engineered systems are often stretched too far beyond their original design space boundaries, becoming "systems with a promising past". Such over-extended systems will feature system brittleness and performance anomalies which diametrically oppose of the central tenant of resilience. Lessons can be learned from Vincenti's theorem of presumptive anomalies (Vincente, 1990):

> "*Assumptions derived from science may indicate that under future conditions conventional systems may fail or that a radically different system will do a much better job.*"

As our societies, economies and natural ecosystems are featuring major shifts in performance requirements and values, such limits of derivative design evolutions are not acceptable. Consequently, a distinction must be made between the suitability of derivatively designed (extended) evolutions of systems, and the suitability of a more regenerative, disruptive form of system evolution. The difficulty lies in a timely consideration, analysis and identification of the need to “shift gears” between these two design approaches. The economic, regulatory and social costs of shifting too early will promote extending systems as far as possible, while shifting too late also leads to the (catastrophic) failures and associated damages to people, planet and/or profit.

In an attempt to clarify a design decision-making process concerning if and when to shift gears, a selection of engineering design methods has been evaluated, including collaborative engineering, knowledge-based design, value chain transitions and cyclic innovation modelling. This contribution describes and evaluates an engineering design methodology to identify and effectuate constraints and transition barriers discriminating between the suitability of either derivative or disruptive design solution strategies in the socio-technical design space. Our inquiry into the history of such anomalies in various socio-technical systems indicate the need for critical self-reflection in such evaluations throughout the areas of design, certification and operation of systems. In this method, the role of the systems architect is clarified to oversee and strategically guide system design at a much higher level of flexibility and adaptivity. The method also elaborates on necessary adaptations to the fundamental steps in the engineering design process to enable foresight on future proof system adaptations, by facilitating an explicit design of system dynamics in both the short- and long-term.

Therefore, instead of pushing the boundaries of resilience under ETTO considerations, the necessity to introduce a transition in engineering design methodology itself is disclosed. This essential perspective enables the identification of design strategy bifurcation points, where resilience-by-extension-of-a-system is exhausted, but that a radically new systems become inevitably superior: resilience by regenerative engineering. Such a self-reflective addition to the resilience engineering methodology will facilitate responsibly extending the existing boundaries of resilience engineering, and ensure that resilience engineering remains relevant in the context of a turbulent yet exiting and promising future in the coming decades. The commercial aviation sector is selected as the shared framework for diagnosing resilience capabilities, their limitations and adaptive potential.

System diagnostics, the aviation engineering design perspective

In order to diagnose the aviation system architecture, configuration and functioning with respect to its optimization and adaptation capacity and resilience capabilities, two analytic tools are applied, derived from the aviation engineering design discipline (Vincenti 1990), railway engineering (Van Kleef 2015) and naval architecture (Veenstra 2023).

A decomposition of the system into its primary system aspects, assumptions, limitations and performance variables subsequently identifies:

1. primary design optimization aspects: air traffic control and management, airport development, aircraft development, pilot competences and airline corporate management; and

2. the flight service operating envelope: this envelope identifies capabilities of a design regarding limit states for a given phenomenon or situation, facilitating predictable, stable and controllable system behavior.

Air traffic control and management

To cope with the expected growth of aviation, modernization of the airspace in Europe covers four key areas: airport operations, network operations, air traffic services and technology enablers. This modernization is embedded in two large research projects: Single European Sky ATM Research project (SESAR) in Europe, and NextGen in the USA. Both of these developments showcase radical restructuring of the airspace, and forgo the incremental, derivative path.

SESAR should open the European skies to new airspace users and allows the aviation industry to become more flexible and agile. The project faces three major challenges. First, safety should be embedded in the layers upon layers of mechanisms and procedures to enable a big jump from controller making the decisions to the technology making the decisions without human checks and balances. Second, complexity in the new concept requires skills and judgement in new, unforeseen scenarios that have to be managed by machines with a 100% correctness rate, while communicating and interfacing with neighboring ATM systems. Third, this requires human acceptance of automation, not only by customers and passengers, but above all between controllers and technology. The operating environment may impact the industry (as seen during the COVID-19 pandemic) requiring adaptable and flexible responses to emerging situations and operating conditions.

In the USA, the NextGen ADS-B project takes a step further in modernization of the airspace. It establishes metrics for a cost effectiveness growth and increasing efficiency. The concept removes a direct link between aircraft navigation and ground-based navigational aids, which should enable reductions in fuel burns and emissions. An increase in capacity is to be achieved by reducing separation minimums and high precision flight paths, increased access during marginal weather and reduced diversions to alternate airports. NextGen claims substantially improving safety by precise positioning in the sky with transponder technology, based on real-time displays for pilots and controllers. In the future, flexible growth is anticipated with a shift of air traffic operations from a short-term tactical control and conflict management to more predictable and planned strategic trajectory-based traffic management. Such a transition enables increases in efficiency and performance with collaborative air traffic management. Pilots and dispatchers can select their own flight path, rather than following the existing system of flight corridors and airways. The ADS-B concept combines the functionalities of tactical conflict management and strategic trajectory-based operations while eliminating the functionality of strategic airspace capacity management. There is a difference in scope between SESAR and NextGen regarding underlaying assumptions. While SESAR almost exclusively focuses on air traffic management, NextGen incorporates both air traffic control, airports, operations, security and passenger management and access of a wide range of new users: urban air transport, UAV's and drones. Interdependencies between the US and EU concepts are not yet settled.

Airport development

A development towards sustainable aviation requires a clear design and management of this transition process, both the technological innovation and procedural and regulatory adaptations. In order to understand the complexity of this transition and underlaying change agents, change drivers and forcefields, a new diagnostic instrument mix is required to provide transparency on the short and long term (Boosten, 2021). Before the COVID pandemics in 2019, the civil aviation industry was operating at a maximum capacity with respect to airports and airspace, while societal acceptance was deteriorating due to climate and environmental loads. Simultaneously, the EU Destination 2050 project focuses on four instruments to address the Paris Climate Agreements: aircraft and engine technology, air traffic management, aircraft operations and sustainable fuels and smart economic measures.

Under these conflicting goals, the aviation industry is facing a first dilemma of successful growth at a higher rate than technology is reducing the environmental impact. The main debate is how to achieve a net zero result considering the growth potential by a multi-value integrative approach incorporating other societal values such as safety, land use, or security. A second dilemma is based on safety and risk management methodologies and their performance indicators. A deterioration of the public perception of aviation as a Non-Plus Ultra-Safe industrial sector is contradictory to the anticipated growth of worldwide air traffic volumes, particularly in the BRICS countries and non-Western world regions.

During the expansion of Schiphol Airport in the 1990's a Boeing 747 freighter crashed in an apartment block in the Bijlmermeer. As clarified in the subsequent RAND report on airport safety at Schiphol Airport in 1993, assuming a linear relation between accident and incident rates and traffic volume increases the prognosed number of accidents to a societal unacceptable level of severe air disasters. Therefore, in their recommendations, the RAND Report did not challenge the already very high accident rate achievements, but instead focused on a managerial multi-actor approach for the airport community by proposing an Integrated Safety Management System (RAND, 1993). To maintain a high safety level playing field. In the aftermath of the crash, the European Commission issued Directives on SAFA ramp inspections (Safety Assessment of Foreign Aircraft) for poor safety performance of aircraft and companies and introduced a Black List for non-admittance of poor performers to the European skies.

However, these safety enhancement measures did not relieve the main obstructions for a further growth by their nature of derivative, monofunctional solutions (Boosten, 2021). Solving the paradoxes of air traffic growth while maintaining safety performance levels versus environmental impact and climate change successfully requires the transition of the entire sector, very much a disruptive, regenerative approach. Innovations and transition processes with disruptive adaptations have to overcome conservative and legacy forcefields in the sector. A driver for innovation in capacity and growth was found in the relocation of the airport or establishing a second national airport. Although Schiphol still has sufficient technical capacity at the present location due to the airport concept as developed by its founding father Dellaert in the 1950's, the societal capacity was the most limiting factor for growth (Boosten, 2021). Schiphol Airport investigated three locations for extension of air traffic capacity in the Netherlands: an artificial island in the North Sea, a new polder in the Markerwaard and an extension to the Second Maasvlakte near the port of Rotterdam. A novelty was that the study also considered a partial replacement of the current airport by a functional splitting up of runway configurations from terminal operations. Also, an outplacement of cargo to Rotterdam Airport was part of the considerations.

In the current debate on airport growth at Schiphol, references are made to this historic reconsideration of airport configuration and location. A high-speed underground connection such as Hyperloop could connect the airside runway configuration with the landside terminal at Schiphol. However, two out of three locations are no longer available: the North Sea is destined to accommodate a European Hub for Energy Renewal by massive wind turbine deployment, and the extension of Rotterdam Port is realized without an airport due to the major hazard footprint of the process industry. The remaining location is the Markerwaard, although commonly allocated for nature preservation purposes. This solution also questions the location of developing regional airports and the interoperability of seamless intermodal connectivity to rail and road landside transport networks and business centers such as Amsterdam Zuidas.

A future Schiphol twin airport configuration has to accommodate sustainable developments on the long term, adhering to the inherent and economic lifespan of the infrastructural assets. Such a new Schiphol Airport is submitted to a transition strategy from a national Airport via a hub-spoke Mainport towards Multimodal City Airport. A transition strategy has to be developed to realize a vision for the future with inherent transition paths and interdependencies. Each of these transition phases identifies technological developments with respect to intermodal integration, seamless transfer of passengers and cargo, traffic efficiency per energy unit, new types of aircraft with electric propulsion and new business models. For the development of such strategies, new tools and notions have to be mobilized, such as the MCIM model for cyclic innovation strategies, the ESReDA Cube for clarification of a system architecture and dynamic system changes, discriminating derivative from disruptive adaptations (ESReDA, 2020; Boosten, 2021; Veenstra, 2023).

Aircraft development

The conceptual design of the present world fleet of large commercial aircraft origins from the 1960s. The 'tube and wing' configuration with jet engines attached underneath the wings have been the dominant form variant. In a series of generations, this concept has evolved into present versions based on the single optimization of primary aspects according to the Breguet equation: speed, aerodynamics, propulsion and structural design (Stoop, 2020).

The design concept of the Boeing 737 is the tube and wing concept, the product of a long line of derivatives stemming from the 1967 B727 design (Stoop, 2020). In successive generations, the concept was extended and upgraded from the original version. Conversions were performed in all primary functions, including aerodynamics, power plants, structural weight reductions, digital flight control systems and glass cockpit equipment, increasing capacity and range representing a 15-20% reduction in direct operating cost. For fuel economy, noise abatement and maintenance reasons, the bigger and more powerful CFM International LEAP engines were installed on the Boeing 737MAX variant, at the detriment of aerodynamic behavior and stability margins. The Boeing 737MAX was not the only aircraft that suffered from excessive pitch up and center of gravity concerns: the Airbus A320Neo and A321Neo encountered similar aerodynamic problems. In all these variants, due to the engine dimensions and ground clearance requirements, these large engines had to be installed more forward and higher up relative to the wing. This configuration change proved to disrupt the airflow over the wing in high angle of attack situations, creating an (unanticipated) pitch up moment at low speed and low altitudes, which would greatly reduce the recovery window that crews had to prevent a more severe (stall) upset. As the aircraft was slightly aerodynamically unstable, it had no aerodynamic solution for stall recovery, and stall was to be avoided rather than recovered. In the 737MAX this problem was addressed with a Maneuvering Characteristics Augmentation System (MCAS) as a stall prevention system which engages a nose down pitch when the aircraft reaches high angles of attack.

Two recent and very similar accidents with the 737MAX, Lion Air flight 610 on October 29th 2018 and Ethiopian Airlines flight 302 on March 10th 2019, brought the design assumptions and certification processes of the tube and wing configuration under scrutiny. Both accidents indicated that a likely malfunction of the angle of attack (AoA) indicators (an incorrectly installed and damaged AoA vane, respectively) resulted in the MCAS "overreacting" and commanding a strong nose-down pitch trim during a normal departure profile. Several investigations into both the accidents and the certification processes brought to light a mismatch between the crew's reaction to this uncommanded pitch trim (which also were also not up to industry standards), and the design assumptions about crew responses to possible MCAS failure modes. Both training and design factors contributed to these accidents, however both factors are the result of incremental, derivative evolutions in the 737 series. These accidents shows similarities with the Air France 447 accident, which revealed a similar mismatch between assumed and actual crew responses to failures that resulted in reduced flight envelop protection in the Airbus A330.

Investigation into Boeing's design process revealed that the changing competitive environment with Airbus in terms of fuel efficiency, production costs and lead times pushed the 737 variant design to undecimated the safety risk of multiple small changes and the possibility of them interacting in with new emergent system behavior, such as the mismatch between the assumed and actual crew responses to MCAS situations.

Investigation into the certification process also revealed there was limited safety oversight by the Federal Aviation Authority FAA, and that delegation of variant certification left these 'emergent' properties unnoticed because there were no criteria for discriminating derivative from disruptive adaptations: the choice between these two certification regimes was left to subjective interpretation of the manufacturer without outside review or perspectives to challenge existing beliefs, assumptions and habits developed throughout the design evolution of the 737. Eventually, after a period of investigations and hearings, the US House of Representatives passed the Aircraft Certification Reform and Accountability Act in November 16th, revising responsibilities and governmental obligations in order to restore faith in the US as participant in the reciprocity of certification regimes globally.

Over the last decade, alternatives concepts to the tube and wing aircraft design have emerged, including the V-wing and Blended Wing Body (Stoop, 2020). Although already designed and introduced in practice in the 1930's in Germany, this concept had not seen wide dissemination due to a lack of aerodynamic stability and control capabilities. However, the introduction of high-performance IT, fly-by-wire avionics and flight envelop protection may facilitate sufficiently reliable stability and control capabilities for commercial pilots and operations. However, a departure from derivative aircraft design toward new control and stability systems should also trigger a regenerative perspective on pilot qualification, training and competencies, so that the human element of the system is not designed around old assumptions, resulting in Vincente's presumptive anomalies such as the Lion Air and Ethiopian Airways accidents.

Changing pilot competences

As section 2.3 illustrates, the aviation sector is experiencing a shift in accident modes and causal factors. A series of hallmark accidents in the past two decades such as Air France flight 447, Asiana flight 214, Air Asia flight 8501, Qantas flight QF 32, Lion Air flight 610 and Ethiopian Airlines flight 302 cases show a troubling brittleness of existing flight crews' capacity to manage unexpected, ambiguous and rare situations. In all these cases, modern, well-equipped aircraft flown by a crew trained to legally required standards have still resulted in deadly accidents or severe damage (Mohrmann, 2019). Despite the non-plus ultra-safe system approaching the mythical 10e-7 accident rate, major events occurred in often quite forgiving circumstances (i.e., no extreme weather, and often only minor initial events or system malfunctions). As stated by Troadec as the chairman of the French Air Safety Investigation Bureau BEA, limits of current HF forensic research and methods have become apparent. Based on the investigation of the AF447 case in 2009, he stated (Troadec, 2013):

> *"This accident has also taught us that hypotheses used for safety analysis are not always relevant, that procedures are not always applied and that warnings are not always perceived. Only an improvement in the quality of the feedback will make it possible to detect any weaknesses in the safety model."*

Where the existing accident analysis models fall short to understand and mitigate such accidents, a new perspective on the human pilot operator is needed. As the context for such pilots has (slowly) shifted to highly reliable systems, a high degree of compliance and proceduralisation and slimmed down training programs, pilots are facing new challenges such as managing events seen only rarely, having to switch from monotonous work to highly complex problem solving, understanding functional and dysfunctional systems which they rarely engage with and managing their own mental condition that suffers from fatigue, startle and surprise and several biases. The slow, derivative drift to reduce "human error" with increased automation, puts pilots out of the control loop and increases complexity, ironically results in subsequent human errors – by design. The complexity and dynamics of the operational system has become the Achilles heel of the system itself. Klein (2011) refers to this as the Self-Reinforcing Complexity Loop.

Mohrmann (2019) proposes Airmanship 2.0 as a regenerative model to perceive the pilot and his/her associated challenges. This model proposes a more cognitive flexible and adaptable air crew with higher-order problem-solving competences, better equipped to handle the complexity and opacity inherent to modern flight operations. Opaque systems require pilots to be the dynamic element in the system, capable of coping with non-expected situations, not trained or anticipated before. Creativity, heuristic strategies, assumption-testing and solving situational variables are learning elements in a new effective understanding of the system. Such crew flexibility serves as a necessary redundancy to prescribed operations.

The Airmanship 2.0 changes the foundational principles of airmanship, nesting the existing procedural, deterministic behavior within a shell of resilience-based behaviors, rather than simply proposing an alternative to procedure-based aviation. This design appeals to the well-known "fail-safe" design principle: it is safer to question a known situation and discover there is a procedure applicable, than assuming an unknown situation is simpler than it is. Resilience based behaviors include a universal attitude that appreciates the innate complexity and associated ambiguity and opacity, an ability to regulate emotions (and thereby cognitive abilities) and lastly learning behaviors by a level of flexibility in mental models.

Such a revised framework also provides a new touchstone for human factors investigators to observe and understand new phenomena and emergency behavior within the socio-technical cockpit system, and letting go of behavioral assumptions and standards that may no longer be valid. The current linear, rigorous standardization of human factors focus on error and non-compliance, and are not suitable to capture new dynamics related to complex systems, ambiguous information and opaque situations. Many systems operate without direct crew intervention or even awareness, such as flight envelope protection, primary flight display declutter modes and alternate flight control law modes. To provide effective feedback to the industry. human factors forensics require a more in-depth pilot accounts, experiences and reasoning and complexity-oriented problem-solving strategies in unforgiving circumstances, as opposed to a classification in a framework based on notions of the past. This natural variance in pilot behavior should be acknowledged as redundancy for automated task execution rather than labelled as deviant behavior and human error.

This approach has implications for training, but more importantly the disruption to human factors forensics to transition from *classification* to *learning* and understanding, introduces a proverbial "canary in the coalmine" when it comes to investigation our own assumptions as an industry. The previously mentioned accidents reflect the limitations of our investigative frameworks: reinventing these frameworks (e.g., by embracing new touchstones such as Airmanship 2.0) allows the industry to check its own assumptions, escape the Self-Reinforcing Complexity Loop and continuously improve its ability to learn and understand, not unlike Nassim Taleb's concept of anti-fragile systems (Taleb, 2012).

Airline corporate management

In a conventional risk assessment, competing variables in corporate performance are traded-off against each other under the ETTO regime: efficiency versus thoroughness trade-offs (ETTO). Such an ETTO decision making process is a simplistic two-variable production versus protection model. Such a 'safe or unsafe' decision is focusing on the individual level of decision-making processes. Within an airline company however, complex and opaque information sharing across corporate levels and organizational interdependencies exist, also both depending on changes in economic markets, technology and society. This complexity requires more advanced management systems to optimize the use of general resources for value creation. Linearized and compartmentalized decision making, based on silo perspectives of competing values and performance indicators, creates potential misalignment between decision making across various stakeholders in a company. In contrast, such complexity requires an integrated management of essential variables on key aspects of safety, economics and passenger experience. Such management diverts from management by classic performance variables, and introduces much needed context to the plethora of available data. This provides more succinct guidance in future strategies, and prevents data-based "fools errands" by conflating correlation and causation.

In airlines in particular, sharing the experiences of flight crews with other company stakeholders would provide highly valuable feedback on the final manifested performance of the entire organization. However, such pilot flight stories on strategies used to manage disturbances and eventful situations are currently rarely applied to facilitate evaluation of performance conditions and the organization's safety performance capability.

Such a disruptive change in the basis of operational feedback requires two adaptations in a company's organization to facilitate an integrated approach. First: safety should be added as a network performance variable and managed as an aspect of operational route-, region- and network decision making. Safety should not be reduced from a corporate value to an operational constraint. Second: flight crews should be considered active, intelligent collective feedback providers and a source of information that big data and artificial intelligence cannot provide. Such aggregated big data processing deprives information from its context and operational conditions. Integration of pilot-provided data can enhance value production solutions beyond the level of isolated safety data processing. To this purpose, an integrated Airline Value Production Management Model has been developed within a major airline, similar to the Integrated Safety Management System as previously developed for the Schiphol Airport community (RAND, 1993; Dijkstra, 2023).

Conclusions

This contribution is a collaborative effort of six PhD research programs at Delft University connected to various socio-technical and socio-organizational domains. They explored the boundaries of resilience engineering from an engineering design perspective at the systemic level. Over past projects, they share the conclusion that to cope with challenges of complexity and resilience in socio-technical systems with a legacy nature, a new design methodology – regenerative engineering- would allow to extend the boundaries of resilience engineering indefinitely. Several additional essentials as formulated by Woods (2019), are necessary but insufficient conditions to get resilience engineering accepted in practice by the aviation community. In addition to the essential 'initiative', 'reciprocity', the 'man-machine interface' as unit of analysis and 'graceful extensibility', we identified several additional essentials from the engineering design perspective and changing operating environment:

First, in order to cope with the dynamics of complex systems, the notion of time has to be introduced. In the short term, 'resilience time' is defined to enable recovery from immanent failure (Beukenkamp, 2016). On the long term, time is essential to clarify life cycle adaptations and transformations in legacy systems. Second, according to Vincenti (1990), science based technological interventions and systemic adaptations are required to reliably analyze, adapt and foresee performance under future conditions. Thirdly, the transition by *derivative* solutions, as form variations, should be distinguished from *disruptive* adaptations, as a change in functional allocations to structural functionalities. Appropriate, discriminating certification regimes should facilitate transparency over future functioning and interdependencies of either derivative or disruptive functionalities, components and subsystems. Fourthly, the rate of adaptation depends on the technology readiness level of innovative technologies, new system states, their stability and control capabilities and requisites. Resilience capability is frequently identified and verified in quasi-static conditions, without contextual interferences as second loop learning processes. Irreconcilable ETTO dilemmas are created by component optimizations and linearized extrapolations, overextending system properties and behavior. Finally, a holistic, integrative, architecture-based design methodology on systems integration itself should be applied to assess future functioning in both their optimized as well as their limit state. This holistic method should be capable of absorbing future, yet unknown demands, assumptions, limitations and operating conditions. Such functioning should be expressed in an 'operating envelope'. Systems should be designed and certified, capable of regenerating their properties, capacity and performance through an adaptive disruptive potential 'to do a much better job than conventional systems' in a new and stable operating environment.

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Design for resilient performance: a study of toolbox talks in construction

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Although resilient performance is intrinsic to complex socio-technical systems, it might also be deliberately supported and engineered through design. This idea is referred to in this paper as designing for resilient performance (DfRP), encompassing design principles developed in an earlier study. There are several engineered practices in organizations that give rise to design decisions that affect resilient performance. However, performing in a resilient manner is not the main purpose of any organization, and therefore DfRP tends to be concealed. This paper explores the utility of re-interpreting existing management practices from the viewpoint of DfRP. For this purpose, a case study of toolbox talks in a construction site was carried out, based on interviews, observations, and documents. Results indicated that the toolbox talks were strongly aligned to the principles of DfRP, suggesting that they were valuable investments of the participants´ time, probably being regarded as cost-effective by managers. This finding also sheds light on why the toolbox talks, which have a long history of application in the construction industry of several countries, are regarded by prior studies as a best practice.

Keywords: resilient performance, toolbox talks, design.

1. Introduction

Resilient performance (RP) is a functional property of complex socio-technical systems, playing a role in their safe and efficient functioning under expected and unexpected conditions (Hollnagel, 2014). RP emerges from both deliberate design decisions and the self-organization of people without reliance on centralized controls. The portion stemming from deliberate design is referred to in this paper as designing for resilient performance (DfRP), defined as "the use of design principles to support integrated human, technical, and organisational adaptive capabilities" (Disconzi and Saurin, 2022). For instance, DfRP can involve the provision of human (e.g., workers on standby), technical (e.g., extra inventories), or organizational (e.g., redundant quality checks) slack resources that can be called on times of need (Fireman et al., 2022).

DfRP creates conditions conducive to self-organization and is often implicit in organizational routines, not being a one-off activity but rather occurring continuously as the socio-technical system evolves (Disconzi and Saurin, 2022). In the realm of practices that contribute to DfRP, this paper explores the role of toolbox talks (also known as toolbox meetings) in a construction site. The toolbox talks usually occur daily, mainly at the beginning of the work shift or during breaks (Jeschke et al., 2017). These meetings typically last from five to ten minutes, involve workers and supervisors (these normally lead the meetings), and address workplace safety, occupational hygiene, ergonomics, and work procedures (Olson et al., 2016). All workers involved in the construction site attend the meetings (Kaskutas et al., 2013). As such, toolbox talks are deliberately designed, even though their everyday occurrence is always unique, displaying social interactions that reflect the local circumstances.

Furthermore, toolbox talks are one of the so-called best practices of safety management in construction sites, being correlated with low accident rates (Bridi et al., 2021). However, it is necessary to understand how these best practices are implemented and under what conditions they are effective, rather than only identifying what the best practices are (Bridi et al., 2021).

It is also worth noting that the toolbox talks are representative of a broader family of reflective meetings concerned with making sense of systems performance, being either prospective or retrospective (or both, occasionally). Other examples of reflective meetings are the daily safety huddles in hospitals, the morbidity and mortality meetings in hospitals, ward rounds, briefings and debriefings in project management, and the resilient performance enhancement toolkit. This last practice is the only explicitly discussed from a resilience engineering perspective, by Wahl et al. (2022) in a healthcare context, and by Martins et al. (2022) in construction sites.

2. Principles of DfRP

Table 1 presents the principles of DfRP adopted as a basis for this study. These principles were developed by Disconzi and Saurin (2022) based on a Delphi study with 27 experts from nine countries. The purpose of developing these principles was twofold: supporting work system designers interested in strengthening the RP of the (re)designed systems; and serving as a basis for the evaluation of existing systems, shedding light on their strengths and weaknesses from the resilience engineering perspective.

The principles recognize RP as a dynamic and functional property of socio-technical systems, besides acknowledging technical, social, and organizational factors that support RP. This contrasts with the narrower perspective of design for resilience in the context of technical infrastructures (e.g., Chatterjee and Layton, 2020).

Table 1. Principles of DfRP (Disconzi and Saurin, 2022).

3. Method

The studied toolbox talks were carried out in the construction of a school in Norway. The project includes the construction of two buildings, a school building of 14,800 m2 and a rehabilitation center with approximately 10,000 m2. The construction activities started in April 2021 and are expected to end in April 2023. The project workforce includes a project manager, a site manager, ten administrative workers, and 130 operatives, who work on-site from Monday to Friday from 7 am to 3 pm. The construction company has over 30,000 employees in 11 countries and develops several types of projects, such as highways, airports, hospitals, buildings, homes, schools, shopping centers, and tunnels.

Data collection involved: (i) non-participant observations of 15 meetings, totalling 7 hours; (ii) documentary analysis of project schedules, standardized operating procedures, and written records of the decisions made in the toolbox talks; and (iii) semi-structured interviews, totalling three hours, with the site manager and two workers. The interviews were based on an interview guide that addressed the description of the interviewees' everyday activities and how the toolbox talks contributed to these activities. Data collection stopped when the researchers perceived that data saturation had been achieved. Data from all sources were subjected to a template analysis (Cassel and Symon, 2004), using the seven principles of DfRP as a starting point to the identification of relevant excerpts of text. The template analysis was conducted by the first author, and her codifications were subsequently reviewed by the other authors.

4. Results

The toolbox meetings occured daily, starting at 7 am in the lunchroom and counting on 60 participants approximately (Figure 1). The site supervisor guided the discussions, and the leaders and workers of the different crews were present such as diggers, electricians, plumbers, and concrete. The observed meetings lasted on average 13 minutes, ranging from 9 to 15 minutes. The meetings were divided into two major parts. Initially, there was an overall toolbox talk with workers from all construction zones (Figure 1, on the left), and then there were meetings specific for each work zone, called after-meetings. These subsequent meetings included only the workers related to the discussed construction activities and they could occur in places other than the lunchroom. Figure 1, on the right, shows workers from the concreting production crew who remained in the lunchroom for the after meeting, while the electricians went to the locker room to hold their own after meeting.

Table 2. Evaluation of the DfRP principles in the toolbox talks

5. Conclusion

This study revealed the utility of the seven principles of DfRP for understanding daily toolbox talks in a construction site. Findings indicate that those talks are strongly consistent with the DfRP principles, providing piece of evidence that they are valuable investments of the participants´ time, probably being regarded as cost-effective by managers. Indeed, the after meetings were introduced as a result of the perceived success of the overall meeting that addressed all construction activities, and also because this meeting did not allow the necessary time for discussing details of each work zone. As such, the alignment of the toolbox talks to the DfRP principles sheds light on why they are regarded as a best practice in the construction industry.

As a limitation, the present study did not investigate how the decisions made in the toolbox talks were actually implemented in the construction site, and what the implications were for performance dimensions such as cost, quality, safety, and productivity. It is possible that this further investigation reveals short comings in the toolbox talks that were not captured by this study.

In the sequel of this research project, other practices supportive of DfRP will be investigated, comprising not only other types of reflective meetings but also practices involving teams that are activated in case of need – e.g., rapid response teams in hospitals and help chains, a standardized routine for coping with abnormalities in manufacturing plants. Results from this expanded investigation will explore the general utility of the principles and set a basis for the development of a protocol for assessing the use of the DfRP principles in socio-technical systems of different domains. This unit of analysis targeted by this protocol will be the socio-technical system rather than the DfRP practices. The assumption is that, in a given system, there will be several DfRP practices that interact with each other, along with interactions with other, designed or not, social and technical artefacts. The protocol will include maturity levels of adopting the principles, consisting of a new approach for resilience assessment. The protocol application is expected to shed light on how existing safety and production management practices can be improved in order to explicitly and systematically support RP through work system design.

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A Joint Activity and Coordination Approach to Graceful Extensibility in Emergency Events

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Events that challenge system's adaptive capacity boundaries depends on coordination between the parties involved to sustain adaptability. This study focuses on analyzing the coordination between different organizations in emergency events. The study context was an emergency drill involving 6 different organizations. The data collected through the observations, interviews, video, and audio recordings were analyzed and a FRAM model was developed considering (i) performed functions to respond to the event; (ii) function´s aspects; (iii) unit´s boundaries; (iv) coordination between units; and (v) opportunities to improve the coordination. The event response modelling identified 54 functions and four were identified as stretching points of the performance envelopes. In this accident scenario, variabilities in how explicitly the expectations between teams were signalized led to a mobilization of resources that did not match with the necessity of the situation. The results indicated that coordination devices are updating mechanisms of common ground between different teams and organizations, influencing the stretch capacity of the system whenever the system's adaptive capacity boundaries have been reached.

Keywords: Graceful Extensibility, Joint Activity, Coordination, Resilience, Adaptability, Emergency Events.

1. Introduction

Systems whose interactions have residual uncertainties due to permeating complexity are part of an adaptive universe in which adaptive capacity emerges from the interactions between units in these systems (Leveson, 2002; Woods, 2018). The theory of Graceful Extensibility puts that complex systems are formed by Tangled Layered Networks (TLN), composed by a myriad of interdependent units with adaptive capacities. These units must coordinate with each other to sustain adaptability in face of threatening conditions to their existence. However, they are spread across multiple vertical and horizontal levels with different local demands in a constantly changing environment, implying that the boundaries of interdependency and adaptive behavior between these units are dynamic and not clear (Woods, 2018).

When facing events that challenge system's adaptive capacity boundaries, a shift in system's regime of performance must occur and new elements must be mobilized to sustain adaptability. Because these elements are part of an interdependent network and due to scarcity of resources, no single unit has enough Capacity for Maneuver (CfM) to respond these demands and handle its risks of collapsing in this shifting zone alone. Thus, coordination plays an important role so different units can support each other. In TLN, coordination is based on a common ground between units, which allows interpredictability between them during challenging events (Klein et al., 2005). Without coordination, local successes of certain units may interact in unpredictable ways with the boundaries of other units, with potential jeopardizing effects (Bergström & Dekker, 2014).

There are many examples of TLN and one of them is the emergency response services of a city. Fire service, Civil Defense, ambulance services, and others, must operate in a coordinated manner since each of them is responsible for dealing with one aspect involving an emergency scenario (DARWIN, 2018). When a certain event surpasses the adaptive capacity of one or more services, they must stretch their capacity of dealing with it by coordinating with each other

(Woods, 2018). This includes mobilizing resources and relaxing unit's individual goals in favor of a broader objective.

Understanding how common ground between these system's unit is updated and repaired whenever is broken can provide improving opportunities for these services in relation to coordination and adaptation in challenging events. It allows understanding how their boundaries dynamically interact and how system level behaviors emerge from these interactions. Therefore, this paper has the following research question: How to improve coordination between different organizations in emergency events? And the aim of the study is to identify unit´s organizational boundaries and analyze coordination between emergency services.

2. Networks of Adaptive Units

Whenever a unit of a complex sociotechnical system is not able to handle a challenging event, it must adapt its functioning, so it does not collapse (Hollnagel et al., 2022). The theory of Graceful Extensibility was coined to explain how units that are part of an interdependent network stretches their adaptive capacity and sustains it in face of events they were not initially capable of handling. The theory is structured in form of ten proto-theorems, divided into three subsets, and is based on the assumptions of scarce resources and continuous changes, demanding adaptive units to manage their risk of collapsing by coordinating with other units and outmaneuvering constraints (Woods, 2018).

Systems must change its regime of performance by mobilizing new resources, new strategies and changing priorities whenever a threaten event forces them to collapse. According to the second subset, the networks of adaptive units in these systems depend on coordination across other units to stretch their adaptive envelope in face of challenging events. However, variabilities in coordination may lead a unit to adapt in such a manner that jeopardize the adaptive capacity of another unit. This may occur whenever the units have access to different data, breaking down the common ground (Klein et al., 2005).

3. Joint Activity and Common Ground

Joint Activity is when two or more people work together towards a common goal (Klein et al., 2005). A joint activity in only possible due to existence of Common Ground between the parties involved. This is the process of communicating, updating, and repairing knowledges, beliefs, and assumptions in common. Common Ground can be divided in three categories: the Initial Common Ground refers to previous knowledge shared between the parties involved in the activity; the Public Events So Far refers to the process of communicating the storyline of the activity; and the Current State of the Activity is all the information that shows what is happening during the activity (Klein et al., 2005).

Breakdowns in common ground are inevitable due to the dynamic nature of complex systems. Whenever they happen, the parties involved in the activity must signalize using the so-called coordination devices. These devices may be an agreement type, based on explicit forms of signaling (e.g., language; signs), a convention type, based on prescriptions that pre-stablishes how the parties must interact; a precedent type, derived from precedents established during an ongoing activity; or a salience type, built on the arrangement of the workspace of an ongoing work (Clark, 1996).

Understanding coordination in interdependent network of adaptive units must be based on the interactions between these elements. The Functional Resonance Analysis Method (FRAM) presents itself as a feasible method to understand coordination based on the couplings between functions (Henriqson et al., 2022). This allows improving opportunities to be suggested regarding responses of emergency services of a city in challenging scenarios.

4. Method

4.1 Study context

This study was conducted during an emergency drill organized and conducted aiming at understanding how coordination between different emergency services occurs in face of a multiple victims' accident scenario. The scenario was a car accident involving a passenger vehicle and a fuel truck in one of the main avenues in one of the biggest cities of Brazil. The truck was filled with water to simulate a fuel leakage to a nearby river and seven undergraduate students from medical school were made up and played the role as victims. This type of accident was chosen to be drilled since it is an unusual accident in the context of the city and used to validate the city's emergency response plan.

When the drill started, an emergency call was made to the Fire Service. As a challenging element, their command center was only informed about a car that hit a fuel truck. They were not informed about the precise number of victims and their health conditions. Based on this information, the Fire Service mobilized other organizations part of the emergency services to attend the accident. These other organizations were responsible for traffic management, environmental emergencies agency, pre-hospital care, emergency coordination and accident scene isolation. None of them knew that it was a drill until they arrived at the scene. The drill lasted 1h and ended as ambulances left the scene simulating conducting the victims to hospitals.

4.2. Data collection

Data were collected through non-participant observations, interviews, and video and audio recordings. Observations totaled one hour, and notes were made in three observation sheets. Non-structured interviews were conducted with the members of the two firefighters' teams that responded to the drill, aiming to understand why the response was conducted the way it was. Also, two debriefing meetings occurred, one right after the drill, and the other a week later. Supervisors of the organizations involved in the drill were present at the second debriefing and explained the actions of their organizations during the drill, as well as their constraints and challenges. At this time, the FRAM modelling was presented and discussed. The meetings and the interviews totaled seven hours. The videos of the drill were recorded using two drones and two GoPros. Besides, radio communications of the fire service, traffic management organization, municipal guard and ambulances service were recorded using voice recorders. Then, the videos and the audio were later synchronized. In total, four hours of radio communications were recorded.

4.3 Data analysis

The data collected through the observations, interviews and video and audio recordings were analyzed considering the main categories: (i) performed functions to respond to the event; (ii) function´s aspects; (iii) unit's boundaries (adaptative capacity and capacity of maneuver); (iv) coordination between units (common ground, communication, and coordination devices); (v) opportunities to improve the coordination. The FRAM (Hollnagel, 2012) was adopted to model the operation, to present the functions, the coupling between functions, and the activation of other units to support the event response when achieved its boundaries.

5. RESULTS AND DISCUSSION

5.1 Event response modelling

In total, 54 functions were identified being 21 related to the firefighters, 4 related to the Civil Defense, 10 related to the ambulance services, 8 related to the traffic management organization, 5 related to the environmental services, and 4 related to the metropolitan police. The functions <Transfer Victims to Ambulances> and <Update Event Information> were shared between firefighters and paramedics. Four functions were identified as stretching points of the performance envelopes of the organizations: <Request Fire Truck 2 Support>, <Request Ambulance Service>, <Request Private Ambulance Support>, <Mobilize Traffic Control Vehicle Support>. For purposes of illustration in this study, the analysis of coordination focused on the function <Request Fire Truck 2 Support>.

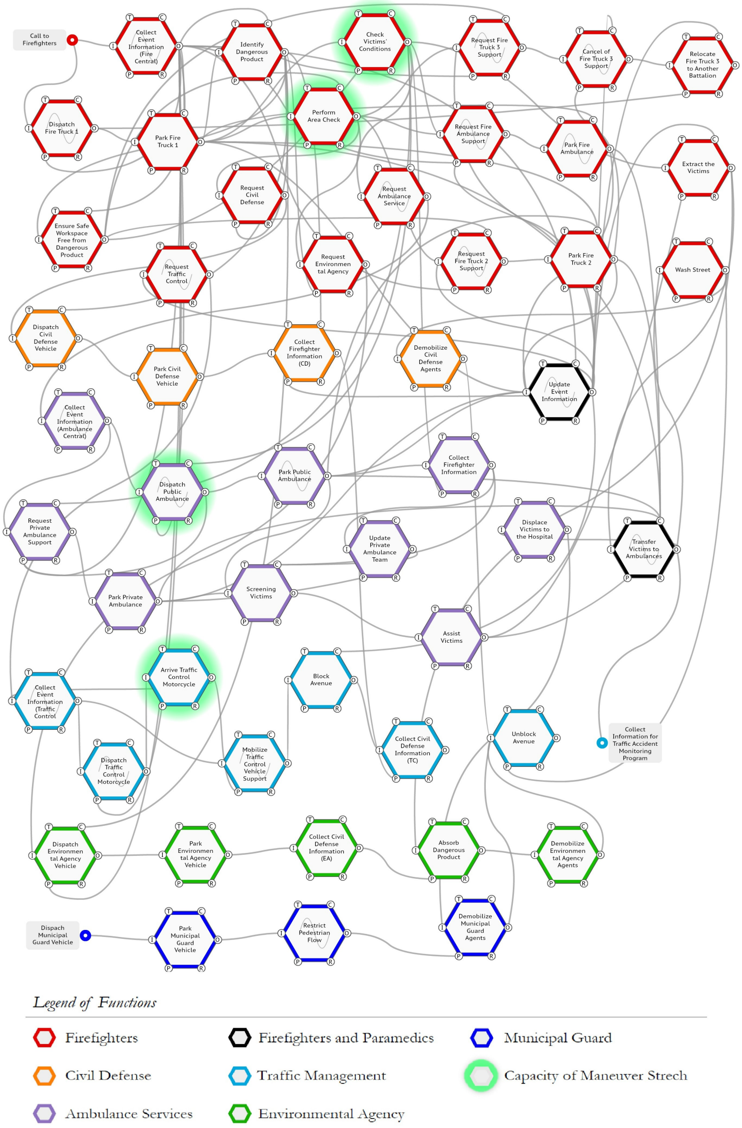

Figure 1 – Modeling of Emergency Drill

5.2 Firefighters' Coordination for Stretching Adaptive Capacity

After <Park Fire Truck 1> , its team <Perform Area Check> and <Check Victim's Conditions>. This allowed them to know that the leakage was under control and the priority should be <Extract the Victims> from inside the vehicle. The team leader realized there were not enough firefighters in his team to do it safely and requested support of a rescue specialized fire battalion. This request was done via radio using internal codes of the firefighters. Although both fire brigades were at the same radio frequency, the command center bridged the communication between the two them. A few minutes later, the second fire brigade arrived and helped extract the victims. Because no information about the type of product that leaked or about the level of control of the situation was given, the second fire brigade anticipated the worst scenario and mobilized their highest-level chemical protection suit. Meanwhile, the first fire brigade started cutting off the roof of the vehicle.

This lack of human resources demanded the first fire brigade to shift its regime of performance to cope with a situation that they could not sustain for much longer and raised the necessity to coordinate with another unit of the system. Since repairing the common ground of the units influences joint activity effectiveness, and there is always a difference between the work-as-disclosed and what is happening (Patriarca et al., 2021), it is argued that variabilities regarding the update of Public Events so far and the Actual State of Activity, gave rise to a margin of error between the expected CfM and the actual CfM of the second fire brigade. This was noted in the mobilization of the chemical protection suit by the specialized fire brigade due to lack of updating between the firefighter's teams.

The process of updating the Public Events so Far and the Actual State of Activity between units differs when the units are already coordinating in a joint activity or are yet to start due to a challenging event. In the latter, there must be a shift in how the updating process occurs to mobilize another unit. This shift extends the boundaries of adaptive units to a communicative dimension that is influenced by how common ground between units is updated and repaired whenever needed. Improving coordination must contemplate the influence of how intentions and necessities are signalized using coordination devices. In this accident scenario, variabilities in how explicitly the expectations were signalized to the second fire brigade led to a mobilization of resources that did not match with the necessity of the situation. This robustized part mobilized of the interdependent network may have increased the potential of a sudden collapse due to unforeseen interactions in other parts of the interdependent network (Woods, 2018). Thus, in this event, the command center may leverage from guidelines of what information should be collected from the first brigade to arrive on scene and be transmitted to the requested support, dampening variabilities in this agreement type of coordination device.

Conclusion

In emergency response scenarios, coordination between different teams and organizations involved in a joint activity is necessary to stretch the capacity of the system to deal with the situation. The mobilization of the appropriate support is necessary, so the system does not collapse unexpectedly. This study presented an analysis of the second subset of proto-theorems from Graceful Extensibility theory based on how common ground is updated and repaired through coordination devices, identifying opportunities to improve coordination between different organizations, which allows extending system's adaptive capacity when surprise events arise and challenge its boundaries.

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Bound by Tradition? FRAM as an Instrument for Organisational Diagnosis in Literature and Practice

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Organizational Diagnosis aims at understanding organizations in order to evaluate or improve. Organizational Diagnosis as a method is known to work & organizational psychology. The growing complexity of sociotechnical systems further increases the usefulness of Organizational Diagnosis. However, the actual use of such instruments seems to lack behind. The functional resonance analysis method can be understood as an Organizational Diagnosis tool but is rarely discussed or applied in the psychological technical literature. Competition from other methods within psychology can be ruled out. The article therefore considers methodological reasons and matches functional resonance analysis method against typical values and criteria of qualitative research which are prominent in psychology. The analysis reveals areas of compliance and hints at fields of improvement. A major difference is that functional resonance analysis method does not center around the individual but around the process. This might constitute a serious boundary for a stronger reception and proliferation of the functional resonance analysis method for the purposes of Psychological Organizational Diagnosis.

Keywords: FRAM, qualitative research, psychological organizational diagnosis, work & organizational psychology, sociotechnical systems, complexity.

1. Introduction

"Organisational Diagnosis" (OD) comprises any method for gaining an understanding of an organisation, often focusing on patterns of attitudes and behaviour of employees with respect to their organization. The variation "Psychological Organisational Diagnosis" (POD) is established in the German technical literature on Work and Organisational Psychology as "Organisationsdiagnose" (Büssing, 2007; Marek, 2010; Kauffeld, 2019; Nerdinger, 2019; Schuler & Moser, 2019; Kluge, 2021; Krumm, Schmidt-Atzert & Amelang, 2021). According to Nerdinger (2019) POD aims at describing and explaining the rule-based behaviour of members of an organisation to illuminate fields of action and prepare organisational development measures. POD deals with diverse topics ranging from culture, work climate, and work satisfaction to work & task analysis. It uses a wide variety of tools from employee surveys to work analysis tools for experts.
As work in organisations becomes more and more complex (Jenkins et al., 2009; Stacey & Mowles, 2016; Braithwaite et al., 2017; Mühlbradt, Speer & Schröder, 2023) there should be a growing request for adequate methods for analysing complex sociotechnical systems (Mühlbradt, Shajek & Hartmann, 2022). Nerdinger (2019, p. 152), however, points out that until now OD received little attention in Psychology. He suspects dominant, more popular tools from other disciplines as an explanation.

2. Functional Resonance Analysis Method

The functional resonance analysis method (FRAM; Hollnagel, 2012) is, following the definition of the term POD above, undoubtedly such an instrument. Its focus on the richness of human experience at work is encapsulated in the work-as-done-principle and the behaviour-shaping aspects of functions. The Efficiency-Thoroughness-Trade-off (ETTO-principle) is illuminating rule-based behaviour. FRAM is especially well-suited for complex sociotechnical systems (Verhagen et al., 2022; Sujan et al., 2023). Sujan et al. also differentiate between two varieties of usage of FRAM: computational and reflexive. The latter one clearly qualifies as a social research instrument.

Considerable usage of FRAM across countries and sectors is documented (Patriarca et al., 2020; Salehi, Veitch & Smith, 2021; Diop, Abdul-Nour & Komljenovic, 2022). One would therefore assume that FRAM would also be known to the technical literature in Psychology, but this is obviously not the case. It is not presented in the German technical literature on POD referred to in the first paragraph, although some of those books were published only recently. A systematic literature research conducted on the search terms "FRAM" or "resilience engineering" or "functional resonance analysis method" in peer-reviewed psychological journals for the years 2019-2022 resulted in 0 findings in German and 8 findings in English. All 8 papers were published in just one journal: Cognition, Technology & Work. This journal describes itself as follows: "Cognition, Technology & Work focuses on the practical issues of human interaction with technology within the context of work …" (https://www.springer.com/journal/10111, assessed February 2, 2023). This finding might invoke the idea that the FRAM was inextricably tied to Human-Machine Interaction which is not the case. It is of course tied to sociotechnical systems but not in the confined meaning of the interfaces of engineering psychology. Unger et al. (2022) and Speer et al. (2022) are first to publish articles on the application of FRAM in non-technical real-world case studies in German, but in both cases, outside of the psychological literature.

Are there then alternative instruments in work and organisational psychology available to gain knowledge about complex systems? One school of thought centred around the Swiss psychologist Eberhard Ulich has the sociotechnical systems theory as foundation for work and task analysis and design (Ulich, 2011, 2013). This school is best known for its so called "Mensch-Technik-Organisation (MTO)- Konzept" (Man-Technology-Organisation) aiming at a "joint optimization" of technical and social subsystem. Various instruments have been developed with this framework and it is considered by some as the most complete methodology in the German speaking area (Latniak, 1999). Ulich speaks of MTO as "ganzheitliche Analyse von Unternehmen" (holistic analysis of companies; Ulich, 2013, p. 10). Contemporary German publications on psychological work analysis and design still refer to this framework (e. g. Mustapha & Schweden, 2021). Mustapha & Schweden also demand methods that fit the growing complexity of work (ibid, p. 4). It remains, however, unclear whether this methodology is thought to go beyond the individual and directly address complex systems (ibid, p. 39 ff.). It is therefore reasonable to conclude that no alternative instruments are available for POD of complex systems at least in the German language area.

3. Values and criteria of qualitative research

Are there methodological reasons to discard the FRAM from the point of view of psychology? Mayring (2016) formulates values and quality criteria for qualitative research methodology in his influential book. His approach goes well beyond the classical criteria (objectivity, reliability, validity) and aims at establishing genuine principles and quality criteria for qualitative methods. With the experience of FRAM-application in the German healthcare sector it seems feasible to match the FRAM against Maying's values and criteria. Figure 1 depicts on the left in short form the major ideas as laid out in his 2016 book. On the right a judgement is made whether FRAM complies or does not comply or might be adaptable to match. There are strengths (green), weaknesses (red) and potentials (yellow) for FRAM.

Major values and quality criteria of qualitative research	FRAM match
Proximity to everyday life	compliance
Necessity of thick description of case	compliance, adaptable
Focus on human subjects	non-compliance
Rule-based procedure and documentation	compliance
Necessity and validation of interpretation	adaptable
Context-specificity and restrained generalizability	compliance

compliance (green) adaptable (yellow) non-compliance (red)

Figure 1: FRAM and the values and quality criteria of qualitative research

FRAM is certainly close to everyday life (WAD, frontline staff, field over laboratory). It is rule-based with written manuals and a software. It is also context specific and does not assume that findings could easily be generalized. The set of aspects of functions allows for a rich description.

There are also fields of improvement. Ulich´s MTO calls for "Analyse der soziotechnischen Geschichte" (analysis of sociotechnical history; 2013, p. 10). Mayring (2016, p. 34) speaks of "Historizität" (Historicity) as a guiding principle for research. In a current field study in healthcare, we therefore include the framework provided by the SEIPS-Modell (Carayon et al., 2020) for questions on changes and events prior to the main interviews on functions.
Validation of interpretation is another topic for improvement. Sujan et al. (2023, p. 9) see a need for a "structured reporting guideline" for the FRAM. Our own group are currently working on a concept for workshops with frontline staff to communicate and discuss models and findings and generate ideas on coping with variability.
Despite all this, the red field signals a major difference. According to Mayring humans are starting and ending points of all research and intervention. The MTO-approach by Ulich subscribes to this view. Humans do also play an important role in the FRAM as they provide essential information. However, the overall priority is to model, understand and ameliorate processes (sociotechnical systems). It might be that it is this feature of FRAM that alienates work and organizational psychologists. As FRAM matches most values and criteria and is amendable in several other respects, that alone should not constitute and perpetuate a boundary to the recognition and use of a viable instrument. The FRAM-community is called upon to provide arguments and examples of good practice to initiate and support this communication.

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Side-Effects of Resilience Engineering Interventions: A Review

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This paper presents the results of a systematic realist review describing the side effects associated with the implementation, activation, and maintenance of interventions concurrent with resilience engineering theory. As with any intervention in complex socio-technical systems, it was considered plausible that resilience interventions could also generate unintended effects outside of their intended purpose. In the final sample of 46 papers found using the PRISMA process, 20 described side-effects. Side-effects were aggregated under four themes emerging from the literature: over-reliance on resilience engineering, downsides of autonomous action, unintended consequences of system adjustments and costs of coordination. Papers drew from range of domains and described theoretical, ethnographic (from case-studies) and experimental work. The majority of side-effects reported were negative confirming that trade-offs are commonplace in resilience engineering interventions and need careful consideration before implementation. Although arguments for resilience engineering remain compelling, gaps in the literature could be identified. Limitations of the review method were also discussed.

Keywords: PRISMA, resilience engineering, side-effect, systematic review, safety, realist, socio-technical

1. Introduction

This paper describes the side-effects of interventions associated with the implementation and activation of mechanisms serving resilience engineering (RE). The over-arching goal of the realist review underpinning this work was to identify the mechanisms and impact of resilient capabilities and performance in complex socio-technical systems. This paper contributes to informing intervention choices through the explicit identification of side-effects as a boundary of RE affecting safety.

RE describes a particular formulation of a socio-technical system with its own set of attributes and capabilities which purpose is to "[generate appropriate] stability or change to the requirements of the environment, in terms of planning, enabling or accommodating of change to meet current and future requirements of the operating environment" (Sundström and Hollnagel, 2006; cited in Patriarca, Bergström, Di Gravio, & Costantino, 2018). While arguments for RE are compelling, it can be tempting to see RE interventions as being universally positive. However, potential unintended consequences to well-meaning interventions should not be ignored.

2. Method

A realist review was performed to understand "what works, for whom, how, in what circumstances and in what respects" (Pawson, 2006) following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology (Liberati, et al., 2009). PRISMA has been used previously in the RE domain (e.g. Iflaifel, Lim, Ryan, & Crowley, 2020).

Inclusion & exclusion criteria

The database search term used to identify papers was: "resilience engineering" AND socio$technical AND measure. The inclusion of "measure" was intended to increase the return of papers reporting empirical research. The selection criteria were adapted from a previous systematic review in RE (Righi, Saurin, & Wachs, 2015). Full papers, articles, books, and book chapters in the English language were included. Excluded during cleaning were isolated abstracts, book reviews, tables of contents, duplicates, front matter, indexes, panel discussion transcripts, posters, reference lists and subject lists. Papers on individual or personal resilience were also excluded.

A representative model of RE was used to evaluate whether candidate papers spoke to a recognizable variant of RE from Huber & Kuhn (2017; 2019). This model distilled key aspects of RE alongside specific developments for operationalization. The model describes an inductive view of resilient performance focusing on the mechanisms, and not a particular outcome profile.

Search strategy and study selection

The database and journal search strategy built on two previous systematic reviews in RE from Righi, et al. (2015) and Bergström, van Winsen, and Henriqson

(2015). Five databases used by Righi, et al. (2015) were unavailable. One database (Scopus) was added for a total of 14 databases: ACM Digital Library, ACS Journals Search, Emerald Insight Journals, IEEE Xplore, IOPscience, Nature, Royal Society of Chemistry, Science (Science Magazine), Science Direct, SpringerLink, Wiley Online Library, Sage Publications (Sage Premier), Taylor & Francis Online, and Scopus. No date constraints were applied to the database search that generated 714 hits from April 2006-April 2022. This number reduced to 635 after initial cleaning against exclusion criteria. A second source, also used by Righi, et al. (2015), were the proceedings of 2nd-8th Resilience Engineering Association (REA) symposia, adding 84 hits. The combined total was 719 papers. Initial results cleaning, paper compilation and screening were performed by one of the authors (Owen). This author also performed title and abstract screening for database results papers and REA symposia papers to produce a short list of 57 candidate papers (databases n=26, REA n=31). Full-text screening was performed alongside results synthesis giving 45 inclusions and 12 exclusions. The inclusion and exclusion judgements were randomly assigned to the other authors for cross-check. Any discrepancies were resolved through discussion. This led to the readmission of one paper giving a final total of 46 papers.

Data extraction and analysis

Papers were analyzed using a modified version of the IMOC classification scheme. Aspiration (A) and fundamental mechanism (FM) categories were added to the basic intervention (I), [front-line] mechanism (M), outcome (O), and context (C) (Saul, Willis, Bitz, & Best, 2013). The definition of side-effects was adapted from the Oxford Learner's Dictionary (Oxford University Press, 2023) for RE as follows: Unintended effects of RE outside its intended purpose. Side-effects were extracted from of key statements identified under the IMOC analysis process based on those describing any negative effects or tensions associated with RE. Statements were kept in their original form where possible, but some were edited for brevity and/or annotated for clarity. Five papers did not contain side-effects and were omitted from further analysis. Thirty-two statements describing side- effects were identified from 20 papers.

3. Results

Results were collated around emergent themes from the side-effects identified. The breakdown of domains represented was as follows: healthcare (6), general (5), aviation (4), nuclear (3), critical infrastructure (1) and transportation (1).

Over-reliance on RE

An irony of resilient capabilities' successes is that they can lead to systems becoming over-reliant on RE for routine operations. Compensatory and adaptive strategies can mask underlying systemic issues, ultimately introducing brittleness and exposing a system to failure. During the COVID-19 pandemic, Disconzi and Saurin (2022) estimated that human cost of sustaining adaptation in this extreme event was high. Berg, Akerjordet, Eksted, and Aase (2018) noted that reliance on front line adaptive capacity can also lead to systemic issues being ignored. Amalberti (2013; cited in Patriarca et al. 2018) questioned whether resilience was a legitimate target for systems in healthcare due to a shift to dependence on resilience for everyday operation. Amalberti identified a risk that resources could be wasted in developing operational adaptations that could otherwise be used to mitigate clearer threats. Moreover, Smaggus (2019; cited in Disconzi & Saurin, 2022) stated an ethical position that "people's self-sacrifice must not be normalized as normal work".

Downsides of autonomous action

A principal mechanism cited in RE literature is action performed autonomously by system units to adapt to and compensate for prevailing conditions (e.g. Huber & Kuhn, 2017). Several authors identified unwanted side-effects associated with autonomous action and self-organization. At system level, autonomous adaption can mask a drift towards a failure boundary (Wears, Perry, & McFaul, 2006) and can obscure underlying systemic issues that may otherwise only be revealed following an accident (Da Mata, et al., 2006). Da Mata et al. (2006) described that permissive organizations can allow unchecked adaptations optimizing for local goals to pull the system into risk. In healthcare, Back, Anderson, Duncan, and Ross (2015) identified routine violations based on individuals' misguided safety practices, resulted in unsafe workarounds within one shift that were unknowingly inherited by the next as latent conditions for error. Woods (2018) summarized that "initiative can run too wide when undirected, leading to fragmentation, working at cross purposes, and mis-synchronization across roles".

Unintended consequences of system adjustments

Making adjustments to systems that aim to enable resilient performance is "not a neutral action" (Saurin, 2015). While this observation was made in the context

introducing system slack, other authors concur. Berg, et al.(2018) unintended consequences from micro-adjustments due to complex interactions and non-linearity. Alternatively, large, transformative adjustments in healthcare were potentially implemented at the expense of other units' capabilities (Son, Sasangohar, Rao, Larsen, & Neville, 2019). Adjustments in air traffic management can come at a cost of efficiency in other key performance areas (Stroeve, van Doorn, & Everdij, 2013).

Saurin (2015), Disconzi and Saurin (2022) and Lalouette and Pavard (2008) discussed adjustments to loosen coupling in systems and give time for performance adjustment (Saurin, 2015). A drawback of introducing slack was increased opacity and complexity in systems and the possibility of new errors. System opacity can hide small changes and the emergence of hazards, while system complexity contributes to subtle and non-linear effects of latent hazards that are difficult to foresee. Excessive slack can be wasteful, and the maintenance of systems providing slack may be costly. Ironically, slack may introduce brittleness under dynamic conditions, especially where it is generated by physical barriers (Hollnagel, 2004; cited in Saurin, 2015). As slack acts to absorb disruptions it also masks their effects, reducing the motivation to resolve underlying issues (Liker 2004; cited in Saurin, 2015). It may not be obvious to managers that the system is being subjected to stress or disruption resulting in a gap between perception and practice which can also impede organizational learning (Lalouette & Pavard, 2008).

Monitoring can enhance learning and anticipation, but the cost of tracking small changes can be information overload and challenges in determining what cues to attend to (Saurin, Righi, & Henriqson, 2013). Learning from monitoring past performance can misdirect attention in complex and variable environments as fixating on common past errors may be inappropriate in the future (Patterson, Woods, Cook, & Render, 2007). Sensitivity to novel deviations emergent in such environments may also be reduced as attention is elsewhere. Rosness, Haavik, and Evjemo (2015) identified a similar issue in the possibility of imaging technology used by surgical teams misdirecting attention away from other phenomena not considered during equipment design.

Takahashi, Karikawa, and Sawasato (2019) reported on simulator experiments examining the effects of the availability of procedures on blackout handling in nuclear. Their results showed that performance without procedures gave improved outcomes (i.e., fewer blackouts) in unexpected abnormal scenarios without procedures, but participants experienced greater frustration and worse outcomes when responding to expected abnormal scenarios.

Woods (2017; cited in Woods, 2018) theorized that seeking performance improvement in units far from saturation can affect their performance near6 titre livre saturation during disruptions. This side-effect was attributed to the consumption of resources and development of capabilities for normal operations leaving less energy for revising and updating operational models in disruptive events.

Costs of coordination

Several papers highlighted the cost of coordination horizontally between stakeholders and vertically through management structures associated with resilient responses. Citing Klein (2001), Costa, Voshell, Branlat and Woods (2008) noted that coordination cost rises as more people are involved. Richters, Schraagen and Heerkens (2015) cited Hayes (2012) that while “a diversity of perspectives to ensure the timely identification of safety issues” is important, this comes at a cost of coordination of activities and integration of perspectives. Igbo, Higgins, Dunstall and Bruce (2013) noticed this effect in airline operation control centers (AOCCs). Lay and Branlat (2013) noted that seeking to expand resilient capabilities themselves stresses resources, creates trade-off challenges, and that requisite expertise may be a key resource in short supply.

Although resilient responses are synonymous with polycentric governance (Woods, 2018), autonomous action and distributed decision-making (Huber & Kuhn, 2017), units may still require senior management support. Coordination through vertical channels can become difficult as information requirements may be different and greater during disruptions (Walker, Deary, & Woods, 2013). An organization may “go solid” while wrangling information during disruptions (Cook and Rasmussen, 2005; cited in Walker et al. 2013).

A practical example of coordination challenges was provided by Mendonça and Wallace (2006) describing the restoration of electricity to Manhattan in the wake of the 9/11 attacks. An innovative solution to route shunts along the curbside and through street intersections was efficient but came at an increased coordination cost with other organizations, complicating work.

4. Discussion and conclusions

This paper collated side-effects of resilience interventions from RE literature under four emergent themes: over-reliance on RE, downsides of autonomous action, unintended consequences of system adjustments, and the cost of coordination. These side-effects gave more nuance to understanding RE boundaries. The case studies that formed the basis of several papers in this review highlighted that side-effects are experienced in real-world settings both where

RE capabilities emerged over time (e.g. EDs) and where they were explicitly introduced (e.g. FLARE process; Lay & Branlat, 2013). Despite the apparent benefits, RE interventions can be burdensome on a workforce especially where systems have become reliant on resilient capabilities for routine operations.

A lack of expected or actual outcome data made it difficult to determine what RE capability effects are on overall system performance in different conditions. Only one paper (Takahashi et al., 2019) presented experimental findings enabling comparison between resilient and conventional non-RE interventions. An observation is that papers describing RE phenomena may be subject to "what you look for is what you find", as alternative explanations for observed phenomena are rarely, if ever, described in the dataset informing this review. This systematic review was limited by database search terms focusing on RE. No results were returned on community resilience or spontaneous volunteering, which may have given further insight to the side-effects of mechanisms recognizably compatible with RE theory.

This review highlights that safety practitioners must be mindful to balance the costs and benefits of RE interventions as they are not neutral. Arguments for RE remain compelling for complex systems, and knowledge of side-effects can help inform the suitability and viability of RE interventions for a given application.

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A graph with a thousand edges: rummaging in complex work varieties

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Context

The increasingly digitalization and technological advances ask for novel perspectives to ensure effective risk and safety management strategies. Socio-technical system (STS) have been advocated as constructs able to achieve a certain goal [1], acknowledging both the symbiotic interactions between technical and human elements. Nowadays, these latter have a dominant informative part, demanding for explicit focus on connectivity and communication aspects. This is where the notion of cyber-socio-technical system (CSTS) can be used to broaden the perspective of systemic analyses. CSTSs are systems where peculiar emphasis is reserved to data-accessing and data-processing activities for and from other socio-technical connected entities [2]. Studying - and even more engineering - resilience in such systems becomes a pressing challenge for these modern systems. On this basis, Patriarca et al. discussed the role of Resilience Engineering in combination with knowledge management, to explore different work varieties, as discussed in the WAx framework (Work-As-X) [3]. The framework is made up of three main elements: (i) the knowledge structure, (ii) the knowledge entities, and (iii) the knowledge dynamics, which are meant to capture diverse knowledge entities [4].

Challenge

The WAx framework embraces the idea of knowledge dynamics to map the creation and/or conversion of knowledge between agents in both tacit and explicit knowledge dimensions. Consequently, a knowledge model can be built with the intention to abandon any trivialized representation of a work setting and to empower analysts in gaining larger understanding of STSs and CSTSs inherent complexity. Nonetheless, in practical terms, these knowledge models become puzzling to manage and to maintain, requiring an additional systematic approach to make them actionable. This aspect in particular represents one of the modelling and computational frontiers of resilience engineering, in line with the 10th REA symposium "Resilience at frontiers, frontiers of resilience".

Contribution

The WAx framework transfers the study of system properties towards the study of the knowledge linked to them, which becomes a big-data management problem. We believe this latter can be tackled as a knowledge graph modelling challenge: a knowledge graph is a model to organize available data based upon the semantic rules of an ontology. Accordingly, a graph $G = (V, E)$ can be defined as a data structure containing a set of vertices V, and a set of edges E connecting them. Each element within the graph is characterized by a label, that classifies each data with an aspect from the common knowledge basis. It is possible to assign properties to each element of the graph with the intention of specifying data values related to certain graph elements. On this basis, a generic vertex in the graph can be defined as:

$$V_n = \left(L_n^V, p_{i\,n}^V\right) \ , \ 0 \leq i \leq I \qquad (1)$$

where V_n represents the n-th vertex in the graph (out of the N vertices), L_n^V is the label to be assigned to the n-th vertex, and $p_{1n}^V, p_{2n}^V, \dots, p_{In}^V$ are the properties that describes n-th vertex. Edges and properties can be defined in a similar way to generate a systematic representation of the phenomenon under investigation.

After the selection of a proper ontology, and the subsequent extraction/classification of data through, e.g., natural language processing algorithm [5], the data from the process under analysis can be converted into a knowledge graph.

Implications

A set of vertices of the graph will represent the system elements to be marked through the agencies mapped via the WAx framework. These latter are all the elements which can generate, transform, or exchange knowledge. On the other hand, any subgraphs of G may represent specific knowledge entities to allow comparing elements (e.g. Work-As-Imagined, Work-As-Done, Work-As-Observed, etc.) across different agents. The interaction between the knowledge entities (i.e., knowledge dynamics) can be explored moving throughout the relationships (edges) connecting nodes (vertices). Such subgraphs can be retrieved by querying the graph and highlighting paths an agent can access offering an unprecedented systematicity to a RE investigation. They permit pinpointing at differences between different work varieties, strengths, ambiguities and weaknesses in the CSTS operations.

This research promotes RE as the discipline the frontier of safety and performance management, and pair it with computational advances to ultimately shorten the distance between its theoretical structure and an actionable proactive safety management.

Keywords

Computational resilience engineering, cyber-physical systems, data-driven resilience, knowledge graphs, knowledge conversions, Work-As-Imagined vs Work-As-Done.

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