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ASSESSING RESILIENCE DURING OPERATIONS:

AN ASSESSMENT FRAMEWORK FOR COMPLEX SOCIOTECHNICAL SYSTEMS

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Master's thesis presented as requisite to obtain the Master's Degree at the Administration and Business Program at the Pontifical Catholic University of Rio Grande do Sul.

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Assessing Resilience During Operations: An Assessment Framework for Complex Sociotechnical Systems

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DEDICATION

To my parents,

for the unconditional love

in every decision I have made in my life.

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RESUMO

Sistemas sociotécnicos complexos possuem, em sua natureza, múltiplos elementos interagindo e que dão origem e incertezas residuais que permeiam o trabalho diário realizado pelas pessoas nesses sistemas. Para esses sistemas funcionarem, agentes estão constantemente adaptando o funcionamento do sistema para responder a ameaças e oportunidades que desafiam o *status quo* do sistema. A Engenharia de Resiliência emergiu como novo paradigma de gestão de segurança operacional com o objetivo de auxiliar esses sistemas a lidar com as incertezas estruturando capacidades adaptativas. Só é possível atingir esse objetivo se houver formas de avaliar a resiliência. Avaliar a resiliência não é um trabalho fácil e deve ocorrer através do entendimento de como o trabalho diário é desempenhado. Esse estudo desenvolveu um *framework* baseado nas *DARWIN Resilience Management Guidelines* para avaliar a resiliência através de observações e entrevistas episódicas, e foi empiricamente avaliado em duas indústrias (Aviação e Óleo e Gás). As instanciações mostraram que as avaliações realizadas contemplaram as interações e relações entre a multitude de elementos da qual a resposta do sistema emergiu. O *framework* pode ser utilizado para níveis organizacionais além dos níveis operacionais, assim como em outros domínios sociotécnicos complexos, para entender como o trabalho diário é realizado.

Palavras-chave: Engenharia de Resiliência, Avaliação da Resiliência, *DARWIN Guidelines*, sistemas sociotécnicos.

ABSTRACT

Complex sociotechnical systems have in their nature multiple elements interacting, originating residual uncertainties that permeates the everyday work performed by the people in these systems. For these systems to work, agents are constantly adapting system's performance to respond to threats and opportunities that challenges the *status quo* of the system. Resilience Engineering emerged as a new safety management paradigm aiming at helping these systems to cope with these uncertainties by engineering adaptive capacities. It is only possible to achieve that if there are ways to assess resilience. Assessing resilience is not an easy task and must occur by understanding how everyday work is performed. This study developed the Resilient Performance Assessment Framework (ResPAF) based on the DARWIN Resilience Management Guidelines to assess resilience through observations and episodic interviews, and that was empirically evaluated in two industries (Aviation and Oil and Gas). The instantiations showed that the assessments made were able to contemplate the interactions and relationships between the multitude of elements that the system's response to a threat emerged from. The framework can be used at organizational levels other than the operational ones, as well as in other complex sociotechnical domains, to understand how everyday work is performed.

Keywords: Resilience Engineering, Resilience Assessment, DARWIN Guidelines, socio-technical systems.

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ATIS - Automatic Terminal Information Service

CC – Capability Card

CTA – Cognitive Task Analysis

CRM – Crew Resource Management

CDM - Critical Decision Method

DRMG – DARWIN Resilience Management Guidelines

DS – Design Science

DSR – Design Science Research

FTD - Flight Training Device

FRAM - Functional Resonance Analysis Method

HSE - Health, Safety and Environment

ICAO – International Civil Aviation Organization

ILS - Instrument Landing System

LOSA – Line Operation Safety Audit

NTNU - Norwegian University of Science and Technology

PAPI – Precision Approach Path Indicator

PUCRS - Pontifical Catholic University of Rio Grande do Sul

RAG - Resilience Analysis Grid

RE - Resilience Engineering

ResPAF – Resilient Performance Assessment Framework

SME - Subject Matter Expert

SPM – Systemic Performance Management

TEM - Threat and Error Management

VHF – Very High Frequency

SUMMARY

1 INTRODUCTION

1.1 THEME AND CONTEXT

A sociotechnical system is the designation given to a system arrangement in which the vast array of elements and relationships among them give rise to system-level behaviors that are not straightforward. The elements of these systems range from government and society to work conditions, equipment, and technology used to achieve the system's goals. These elements and their different characteristics interact with each other and exposes the system to environmental stressors – *e.g.,* financial pressure; regulatory obligations; and politics, and influences the way the system works towards achieving its objectives (DEKKER, 2014; RASMUSSEN, 1997)

Complexity is more present in some sociotechnical systems than others due to the highly dynamic interactions between their elements and the uncertainties in operations originated by a constantly changing environment. The fast pace of technological development within these organizations and the pressures these systems are submitted to also figure among the contributing factors to the complexity. The interactions between the social and the technical elements, since different parts of the system perform multiple functions, often contain an unexpected non-linear cause-effect relationship. These factors give rise to the necessity of the system to constantly adapt its performance (RASMUSSEN, 1997; SAURIN; GONZALEZ, 2013; WALKER *et al.*, 2008).

During the 20th century, permeated by the thoughts of Enlightenment and aiming at addressing the necessities of industrial development, models and methods were developed to understand how accidents occur in these systems and, consequently, to make them safer. Based on the rationality birthed by the Enlightenment, this so-called traditional view of safety, assumed a static reality; a linear cause-effect relationship between elements of the system; and, typically, focused on segregating the system from the source of hazards, whether they were technical or human. However, due to the incapacity of providing a holistic view of the systems, models and methods based on this Cartesian-Newtonian logic of linearity and reductionism (*i.e.*, macro properties of the system are a direct product of interactions between its elements) are ineffective regarding complex sociotechnical systems. That is because, in this type of systems, safety and risks are emergent phenomena (*i.e.,* it cannot be attributed to specific parts of the system, but to the interactions among them) (DEKKER, 2014; HOLLNAGEL; WOODS; LEVESON, 2006; RASMUSSEN, 1997).

Resilience Engineering (RE) emerged as safety management paradigm focusing on understanding complex sociotechnical systems, as well as developing tools to proactively manage risk. Definitions of resilience are present in many studies across different domains (*e.g.*, see Dekker (2019, p. 399). Within RE, resilience is defined as the ability of a system to adjust its functioning given either expected or unexpected situations to continue with the required operation (HOLLNAGEL, 2009; PATRIARCA *et al.*, 2018b).

Resilience Engineering enforces that, to achieve its purposes, variabilities (*i.e.,* the range of outcomes around an average that represents all the possible outcomes of a process, function, or operation (STORY, 2010)) of everyday work (*i.e.,* work-as-done) must be monitored to enhance the capacity of anticipating future events. Different methods were developed to address this necessity. Functional Resonance Analysis Method (FRAM), proposed by Hollnagel (2012), models how work is performed in practice by identifying the functions of a system (*i.e.*, activities performed by operators to achieve a certain goal) and by analyzing how variability may propagate and combine with other variabilities in the system throughout the functions.

Another method, this one focusing on assessing the cornerstones of resilience (*i.e.,* abilities a system must possess to have the potential to perform resiliently), is the Resilience Analysis Grid (RAG). Created by Hollnagel (2010), the RAG is a set of four groups of proposed questions, each group focusing on assessing each cornerstone. The answers can be given through a Likert-type scale and the results show the level of each of the four abilities. This method helps operators to know which cornerstone should be given attention to have the potential for a resilient performance.

Recently, Hollnagel, based on RAG, worked on developing the Systemic Potentials Management (SPM). The SPM presents questions that are divided in foreground and background ones and can be used as a tool for managing organization’s performance and the implementation of changes. The SPM is being used at the Weak Signals Project to assess the resilience potentials in Eurocontrol (EUROCONTROL, 2021).

Resilience is something a system does, rather an inherent characteristic of the system. Since resilience is context-dependent, it is only possible to state that a system performed resiliently after an event. Because of that, RAG focus on assessing the potential a system must have to perform resiliently, not the resilience itself.

Although targeting the promotion of resilience in highly dynamic sociotechnical systems and acknowledging the necessity of understanding the variabilities in everyday work, RE still lacks methods to assess how everyday work is performed and to understand the interactions between different elements of the system interact so to cope with complexities and uncertainties. That is because FRAM is not, *per se*, a resilience assessment method and the questions of RAG do not provide the understanding of how different elements of these systems interact with each other.

Targeting at reducing the gap between the theory and the practice in the field of RE, a set of guidelines, named DARWIN Resilience Management Guidelines (DRMG), was developed. These guidelines aim at improving the ability of complex sociotechnical system to operate efficiently in crisis situations by addressing aspects related to various levels of these systems (*e.g.,* regulators and society) (DARWIN, 2018). Besides, they were conceived from multiple meetings and surveys with crisis management experts.

Considering these aspects, this study has the following research question: **how to assess resilience in everyday operations using DARWIN Resilience Management Guidelines?** Considering the criticality of operations in Oil & Gas industry and aviation in relation to safety and risks, this research question will be addressed in the context of activities performed in Oil & Gas operations and aircraft cockpit operations. Besides, since DARWIN (2018) provided an operationalizable way to reduce the gap between theory in practice by elaborating guidelines that contribute to a resilient performance, the assessment artifact developed in this research will be based on these guidelines.

1.2 STUDY OBJECTIVES

1.2.1 Main Objective

This study aimed at proposing an observation and interview-based framework to assess resilience in complex sociotechnical systems.

1.2.2 Specific Objectives

This study has the following specific objectives:

a) Developing an assessment framework of resilience;
b) Instantiating the proposed assessment framework in two industries; and
c) Evaluating the assessment framework regarding its utility and usability.

1.3 JUSTIFICATIVE

To engineer resilience in a complex sociotechnical system, we must assess resilience in the first place (NEMETH; HERRERA, 2015). Although between 2005 and 2015 researchers made progress at identifying factors and patterns related to a resilient performance, the topic of resilience assessment still uncharted (DEKKER, 2019). On one hand, FRAM is a method that focus on developing a functional model of the system. On the other hand, RAG is a tool that focus on a broader diagnostic of the resilience potential of a system, not providing a deeper understanding on how interactions between elements of a system occur so adaptation are possible. Because of that, this study is theoretically justified since it provides a resilience assessment framework, contributing to lessen this gap in the field of RE.

Pragmatically, this study contributes to complex sociotechnical systems since it provides an instantiated resilience assessment framework based on the DARWIN Resilience Management Guidelines. The theoretical foundation of this framework differs from the one in RAG, allowing to understand how adaptive performance emerged from the interactions between the elements of these systems.

1.4 DOCUMENT STRUCTURE

This document is divided into four sections. The following one exhibits the theoretical background of this study. The third one presents the methodology of this study and how data was collected and analyzed in each phase of the research. The fourth one presents the results regarding the data collected. The fifth one discusses the instantiations and possible uses for the proposed framework. Finally, the sixth section summarizes what was done is this research.

2 THEORETICAL BACKGROUND

2.1 COMPLEXITY IN SOCIOTECHNICAL SYSTEMS AND INHERENT VARIABILITIES

2.1.1 Complexity in Sociotechnical Systems

Complex sociotechnical systems have complexity permeating most of the interactions between their elements. Albeit there is no consensus among researchers about its definition, complexity in sociotechnical systems is originated due to a multitude of elements in these systems and the diversity of nature of these elements as they dynamically interact with each other and with the environment where activities occur (JACOBS, 2013; RASMUSSEN, 1997; SAURIN; GONZALEZ, 2013). These interactions give rise to unexpected behaviors between independent elements of independent subsystems of the system (PERROW, 1999).

The large number of elements in complex sociotechnical systems relates to the necessity of operating in hostile environments and covering several functions efficiently (PERROW, 1999). Because the interactions between elements are dynamic, its resultant performance may become non-linear (*i.e.,* the effect is not proportionate to the cause). An example is how a financial crisis may affect the way people perform specific tasks of their jobs. As a result, system's operation is indirectly affected by these interactions (LEVESON, 2011).

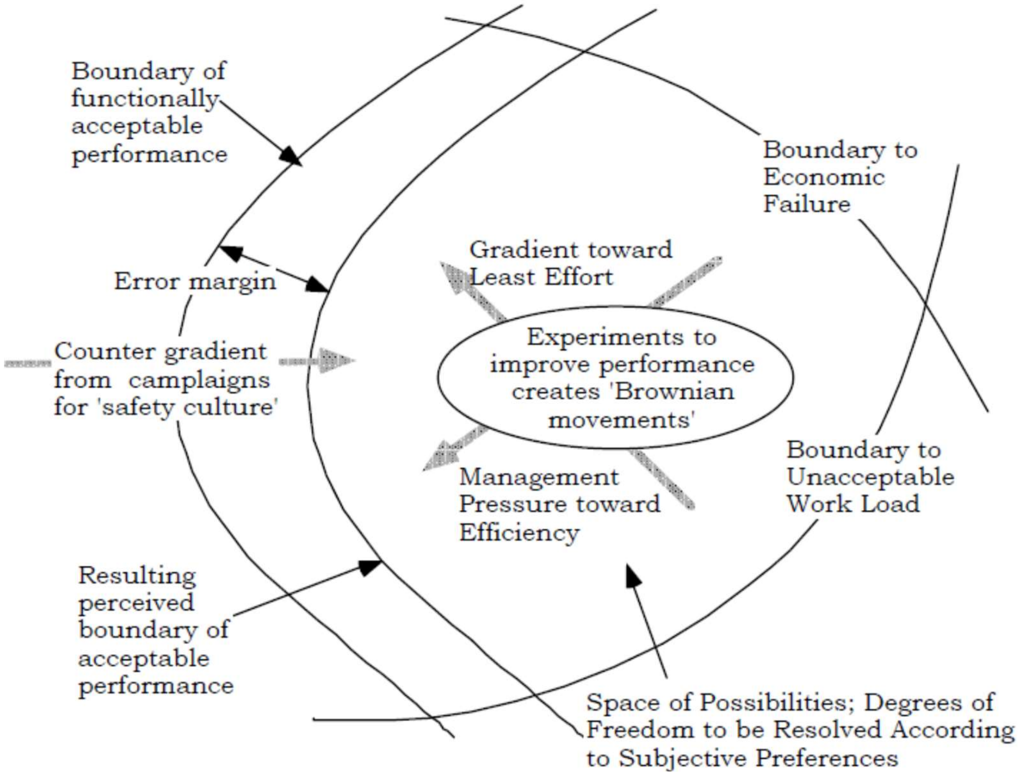
The more elements a system has, the vast array of possible interactions between them exists. Moreover, to increase efficiency in complex sociotechnical systems, these elements are tightly coupled (*i.e.,* there is no slack between two elements, and what happens in one quickly affects the other). The consequence is that any disturbance in one of them will propagate throughout the system very quickly (PERROW, 1999).

However, the number of elements is not the only contributing factor to complexity. The more diversity regarding elements' characteristics a system has, the more complex the interactions between them will be (VESTERBY, 2008). Since these systems were conceived to operate in a fast, better, and cheaper logic in challenging environments, their elements have been designed to optimize the performance by performing multiple tasks (PERROW, 1999). An example is a pilot who is not only responsible for the piloting but also the communication, pre-flight inspection, etc. The consequence is that the effects of the interaction between these elements may give rise to system level behaviors that operators are unable to understand or even see (LEVESON, 2011)

According to Rasmussen (1997), complex sociotechnical systems are dynamic and operate within a workspace limited by three margins. These systems are also always migrating towards one of them. These margins are (1) unacceptable workload; (2) economic failure; and (3) functionally acceptable performance. These boundaries are illustrated in Figure 1. The unacceptable workload margin refers to the point where, beyond that, the operator is not able to handle the work demands anymore by a variety of factors (*e.g*., physical limitations; time constraints; etc.) and the economic failure margin is the one that, in case the system trespass, it will not be able to financially sustain its operation (*i.e.,* it goes bankrupt).

People within a system make decisions that are locally rational (*i.e.,* it makes sense to them regarding their objectives; resources constraints; and time constraints). These decisions are made focusing on being both cost and workload efficient (DEKKER, 2002). Because the interactions are non-linear, people who make these decisions are not able to contemplate the whole array of events that may happen in other parts of the system (DEKKER, 2011). As a result, the system migrates, as a live entity, towards the functionally acceptable performance margin. In the case the system trespasses this margin, an accident may occur. As a counterforce, safety campaigns and risk management actions try to move the system away from this boundary. These strategies give rise to a difference between the functionally acceptable performance margin and a perceived one (*i.e.,* an error margin). However, normally, they are not sufficient to counteract the system's migration (RASMUSSEN, 1997).

Figure 1: Rasmussen’s boundaries of complex sociotechnical systems



Source: Rasmussen (1997)

2.1.2 Variability and Everyday Work

The very dynamic nature of these systems imposes limitations to designers to predict with accuracy the system’s performance and to the operators to anticipate its future status (HOLLNAGEL, 2004). As a result, operations in complex sociotechnical systems always present some level of variability, which can be defined as any outcome from any function, operation, or process, within the range of possible outcomes, that differs from the average, being either expected or unexpected, that influences the system's performance (HOLLNAGEL, 2012a; STORY, 2010).

Variabilities can be classified as endogenous or exogenous, according to their source (HOLLNAGEL, 2012a). Endogenous variabilities relate to subsystems within the system. For example, the person in charge of the installation of the blowout preventer (*i.e.,* equipment located in the wellbore that prevents uncontrolled flux of hydrocarbon to the surface in offshore drilling operations) takes informal notes about the conditions of the equipment before the installation. This action is not prescribed in any procedure regarding the operation and influences the system's performance by recording data that may be useful in the future. Exogenous variabilities relate to the environment the system is inserted (HOLLNAGEL, 2006). For instance, wind velocity and its direction influence aircraft performance during takeoffs and may be different from what was predicted during the pre-flight briefing.

However, not only variabilities are a normal aspect of the system, but also it is what makes complex sociotechnical systems achieve their goals safely and efficiently (HOLLNAGEL, 2006). As an example, to achieve a safe landing, pilots may change the moment they execute the landing checklist (*i.e.*, interaction between two elements of the system) due to the unique complexity present in each landing (*e.g.,* traffic load; weather conditions; and control tower instructions). This adjustment in the performance occurs even though the standard procedure is to execute the checklist at a certain distance from the runway (DEKKER, 2019).

Because it is not possible to predict the whole array of interactions that may occur during an operation, operators are unable to predict the exact behavior of a complex sociotechnical system (SOLIMAN; SAURIN, 2017). Thus, successful outcomes are achieved by workers adapting their performance to cope with the complexity of a given situation. They play a crucial role by adjusting the system's performance to compensate for situations that were not predicted, reconciling the gap between the design and the real operation (VICENTE; BURNS, 1995). Therefore, in complex sociotechnical systems, there is always a difference between work-as-done and how the work was prescribed in checklists, established in laws and regulations; explained by the operators; or imagined by the designers of the system (PATRIARCA *et al.*, 2021).

2.2 RESILIENCE AND RESILIENCE ENGINEERING

2.2.1 Resilience

Notwithstanding the inherent characteristics of complex sociotechnical systems that tend to push the system to its limits, one may notice that there are much more successful outcomes in operations than negative ones in these systems. For example, according to the yearly safety report, made by the aircraft manufacturer Airbus, regarding commercial aviation, there were only four fatal accidents in 2019, while in the same year, there were over 36 million flight departures (AIRBUS S.A.S., 2020).

Some authors, according to Bergström, Van Winsen and Henriqson (2015) link this capacity of a system to achieve these successful outcomes to the ability to maintain itself within the margins proposed by Rasmussen (1997). Based on that, resilience can be defined as system's capabilities to maintain or to recover to a stable condition before, during or after expected or unexpected events to maintain the required operation (PATRIARCA *et al.*, 2018b). It is seen as an adaptive capacity to manage complexity within the system and to maintain the system within its performance boundaries (BERGSTRÖM; VAN WINSEN; HENRIQSON, 2015) even though this stable condition be different from before the event.

A system's response to a threat can be characterized in three ways according to when it occurred and the system's operating state. The first one is **disarm**, when the system is able to anticipate events that have the potential to take the system out of a state of normality and acts so that this does not occur. The second one is **recovery**, in which the system did not anticipate or could not avoid the event. However, the system returns to the previous stable condition after responding to it. Finally, the third one is **adaptation**. In this case, the system did not anticipate or could not avoid the event and, after responding to it, it did not return to the pre-event stable condition and started to perform in a new stable condition.

Finally, resilience is not restricted only to people working at the sharp end of an organization (*i.e.*, people working directly on safety-critical tasks (FLIN; O'CONNOR; CRICHTON, 2008)) as it possesses a fractal property. It applies to all levels of a system, ranging from an individual worker performing tasks to an organization as a whole and even reaching a government and society level (BERGSTRÖM; VAN WINSEN; HENRIQSON, 2015; COSTELLA; SAURIN; DE MACEDO GUIMARÃES, 2009).

2.2.2 Resilience Engineering

Since the early 1900s, safety is viewed as the absence of unwanted events (*e.g.*, accidents; incidents; and near misses) and these events were attributed to workers not following the rules and acting unsafely. As a result, methods were developed aiming at shaping the operator's behavior and to achieve a strong standardization and compliance, resulting in a safe operation (PROVAN *et al.*, 2020).

However, this logic no longer applies to a reality with complexities and residual uncertainties that safety-critical systems are immersed nowadays (BRAITHWAITE; WEARS; HOLLNAGEL, 2015). The necessity to develop new methods and perspectives regarding safety-critical activities to cope with the complexity in society and the industry has been raised by researchers and practitioners (WOLTJER *et al.*, 2015). For that, RE emerged as a new safety management paradigm aiming at helping systems to cope with complexity and uncertainty (PATRIARCA *et al.*, 2018b).

One of the assumptions that RE has regarding complex sociotechnical systems is that failure and success both have their origins in inherent variabilities in the system. RE focuses on enhancing those variabilities that make the system achieve its goals and at dampening or removing those that negatively affect the system. This is accomplished by eliminating or managing them, whichever is possible (HOLLNAGEL, 2012). Finally, RE argues that the system must be constantly monitored. The dynamic nature of interactions imposes that the system changes over time. Thus, knowing the actual status allows operators to visualize the migration towards the system's unacceptable performance margin.

2.3 ASSESSMENT METHODS IN RESILIENCE ENGINEERING

The development of RE and its objective of helping systems to cope with complexity gave rise to the necessity of understanding and assessing the features of a system that make it resilient. According to Nemeth and Herrera (2015), it is only possible to engineer resilience in a system if there are ways to assess it. Assessing resilience relates to understand how work-as-done is performed and how system level performance emerges from local adaptations. To address this necessity, different methods were developed focusing on various aspects that influence the system's resilience.

Functional Resonance Analysis Method (FRAM), created by Hollnagel (2012), aims at identifying the sources of variability in a chosen activity. This is accomplished by modeling the system according to how activities are performed in practice (*i.e.*, work-as-done) instead of focusing on the system's physical structure (PATRIARCA *et al.*, 2017b). One of the greatest contributions of FRAM is to make possible to visualize how different functions (*i.e.*, activities performed to achieve a goal) interact with each other and how variabilities in complex sociotechnical systems propagate and combine with each other throughout the system (HOLLNAGEL, 2012).

Despite FRAM has been proved as a very useful tool to model work-as-done, it is not, *per se,* an assessment method of resilience. Rather, its objective is, through this modeling, identifying how functions are coupled and how variabilities may propagate and resonate with each other in the system. This allows actions to be taken regarding managing these variabilities (PATRIARCA *et al.*, 2017a).

An attempt to assess the potential of a system to perform resiliently was made through the creation of the Resilience Analysis Grid (RAG) (HOLLNAGEL, 2010). RAG is a question-based method to assess the level of some capabilities that contributes to a system to perform resiliently (*i.e.,* the resilience cornerstones), and the questions are grouped according to the related capability (HOLLNAGEL, 2011). The author proposed a set of generic questions that must be domain-adapted and suggested that questions may be removed, and new ones can be added, if needed. The answers to the questions can be given on a Likert-type scale of six points, ranging from Missing to Excellent. After that, an average is calculated, and the results can be presented in a radar chart. It is important to note that the result is a snapshot of the resilience potentials of the organization and a way to visualize where improvements can be made in the system. Therefore, assessments should be made routinely to know the evolution of resilience potentials levels.

RAG is a easy-to-use tool and allows data to be analyzed very quickly. Because of that, it has been used in several domains. For instance, Patriarca et al., (2018a) applied RAG combined with Analytic Hierarchical Process in the anesthesia department of a hospital. RAG was also used to in the rail sector to evaluate trains departure and arrival management system (RIGAUD; NEVEU; LANGA, 2018).

Although being an assessment method, RAG has limitations regarding understanding how system’s performance emerged from the interactions and relationships between its elements. Its objective is to provide a broader diagnostic of the system in relation to the so-called resilience cornerstones, focusing on assessing a macro-organizational level of resilience, not a micro one. This stems from the fact that it is based on a question-answer rationale focusing on assessing the level of each resilience cornerstones, not on understanding how adaptations occur during operations.

This is exemplified by some suggested questions of RAG that relates to aspects not observable during operations (*i.e.,* research activities (PATRIARCA et al., 2018a)). Besides, some critics regarding the theoretical foundation of the RAG (*i.e.,* the resilience cornerstones) were raised, since it lacks literature foundation to them (DEKKER, 2019; HOPKINS, 2014).

To assess resilience, the interactions between the elements of the system must be contemplated. Besides, they should be based on data collected from everyday work, allowing to understand how system's response emerged from local adaptations. While RAG has a diagnostic nature to assess *what* aspects of the system must be devoted attention, FRAM aims at analyzing how different functions interact with each other and how variabilities may combine in the system. Although being useful for their purposes, both methods present limitations in relation to deepen the understanding regarding how local adaptations allowed the system to cope with complexity. Therefore, despite the development of these different methods that focus on distinct aspects of complex sociotechnical systems, the assessment of resilience still a topic that deserves further development in RE considering these aspects.

2.4 DARWIN RESILIENCE MANAGEMENT GUIDELINES

Some critics were raised regarding the non-applicability of the concepts and precepts tailored in RE (HERMELIN *et al.*, 2020). To address the gap between the theory and the practice in RE, a project called DARWIN (2018) under the Horizon 2020[1] European Union's research program, was developed. This project had the support of more than 240 practitioners from more than 20 different countries and the main product was the creation of guidelines, so called DARWIN Resilience Management Guidelines (DRMG) that are an attempt to operationalize the concepts of RE in crisis management situations. These guidelines aim at helping complex sociotechnical systems to proactively deal with their inherent uncertainties and to shed light on areas related to crisis management, so they can respond to expected and unexpected situations.

There are three groups of users who are the beneficiaries of the guidelines. The first group is composed by the people and organizations who are directly responsible for managing crises and emergencies. The second group is composed by those people

[1] Available at: https://cordis.europa.eu/project/id/653289

who are affected by the guidelines. Front-line operators and policy makers figure in this group. Finally, the third group is composed by those people who are not directly in charge of developing the guidelines in organization but exerts influence in relation to a successful implementation. Consultants, for example, compose this group. These guidelines are divided in thirteen topics that are related to six high-level themes. These topics were developed after a detailed literature review and each one is presented in the form of a Capability Card (CC).

2.4.1 Capability Cards

The purpose of each CC is to present actions to operationalize each of the DRMG. It describes its purpose; implementation fields; background and context information; relevant material; and navigation fields. Moreover, each CC has triggering questions. aiming at identifying important aspects addressed by each CC. Table 1 presents the six high-level themes and their topics. A complete list with CCs, the rationales and the triggering questions is presented in Annex A. An example of a CC is presented in Figure 2.

Table 1: Darwin Resilience Management Guidelines

High-Level Themes	DRMG Topics
Supporting coordination and synchronization of distributed operations	Promoting common ground for cross-organizational collaboration in crisis management
	Establishing networks for promoting inter-organizational collaboration in the management of crises
	Sharing information on roles and responsibilities among different organizations
Managing Adaptative Capacity	Enhancing the capacity to adapt to both expected and unexpected events
	Establishing conditions for adapting plans and procedures during crises and other events that challenges normal plans and procedures
	Managing available resources effectively to handle unusual changing in demands

Table 1: Darwin Resilience Management Guidelines (conclusion)

Assessing Resilience	Assessing community resilience to understand and develop its capacity to manage crisis
	Noticing brittleness
	Identifying sources of resilience: learning from what goes well
Developing and Revising Procedures and Checklists	Systematic management of policies
Involving the Public in Resilience Management	Communication strategies for interacting with the public
	Increasing the public's involvement in resilience management
Managing System Failure	Supporting Development and Maintenance of Alternative Working Methods

Source: Adapted from DARWIN (2018)

Figure 2: Example of Capability Card

2.1. Promoting common ground for cross-organizational collaboration in crisis management

Promote periodic cross-organisational dissemination exercises to increase organisations mutual awareness of other motives, perspectives, terminologies and working practices. In turn, this can support improved collaboration at the time of crises, because first responders are more aware of the behaviour to expect from staff of other organisations.

IMPLEMENTATION

INTRODUCTION

What is needed to promote common ground:

To promote common ground and improved cooperation among the front-end staff of different first responders' organizations involved in crisis management, the managers of these organizations need to organize shared activities that allow the respective personnel to know each other. Differently from what advised by the CC 2.3. Understanding roles and responsibilities, in this case such activities should necessarily involve front-end staff and should not be limited to the managerial levels, nor to people simply delegated by them. In fact, the common ground implies a deeper understanding of working practices, motives and values that cannot be limited to the explicit knowledge encompassed by formal procedures and policies, but should also consider the way knowledge is concretely put into practice.

A prerequisite for the application of the actions described in the card is the existence of a network of organizations already collaborating among them in crisis management activities. If each organization is mostly operating in isolation and no mutual relationships have been established beyond those mandated by the law, it is advised to first apply the principle of the CC 2.2 Establishing networks. Depending on the specific phase (Before, During or After a crisis), the activities can be instantiated differently, as explained in the following sections.

Healthcare implementation – Introduction

In order to "Establish common grounds", involved actors need to plan and discuss this issue jointly prior to the event. The predetermined common grounds is then implemented during the event. After the event, it is important to analyse the work performed and examine what can be improved.

BEFORE A CRISIS

Promoting common ground among different organization before any type of recent crisis or accident has occurred is in principle the most favourable situation. The managers of the different organizations are not biased by the interpretation of the events occurred during a previous crisis and less concerned by the sharing of information that might be used to assign responsibilities regarding past events. On the other hand, the managers my face the problem of justifying their investments on common ground activities, in the absence of any recent event causing concerns in the organization (owners or shareholders) or in the public opinion (taxpayers or other users of the service). The managers should first identify potential gaps in the mutual understanding between their own organization and the other organization with whom there is a collaboration in place, and then they should be promoters of one or more of the following actions:

- **Organise information sharing workshops**. The main goal of these workshops is that of allowing the staff of your organization to gain useful insights into the mission, culture and

~ 14

Source: DARWIN (2018)

Considering the nature of complex sociotechnical systems, all the CCs relate to each other. For example, the CC Noticing Brittleness provides input for the CC Managing Available Resources Effectively. That is because understanding how the system may collapse provides information on what resources should be mobilized and how.

For being a recently developed project, not many studies involving the DRMG were published. After a systematic search in Scopus, Google Scholar and Science Direct databases using the term “DARWIN Resilience Management Guidelines”, ten studies were found, considering articles, conference papers and book chapters.

Hermelin et al. (2020) adapted a subset of these capabilities to Swedish Regional Medical Command and Control Team, a healthcare crisis management team responsible for the resources in the region of Östergötland, in Sweden. The adaptation was achieved with the help of experts of the domain and considered organization-specific policies and practices. The study showed the importance of aggregating developmental learning of practitioners, contextualization of the guidelines and the use of simulation-based training as part of a training program.

Another studied, conducted by Pettersson et al. (2021), to operationalize the DRMG, tried to link the resilience concepts presented in DRMG to observable behaviors in the context of a disaster medicine management system. The studied was conducted in a large-scale crisis management exercise. They used Furniss et al. (2011) analytical framework of markers and strategies to classify the observed behaviors according to the DRMG. Through observations, the authors were able to connect some behaviors to concepts presented in the guidelines.

For example, during the simulated scenario of a collision between two ships, the regional command and the control command received the information that one of the ships had changed its course to another port. This fact changed previous assumptions in relation to where the ship would dock. Based on this information, a coordination was made so that patients of the city the ship was going to dock were not sent to the hospitals there. This decision was because the hospitals capacity would be destinated to the injured people of the ship. Based on this observation, the authors were able to notice the presence of an ability to enhance the capacity to adapt to both expected and unexpected event, which is one of the guidelines.

The authors concluded that the study succeeded in identifying behaviors that allows a system to perform resiliently. Moreover, further studies could focus on developing a set of observable indicators of resilience based on DRMG. This would contribute to an operationalization of resilience.

Låstad and Larssen (2020), from the Norwegian University of Science and Technology (NTNU), adapted the guidelines to the context of the petroleum industry, focusing on everyday work of Remote Operation of Underwater Inspection Drone. They selected some CCs and, using the triggering questions, conducted interviews to assess how the DRMG could be used to improve resilience management in this operation. Although being conducted in a single case study and, therefore, not eligible for generalization, the study concluded that the triggering questions have the potential to stimulate reflections regarding resilience management in complex sociotechnical systems and further research could be conducted to adapt the DRMG to other cases.

2.5 SUMMARY OF RESEARCH ASSUMPTIONS

The field of Resilience Engineering has focused on understanding what resilience is and what the indicators for a resilient performance are. Although a lot has evolved related to this topic, the development of new methods to assess resilience has not follow this evolution. The two most used methods developed so far present limitations in face of the dynamic nature of these systems. This imposes restrictions in relation to the objective of Resilience Engineering in complex sociotechnical systems: engineer resilience.

In a recent effort, the DARWIN project developed the so-called DARWIN Resilience Management Guidelines (DRMG) aimed at helping complex sociotechnical systems to deal with its inherent uncertainties due to complexity. Moreover, the study developed by Pettersson et al. (2021) showed that behaviors observed in practice can be linked to the concepts presented in these guidelines. These findings pave the way for developing a protocol to assess resilience in practice.

Therefore, some assumptions for this research must be made explicit. First, it is assumed that assessing resilience depends on collecting data of everyday work, since successes and failures stem from variabilities in work-as-done. Second, these assessments must contemplate how the elements of the system interact with each other, in consideration of the emergent behavior of the system. Third, the assessments must occur in a structured way based on concepts of RE. Fourth, DRMG provides ways in which the RE concepts are operationalizable, figuring as a viable option to be the foundation of an assessment tool.

3 METHODOLOGY

3.1 RESEARCH APPROACH

This study adopts Design Science (DS) as the scientific paradigm and Design Science Research (DSR) as methodology. According to Simon (1996), Design Science is the science of the artificial (*i.e.*, inventions made by humans or that suffer influence by them) and aims at developing solutions to make existent systems better. Since DS aims at solving problems of the real world, these solutions must focus on solving problems in a pragmatical way (DRESCH; LACERDA; JÚNIOR, 2015)

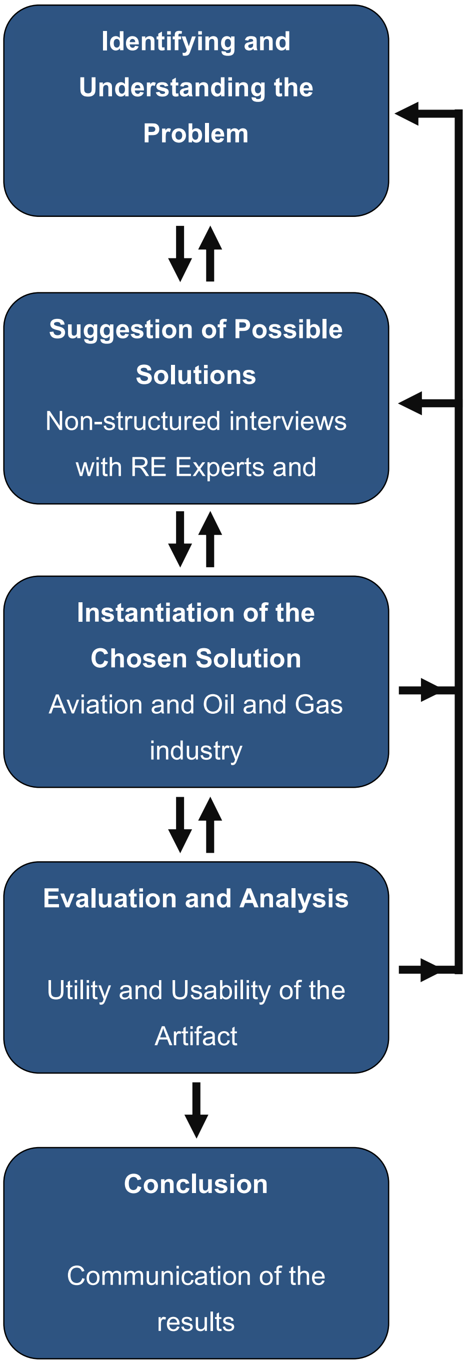
DSR approaches the artificial through the creation of artifacts. Artifacts can be constructs, models, frameworks, architectures, design principles, methods, instantiations, or design theories (VAISHNAVI; KUECHLER, 2015). It is possible to categorize the artifacts as product or process ones. Product artifacts are used by people to accomplish a given task (*e.g.,* tools, equipments, softwares). Process artifacts guides people on how to perform a task (*e.g.,* model, method, framework). Besides, artifacts can be classified as technical (*i.e.,* once instantiated, do not need someone using them) or sociotechnical (*i.e.,* it only works with someone interacting with it).

DSR figures as an appropriate research method for this study since the main objective is the development of an assessment framework to assess resilience. It is important to note that DSR does not seek to provide an optimal solution. Rather, it focuses on developing satisficing results to address pragmatic issues (AKEN, 2004). The results obtained through DSR must be generalizable to a set of theoretical or pragmatical problems, named class of problems. Classes of problems have artifacts that provide useful ways to deal with these problems. Their importance relies on being how researchers communicate the scope of their results (DRESCH; LACERDA; JÚNIOR, 2015). For example, Task Analysis can be understood as a class of problems and it has different artifacts to address its problems (*e.g.*, Cognitive Task Analysis (CTA) to understand how a task is performed regarding cognition).

3.2. RESEARCH DESIGN

According to Vaishnavi and Kuechler (2015), a study conducted according to the DSR has five phases: (1) identification and understanding of a problem; (2) suggestion and discussion of possible solutions; (3) instantiation of the chosen solution; (4) evaluation and analysis; and (5) conclusion. Figure 3 presents these phases.

Figure 3: DSR Phases



Source: Adapted from Vaishnavi and Kuechler (2015)

3.2.1 Phase 1: Identification and Understanding of The Problem

When conducting research using DSR, the first phase of the study is consisted of identifying and understanding a problem that has a pragmatical relevance, and already developed artifacts to address the problem. Dresch, Lacerda and Júnior (2015) suggest that this can be achieved, for instance, through a literature review and/or interviews with practitioners. Normally, in a study adopting DSR as methodology, the data collected in this phase are presented in Introduction and in Theoretical Background section and bases the formulation of the research question.

3.2.2 Phase 2: Suggestion of Possible Solutions

After identifying and understanding a problem with pragmatical relevance, and identifying the already developed artifacts, an artifact to provide a satisficing solution to the problem must be suggested. This is a creative process since, according to Alturki, Gable and Bandara (2011), this is the phase in which a new solution for the problem is envisioned. For that, aspects like the context in which the artifact will be used and how will be used must be considered.

3.2.3 Phase 3: Instantiation of The Chosen Solution

According to Vaishnavi and Kuechler (2015), this phase represents the further development and instantiation of the proposed artifact. The main objective of this phase is to demonstrate whether the artifact and its design process are feasible (HEVNER *et al.*, 2004). According to Simon (1996), during this phase, the internal environment of the artifact is developed. It is important to note that this is an iterative process, being the artifact constantly refined according to the evaluation that follows each instantiation. This allows the final version of the artifact to be achieved through successive approximations.

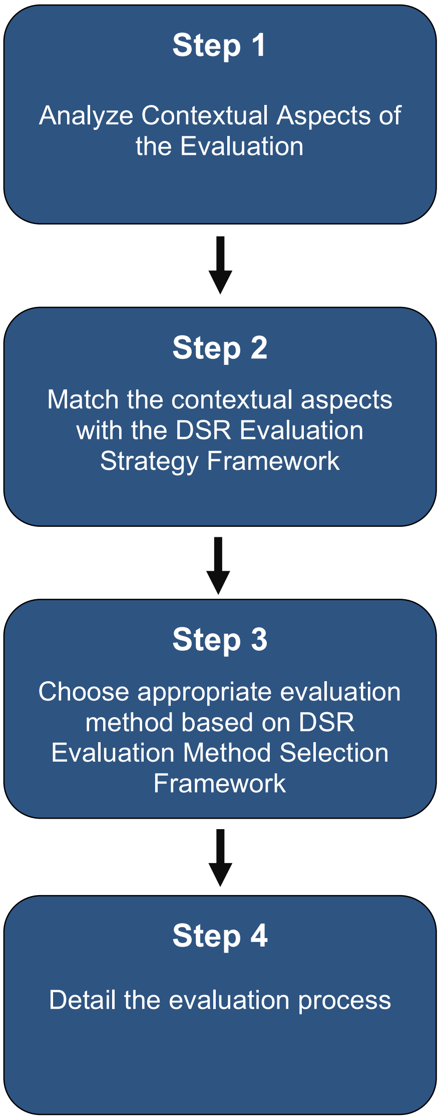
3.2.4 Phase 4: Evaluation and Analysis

According to Hevner et al. (2004), evaluating what is being developed in DSR-conducted studies is crucial for research. It provides evidence that the artifact works in the context for which it was developed. However, since it depends on the intended use, the evaluation is a complex process (ALTURKI; GABLE; BANDARA, 2011). Besides, the evaluation method depends on the type of artifact being evaluated (VENABLE; PRIES-HEJE; BASKERVILLE, 2012).

Pries-Heje, Baskerville and Venable (2008) states that the evaluation can be an *ex-ante* (*i.e.,* evaluation of an uninstantiated artifact) or an *ex-post* (*i.e.,* evaluation of an instantiated artifact) evaluation. Besides, it can be conducted artificially or naturalistically. Artificial evaluation occurs in a static way, like laboratory experiments and theoretical arguments. On the other hand, naturalistic evaluations occur in a real environment with real people.

Venable, Pries-Heje and Baskerville (2012) developed a framework and a four-step method that guides researchers on how to conduct evaluations of an artifact. The steps are illustrated on Figure 4.

Figure 4: Framework Evaluation Process



Source: Adapted from Pries-Heje and Baskerville (2012)

Step 1 is about analyzing the contextual aspects of the evaluation. This step comprises: (a) determining the type of artifacts that will be evaluated; (b) determining the nature of the artifacts; (c) determining the properties that must be evaluated; (d) determining the goal of the evaluation; (e) identifying and analyzing what constrains the research environment; (f) considering the level of rigor that is necessary for the evaluation; and (g) prioritizing the aforementioned factors to determine which ones are more relevant to the study.

Then, in **Step 2**, these contextual factors must be matched with the DSR Evaluation Strategy Selection Framework (Figure 5). This should be done by looking the white boxes and the blue quadrants. In this step, some aspects are considered. For instance, the risk of interpreting that a result from the artifact exist when in fact it does not (*i.e.,* false positive) (VENABLE; PRIES-HEJE; BASKERVILLE, 2016). It is also considered whether using the artifact present some risk to the users, especially with safety-related artifacts.

After that, in **Step 3**, the most appropriate evaluation method must be selected. This should be done according to the DSR Evaluation Method Selection Framework (Figure 6). Finally, in **Step 4,** the evaluation process must be detailed in the study. The fourth step is presented on section 3.4.4.

Figure 5: DSR Evaluation Strategy Selection Framework

DSR Evaluation Strategy Selection Framework		**Ex Ante**	**Ex Post**
		•Formative •Lower build cost •Faster •Evaluate design, partial prototype, or full prototype •Less risk to participants (during evaluation) •Higher risk of false positive	•Summative •Higher build cost •Slower •Evaluate instantiation •Higher risk to participants (during evaluation) •Lower risk of false positive
Naturalistic	•Many diverse stakeholders •Substantial conflict •Socio-technical artifacts •Higher cost •Longer time - slower •Organizational access needed •Artifact effectiveness evaluation •Desired Rigor: "Proof of the Pudding" •Higher risk to participants •Lower risk of false positive – safety critical systems	•Real users, real problem, and somewhat unreal system •Low-medium cost •Medium speed •Low risk to participants •Higher risk of false positive	•Real users, real problem, and real system •Highest Cost •Highest risk to participants •Best evaluation of effectiveness •Identification of side effects •Lowest risk of false positive – safety critical systems
Artificial	•Few similar stakeholders •Little or no conflict •Purely technical artifacts •Lower cost •Less time - faster •Desired Rigor: Control of Variables •Artifact efficacy evaluation •Less risk during evaluation •Higher risk of false positive	•Unreal Users, Problem, and/or System •Lowest Cost •Fastest •Lowest risk to participants •Highest risk of false positive re. effectiveness	•Real system, unreal problem and possibly unreal users •Medium-high cost •Medium speed •Low-medium risk to participants

Source: Venable, Pries-Heje and Baskerville (2012)

Figure 6: DSR Evaluation Method Selection Framework

DSR Evaluation Method Selection Framework	**Ex Ante**	**Ex Post**
Naturalistic	•Action Research •Focus Group	•Action Research •Case Study •Focus Group •Participant Observation •Ethnography •Phenomenology •Survey (qualitative or quantitative)
Artificial	•Mathematical or Logical Proof •Criteria-Based Evaluation •Lab Experiment •Computer Simulation	•Mathematical or Logical Proof •Lab Experiment •Role Playing Simulation •Computer Simulation •Field Experiment

Source: Venable, Pries-Heje and Baskerville (2012)

3.2.5 Phase 5: Conclusion

After evaluating the artifact and attesting that it provides a satisficing solution to the identified problem, the researcher must publicize the study's results. That is the last phase of a DSR-conducted study and comprises the communication of opportunities, limitations, and challenges during the study.

3.3 THE EMPIRICAL CONTEXT OF THE STUDY

This study was conducted in two different contexts: Aviation and Oil & Gas industry.

3.3.1 The Context of Aircraft Cockpit Operations

Composed by multiple elements interacting with each other, aviation was chosen because it is considered a complex sociotechnical system. Accidents involving aircraft operations are often disastrous and involve multiple deaths and materials damages. Moreover, the context of aircraft cockpit operations, which are highly dynamic, demands adaptions from pilots to deal with threats and opportunities that may jeopardize safety.

In this context, pilots, air traffic controllers, flight attendants and the technology aboard the aircraft work interdependently so the aircraft can operate safely and efficiently. Moreover, some other elements can be mentioned that, although not directly present in the context of a cockpit operation, influence and are influenced by what occurs in this context. For example, in case of a malfunction that the crew is unable to solve, the Maintenance department can be contacted via radio by the pilots. This contact can reach up to the aircraft manufacturer.

The cockpit crew can be composed by one pilot up to four pilots. In airline operations, there must be, at least a two-pilot crew operating the aircraft. During flight, one of the pilots is responsible for operating the aircraft (*i.e.*, the Pilot Flying) and the other one is responsible for monitoring the operation (*i.e.,* Pilot Monitoring).

Regarding the technology aboard an aircraft, the pilots have some resources that can be used during the flight. For example, the weather radar shows where thunderstorms clouds are in relation to the aircraft. Besides, the pilots can use the autopilot to reduce the workload of having to operate the aircraft applying manual inputs using the control wheel and to obtain a more refined control of the during maneuvers.

3.3.2 The Context of Oil and Gas Operations

Like aviation, the Oil & Gas industry is also characterized as a complex sociotechnical system. The operations that occur in this domain are characterized by multiple companies, each one specialized in a phase of operation, interacting with each other and with artifacts. Besides, major accidents in this industry are also related to multiple deaths and disastrous environmental damages.

Operations in oil and gas industry can be divided in exploration and production. Exploration operations have the objective of drilling a well to reach a reservoir that has gas and/or petroleum and occur both onshore and offshore. When offshore, this can be done using a drilling ship or a drilling rig. For this operation to occur successfully, it depends on several other operations.

One of them is called cargo handling, in which a team of six people, including a crane operator and a signalman, move heavy cargos (*e.g.,* equipment, trash, containers) from one place to another according to the demand. The role of the signalman is to guide the crane operator, using hand signals and radio communications, so the cargo can be moved safely from one place to another. These operations are permeated with residual uncertainties since, analogous to the aviation, it has several elements interacting with each other (*e.g.,* weather and sea conditions, cargo weight, time constraints).

Finally, after reaching a reservoir, a production ship, called FPSO (Floating Production Storage and Offloading) or a production rig starts to process the hydrocarbons. These production units stay connected to multiple wells at the same time. Finally, when the well is not providing enough hydrocarbons anymore, these units move to another place.

3.4 DATA COLLECTION AND ANALYSIS

3.4.1 Phase 1: Identification and Understanding of the Problem

The identification and understanding of the problem, as well as the awareness of the developed artifacts to address it were achieved through literature review and informal meetings with experts. The results from this phase of the research are presented in Introduction and in Theoretical Background sections. Based on that, the identified problem can be presented in the class of problems **Resilience Assessment**.

3.4.2 Phase 2: Suggestion of a Possible Solution

The suggestion of an artifact that addresses satisfactorily the identified problem was envisioned based on two sources of data: literature and meetings with RE experts. Considering the necessity of assessing resilience in complex sociotechnical systems, initially, a way of structuring this assessment was sought. Then, the field of RE was explored for solutions that theoretically support this structured assessment.

In addition to that, non-structured interviews were conducted with RE experts to debate how these assessments should be structured and used, possible limitations and how to overcome them. This process totaled 17h45min and was conducted both in person and online via Zoom/Teams. Table 2 present their work domain, years in the field, work positions and the major of their studies.

Table 2: Work domain, years of experience, work position and study's major of RE experts consulted in Phase 2

Expert	Work Domain	Years of Experience	Work Position	Study's Major
#1	Oil & Gas	14	Work Safety Engineer	Human Factors
#2	Oil & Gas	22	Human Factors Facilitator	Resilience Engineering
#3	Oil & Gas	35	Human Factors Leader	Resilience Engineering
#4	Aviation	16	Aeronautical Sciences Course Coordinator	Resilience Engineering

3.4.3 Phase 3: Instantiation of the Proposed Artifact

Considering the sociotechnical and processual nature of the proposed artifact (*i.e.,* a framework to assess resilience), it was chosen to instantiate it naturalistically. Two domains were selected to conduct these instantiations: Aviation and Oil and Gas.

3.4.3.1 *Instantiation in Aviation*

Data for the instantiation of the envisioned solution in aviation domain were collected through documental analysis and interviews. For the first step of the protocol, since the main author is from aviation domain, the selection and the adaptation of the CCs were made by him and validated by other two experts in aviation and in RE. Then, for the second step, for illustrative purposes, a documental analysis of document 9803 from International Civil Aviation Organization (ICAO) was conducted to develop the Threat Classification Category. For the third step, since the objective is developing an assessment form, a documental analysis of document 9803 from ICAO was used to base the form's layout. Finally, for the fourth step, interviews and a non-participant observation were conducted.

For the assessment of the resilience based on interviews, four episodic interviews were conducted with pilots. It followed a semi-structured guide adapted from the Critical Decision Method (CDM) guide based on the selected CC from the first step. A CDM interview starts with a narrative by the interviewee about a challenging episode experienced by her/him. Then, a series of probe questions are asked to deepen the analysis regarding the decision-making in the narrated episode. For this study, the narrative part was maintained, and the probe questions were adapted to deepen the analysis regarding the selected CCs. These interviews occurred both in person and via Zoom/Teams, lasting 4h24min in total. These interviews were video, and audio recorded, and transcribed. Then, the content was analyzed using a thematic analysis with the categories defined *a priori* based on the selected CCs from the first step. Finally, the assessment form was filled by the first author of this study.

For the assessment through observations, a simulated flight was performed. This simulation occurred in a Flight Training Device (FTD) with visual representation of ground and flight operations; and representation of instruments in a Seneca III aircraft cockpit. The crew was composed by two students of the Aeronautical Sciences course who has experience in that type of flight simulator. The crew operation was video, and audio recorded using a GoPro 4 and a voice recorder. The camera was positioned in a seat behind the crew to simulate the position an observer would have if inside the cockpit. The voice recorder was positioned in front of the crew, since an observer inside a cockpit would have no difficult to hear what the crew was saying. In addition to the crew, a flight instructor in charge of setting the scenario and performing the role of air traffic controller; and the main author were also present at the simulator.

The recordings were sent to a Subject Matter Expert (SME) to be assessed using the assessment form. According to Klein, Calderwood and Macgregor (1989), SMEs are people who distinguish themselves from their coworkers due to their distinct knowledge and understanding regarding the job they perform. They have achieved a level of expertise that led them to develop certain characteristics of performance (*e.g.,* mental models, perceptual skills, routines, etc.). The chosen SME is a captain that has 27 years of experience as an airline pilot, worked as a Crew Resource Management (CRM) facilitator, LOSA[2] observer and LOSA instructor. A meeting with the SME was conducted to explain the purpose of the study and the objective of the assessment framework. Then, a two-page file was sent to the expert. This file guides how to perform the assessment, detailing the sections presented at the assessment form. Table 3 summarizes how data was collected in each step of the framework.

[2] LOSA is the acronym for Line Operation Safety Audit, which is a program of structured observations conducted in aircraft cockpits to identify threats, crew errors and undesired states of the aircraft.

Table 3: Steps of the framework and the respective objectives and data collection method in aviation

Step of the Framework	Objective	Data Collection	Conducted by:
Step 1: Selection and Adaptation of the Capability Cards	Select and adapt the Capability Cards to the context that the assessment will be performed	-	The author
Step 2: Definition of Threat Classification Categories	Define threat categories that can be used to classify the threats faced by the system.	- Documental Analysis of Document 9803 of ICAO	The author
Step 3: Development of the Assessment Form	Develop an Assessment Form to be filled.	- Documental analysis of Document 9803 of ICAO	The author
Step 4: Assessment	Assess resilience	- Non-participant observations - Interviews	Aviation expert (Observation) The author (Episodic Interviews)

3.4.3.2 *Instantiation in Oil & Gas*

Data collection regarding the instantiation of the proposed framework in Oil & Gas operations was based on interviews and a non-participant observation. For **Step 1**, interviews with two experts were conducted. Both experts have more than 15 years of experience in this operational context. These interviews had the goal of presenting the rationale of each CC and ask whether they agree or disagree that the elements of the CCs are operationalizable in the operational context of Oil and Gas operations. The interview guide followed in **Step 1** is in Appendix B. In **Step 2**, for illustrative purposes, the categories were based on the work of Kvalheim and Haugen (2013) that applied the Threat and Error Management framework in drilling operations. For **Step 3**, data from the last two steps were used and the form layout was also inspired by document 9803 from ICAO. Then, for **Step 4**, episodic interviews and a non-participant observation were conducted.

The assessments based on episodic interviews occurred with four operators from Oil & Gas operational context. These interviews were audio recorded and transcribed for the purpose of the assessment. These interviews occurred via Zoom/Teams and had an average of 1h15 min. It also followed a semi-structured guide adapted from the CDM guide based on the selected CCs. After that, the assessment form was filled by the main author of this study.

For the assessments based on observations, a non-participant observation occurred aboard a drilling ship. The operation chosen to be assessed was the cargo handling operations. The expert selected to act as an observer was the supervisor of the cargo handling team. The supervisor has 30 years of experience in Oil & Gas offshore operations and 10 years as a supervisor on cargo handling operations. The purpose of the assessment was explained to the supervisor, and he was instructed to observe, collecting as many details as possible, the operation that was happening. The main author followed both the operation being observed and the filling process of the assessment form. Table 4 summarizes the steps of the framework, the respective objective, and the data collection method.

Table 4: Steps of the framework and the respective objectives and data collection method in Oil and Gas

Step of the Framework	Objective	Data Collection	Conducted by:
Step 1: Selection and Adaptation of the Capability Cards	Select and adapt the Capability Cards to the context that the assessment will be performed	- Interviews	- Oil & Gas experts - Main author
Step 2: Definition of a Threat Inventory	Create a threat inventory that can be used to classify the events being assessed.	- Literature	- The author
Step 3: Development of the Analysis Sheet	Develop an analysis sheet to be filled based on the assessments.	- Documental analysis of Document 9803 of ICAO	- The author
Step 4: Assessment	Assess resilience	- Non-participant observations - Interviews	- Oil & Gas expert (Observation) - The author (Episodic Interview)

3.4.4 Phase 4: Evaluation and Analysis

For evaluating the proposed artifact, the framework and the four-step method developed by Venable, Pries-Heje and Baskerville (2012), was adopted. Considering the main purpose of a DSR-conducted study being developing an artifact that is useful do address a problem (HEVNER *et al.*, 2004), utility was one characteristic chosen to be evaluated. Another characteristic of the artifact that can be evaluated is usability (HEVNER *et al.*, 2004), especially considering the artifact should be used without the support of the researcher. The first step was to list the contextual factors related to the instantiation. Table 5 presents these aspects.

Table 5: Contextual factors of the proposed artifact

Type of Artifact	Framework
Nature of the Artifact	Processual and Sociotechnical
Properties to be evaluated	Utility and Usability
Purpose of Evaluation	Evaluate two instantiations of a designed artifact to establish its utility and usability for achieving its stated purposes.
Constraints of the Research Environment	Experts to assess resilience Available Time
Rigor of the Evaluation	Preliminary evaluation
Prioritization	Evaluate utility and usability

For the second step, the DSR Evaluation Strategy Framework was used in conjunction with these contextual aspects to select the appropriate strategy of evaluation. Since the artifact was instantiated naturalistically and the aim of the evaluation is to evaluate the artifact's utility and usability considering real people in a real environment, an *ex-post* evaluation was chosen to be performed. Then, the third step was to identify the most appropriate method for the evaluation process. Considering the naturalistic *ex-post* nature of the evaluation, the chosen method was case study.

For conducting a case study to evaluate the artifact, interviews were conducted with the experts who assessed the resilience performance through observations, since the assessments of the episodic interviews were made by the main author. These evaluation interviews sought to assess the utility and usability of the artifact. Table 6 presents the questions asked to the experts.

Table 6: Questions to assess the utility and usability of the artifact

Utility	Do you think this protocol helps understanding how work-as-done is performed? How?
	Do you think the aspects addressed in the protocol are pertinent?
	Can you envision an applicability for the data collected using this protocol?
Usability	Were you able to assess the elements in the protocol with your current knowledge?
	Do you think you would be able to conduct the assessment without the aid of the researcher?

3.5 ETHICAL CONSIDERATIONS

This study was conducted within the scope of the Human Factors Project (HF Project) of the Pontifical Catholic University of Rio Grande do Sul (PUCRS) which is funded by the Libra Consortium with support from the ANP (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis, Brazil) associated with the investment of resources from the R, D&I Clauses - Regulation No. 03/2015 (process 2019/00105-3).

The project and all studies developed in its scope were approved by the Research Ethical Committee of Pontifical Catholic University of Rio Grande do Sul – PUCRS and observes Resolution No 510 of 2016 regarding Standards Applicable to Research in Human and Social Sciences from the National Research Ethics Commission.

The participants of this research received a document explaining the purposes of this study and a consent form. These documents aim at validating their knowledge regarding the participation in the study and confirming their understanding concerning the principles of willingness and confidentiality. The data collected in this study were de-identified so the anonymity of the participants and entities involved in the research be preserved.

4 RESULTS

DSR-based studies have the main objective developing artifacts that provides satisficing solution to pragmatical problems. In this study, the main objective was to develop an assessment framework to assess resilience in everyday operations. Therefore, the main result is the proposed assessment framework that is presented in the next section. Then, data collected using the framework is presented.

4.1 DEVELOPED RESILIENT PERFORMANCE ASSESSMENT FRAMEWORK (ResPAF)

The first two phases of DSR (*i.e.,* Identification and Understanding of the Problem and Suggestion of Possible Solutions) led to the development of a four-step framework to assess resilience through episodic interviews and observations. A solution for structuring the assessment was found in Document 9803 from ICAO. This ICAO document is about how to structure Line Operation Safety Audits programs in airlines, which are structured observations conducted in aircraft cockpit environments.

The theoretical foundation of these observations is the Threat and Error Management (TEM) framework (KLINECT *et al.*, 2003). These observations are conducted by an experienced pilot and have the purpose of identifying threats, errors, and undesired states of the aircraft. These elements are registered in a form that feed an organization database and can be further used for training purposes and risk analyses.

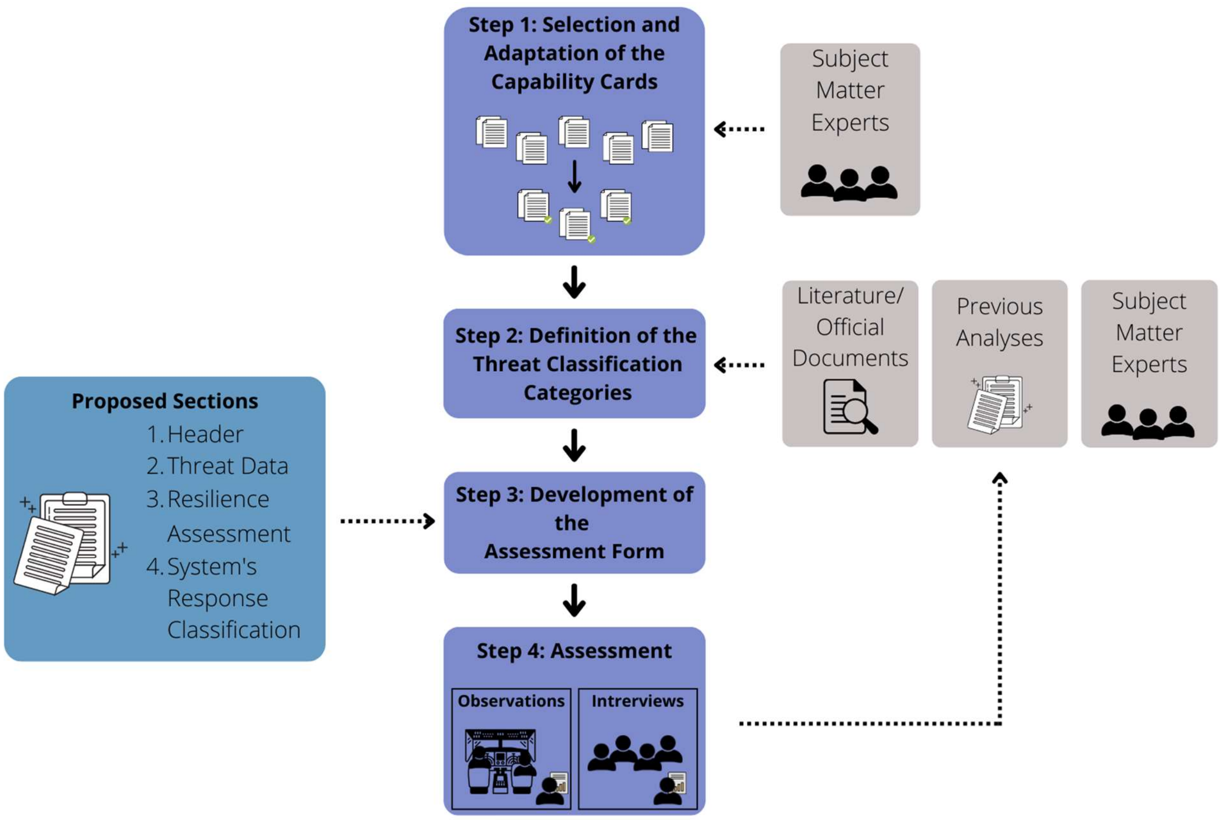
Although providing a structured manner to conduct observations, LOSA was developed considering a traditional view of safety, which is based on the information-process paradigm and assumes that humans process information in the same way machines do. This positions the focus of the analysis on the operator's behavior and, using behavioral markers to guide the observation, focus on counting and categorizing errors to eliminate them. However, this limits the comprehension of the context, simplifying the complexity in these systems (BERGSTRÖM; HENRIQSON; DAHLSTRÖM, 2011).

What these three authors argued in their study is that the unity of analysis must be shifted from the individual to the emergent phenomena in the system. Methods, in the light of RE, must allow understanding how different judgments arise and how people are “invited” by the system to do what they do. This includes comprehending how the environment in which the system exists influences the strategies adopted by the workers (BERGSTRÖM; DEKKER, 2014).

Considering the limitations that methods based on the information-process paradigm have, a theoretical foundation was sought in the field of RE and was found on the DARWIN Resilience Management Guidelines. The DRMG presents concrete ways to operationalize concepts of RE in complex sociotechnical systems. Added to that, the study conducted by Pettersson et al. (2021) shed light on the possibility of structuring an observation protocol based on the DRMG.

Therefore, it was proposed that assessing resilience could be achieved by structuring an assessment based on the structuration of LOSA, but with the theoretical foundation of the DRMG. Besides, it was suggested that these assessments could be performed through observations and episodic interviews. These assessments must allow comprehending the interactions between the elements of complex sociotechnical systems. Based on this requirement, Figure 7 presents the Resilient Performance Assessment Framework (ResPAF) developed operationalize this assessment.

Figure 7: Resilient Performance Assessment Framework - ResPAF



4.1.1 Step 1: Selection and Adaptation of the Capability Cards

The elements presented in each of the CCs show how to operationalize a certain guideline in a complex sociotechnical system. Since the DRMG were developed aiming at various levels of sociotechnical systems (*e.g.,* policy makers, regulators, society), **Step 1** of the ResPAF has the objective of selecting the CCs whose rationales are operationalizable in the context in which the assessment will occur. For instance, some CCs are related to the promotion of resilience in a community level (*i.e.,* society). It must be analyzed whether these CCs belong to the context of the activity to be assessed. Besides, some adaptations must be needed since the DRMG were not developed with the objective to assess activities. For instance, it must be considered whether the terms presented in the CCs will be understood by practitioners performing an assessment.

Step 1 can be conducted, for instance, through focus groups or interviews with SMEs. The support of these experts is crucial since they have experience in the activity. It is desirable that these experts also have the knowledge regarding the DRMG and the CCs. However, it is possible to conduct this process through the mediation of a RE expert.

4.1.2 Step 2: Definition of the Threat Classification Categories

The assessment of resilience using the ResPAF must be triggered by a threat that challenges the *status quo* of the system. This derives from the fact that the performance of a system can only be assessed in terms of resilience in relation to a threat (BERGSTRÖM; DEKKER, 2014). Thus, **Step 2** has the objective of defining the Threat Classification Categories to classify the threats that triggered the assessment. These categories can be based on literature, regulatory documents, experience of SMEs, and/or on previous analyses using this framework.

4.1.3 Step 3: Development of the Assessment Form

An Assessment Form must be developed in a manner so the person conducting the assessment can fill it with collected data. This form must aid the expert regarding on what elements should be assessed during an activity. Besides, the Assessment Form must allow the establishment of a database in the organization based on these data. Therefore, **Step 3** of the ResPAF aims at guiding the development of an Assessment Form.

Since it must allow the storage in a database, some sections be present in this form for further data analysis. The suggested sections are: 1) Header; 2) Threat Data; 3) Resilience Assessment; and 4) System's Response Classification. A Header must contain information regarding the identification of the assessment in a database (*e.g.,* an identification number). Threat Data section may contain information about what threat is being faced by the system; possible situation escalation; whether the threat was expected or not; and in which phase of the operation occurred. Besides, a field for the experts to describe what happened is also desirable since it provides contextualization to the assessment. Then, there must be a section for the assessment based on the elements of the selected CCs. It is important that this section aids the experts regarding the elements that should be assessed (*i.e.*, guiding the assessment). Finally, it is proposed that this section be filled in a descriptive manner, allowing understanding how these different elements interacted with each other during the situation. Finally, it is suggested a section for the classification of the system's response. This section allows linking the system's response to the other aspects assessed by the expert.

4.1.4 Step 4: Assessment

After developing the Assessment Form, the assessment of resilience can be conducted. It is suggested the assessments to be performed by a SME through episodic interviews or observations. Assessments conducted by SMEs have the potential to contemplate more interactions between the elements in the context of an activity.

The assessments based on episodic interviews start with the interviewee narrating an event that threatened the operation. Then, a series of probe questions elaborated according to the selected CCs on **Step 1** are asked to deepen the analysis. On the other hand, assessments based on observations may occur during an ongoing activity. The assessment is triggered by a threat and must be performed independently of the situation's outcome.

4.2 FRAMEWORK INSTATIATION IN AVIATION

4.2.1 Step 1: Capability Cards Selection and Adaptation

The CCs were selected considering the cockpit operational environment and the activities performed by the pilots in it. The process led to the selection of four Capability Cards: (1) Noticing Brittleness; (2) Enhancing the Capacity to Adapt to Both Expected and Unexpected Events; (3) Managing Available Resources Effectively to Adapt to Change in Demands; and (4) Establishing Conditions for Adapting plans and Procedures During Crises that Challenge Normal Plans and Procedures. The other cards did not present actions that are operationalizable in a cockpit environment. For example, the CC Promoting Common Ground for Cross-Organizational Collaboration in Crisis Management presents actions related to promoting exercises between organizations. These actions don’t belong to the context of activities performed by pilots in the cockpit, therefore, could not be assessed in this environment.

The selected CCs were adapted considering their core ideas and aiming at its usability by practitioners. Thus, Noticing Brittleness was changed to Identifying Fragilities. This adaptation was made aiming at making clearer the central idea of this card. Enhancing the Capacity to Adapt to Both Expected and Unexpected Events was modified to Adaptive Capacity in Relation to an Event Escalation. It was noted that this CC represents the unit of analysis of the assessment, since the response of a system in face of a threat is to avoid an escalation of the situation. Thus, this CC was summarized as a field that should be filled with the possible escalation of the situation in Threat Data section.

The CC Managing Available Resources Effectively to Adapt to Change in Demands was changed to Managing Available Resources. This modification is because, since the objective is to assess resilience, the act of managing available resources is already related to adapt to some form of change. Finally, the CC Establishing Conditions for Adapting Plans and Procedures During Crises that Challenge Normal Plans and Procedures was modified to Adapting Plans and Procedures. This modification was made because the core idea of this card during crisis situations is about the conditions to adapt plans and procedures and how they were established. These changes were made by the main author and validated by the other two authors. They were further validated empirically during the instantiations. Table 7 presents the modifications suffered by the CCs.

Table 7: Selected Capability Cards and respective modifications in aviation

Original Name	Modification
Noticing Brittleness	Identifying Fragilities
Enhancing the Capacity to Adapt to Both Expected and Unexpected Events	Field "Possible Situation Escalation" in Threat Data section
Managing Available Resources Effectively to Adapt to Change in Demands	Managing Available Resources
Establishing Conditions for Adapting Plans and Procedures During Crises that Challenge Normal Plans and Procedures	Adaptation of Plans and Procedures

4.2.2 Step 2: Definition of the Threat Classification Categories

For illustrative purposes, the Threat Classification Categories for this domain was based only on the document 9803 from the International Civil Aviation Organization (ICAO, 2002). This document regulates the LOSA programs in aviation. It figured as a viable option because it presents a list of threats in aviation domain. Due to time constraints in this research, this step was not based on expertise from experts neither on previous analyses using the assessment framework. The classification categories of threats are presented in Table 8:

Table 8: Threat classification categories in aviation

Departure/ Arrival Events	Aircraft Events	Operational Events	Cabin Events	ATC Events	Ground Crew Events
Adverse Weather	Aircraft malfunction	Operational time pressure - delays, OTP, late arriving pilot or aircraft	Cabin event/ distraction/ interruption	ATC Command - challenging clearances, late changes	MX Event
Terrain	Automation event or anomaly	Missed approach	Flight attendant Event	ATC Mistake	Ground handling event

Table 8: Threat classification categories in aviation (conclusion)

Traffic - Air or Ground Congestion, TCAS warnings	Communication event - radios, ATIS, ACARS	Flight diversion	-	ATC language difficulty	Dispatch/ paperwork event
Airport - construction, signage, ground conditions	Communication event - radios, ATIS, ACARS	Unfamiliar airport	-	ATC non-standard phraseology	Crew scheduling event
TCAS RA/TA	-	Other non-normal operational events - max gross wt. T/O, rejected T/O.	-	ATC radio congestion	Manuals/ charts incomplete/ incorrect
-	-	-	-	Similar call signs	-

4.2.3 Step 3: Development of the Assessment Form

The Assessment Form layout was developed in a Microsoft Excel sheet based on the proposed sections in Step 3 of the framework. The Header Section contained a field for the Assessment Identification Number. The Threat Data contained five fields: (1) Threat; (2) Threat Classification Category; (3) Threat Expectedness; (4) Possible Situation Escalation; and (5) Phase of Operation.

Then, the Resilience Performance Assessment Section was composed by the selected and adapted versions of the CCs. For the CC Identifying Fragilities, four fields to be filled were established: (1) Non-available information; (2) Non-available resources; (3) Goal conflicts; and (4) Bottlenecks/Restrictions in the operation. For the CC Managing Available Resources, the fields were: (1) Identification; (2) Mobilization; and (3) Utilization. Finally, for the card Adapting Plans and Procedures, the fields were: (1) Recognition of Inadequacies/Ambiguities; (2) Available Information; and (3) Alternative Courses of Action. The fields were established by synthetizing the content of the selected CCs. Finally, the System's Response Classification Section was developed. The expert must select one of the three options: (1) Disarm; (2) Recovery;

and (3) Adaptation. The final version of the Assessment Form is presented in Appendix C.

4.2.4 Step 4: Assessment

4.2.4.1 *Episodic Interviews*

The following episodic interviews were assessed since they present events that threatened the systems that faced them. The events are as follows:

The first event occurred in a shuttle flight from Africa to Brazil and was described by the captain of the flight. When reaching the non-returning point (*i.e.,* the point in a flight in which there is not enough fuel to return to the departure airport), the captain started to check the instruments looking for any abnormal indication. At this time, he noticed that the cabin pressurization indicator was indicating that a leakage was occurring. Due to the risk of hypoxia, the crew tried to find the place where the air was leaking. That was their first option since descending to a lower altitude would compromise their fuel endurance. Finally, they were able to locate the spot and stop the leakage using wet paper.

The second event was described by the captain of the flight and occurred in a cargo flight landing at Rio de Janeiro at 4 a.m. When turning to final approach, the Autopilot and Flight Director disengaged without a motive, but the indications from the Instrument Landing System (ILS)[3] remained unchanged. The crew continued the approach based on the ILS indications only. The captain stated that the risk they were facing was the presence of high elevations on the left side of their track. Since it was a night flight, the crew was not able to precise the exact location of these elevations.

The third event occurred in an approach at São Paulo in adverse weather conditions. When starting to reduce speed, the stick shaker[4] of the aircraft activated, even though the aircraft speed was above the one this should happen. The crew was worried that, near the ground, some input from the stick pusher[5] would put the aircraft in a downward trajectory. They decided to discontinue the approach and performed a troubleshooting while in a holding pattern. They called the maintenance department of

[3] ILS is a system that guides the aircraft to the runway via radio frequencies.
[4] Stick shake is a system that vibrates the control wheel to warn the pilots that they are close to lose lift
[5] Stick pusher is a system that inputs downwards commands at the control wheel to regain lift

the company via radio and, with their support, tried to solve the problem. However, they were not able to figure out what was causing that malfunction. Finally, they decided to turn off the circuit breaker of this system and proceeded to land.

The fourth event occurred in a landing at Porto Alegre and was described by the copilot of the flight. During the final approach, the aircraft was lower than it should be based on the visualization of the PAPI[6]. Then, a correction by the copilot was made to return the aircraft to the ideal flight path. However, this correction took longer than it should and the aircraft, by the time it crossed the runway threshold, was higher than the recommended altitude. Then, the copilot, when performing the flare (*i.e.,* maneuver to drain airspeed so the aircraft can settle to land), finished it higher and the aircraft passed the touchdown zone of the runway. The captain, then, took the controls of the aircraft and forced the aircraft to the ground. Since they landed after the touchdown zone, they had to use manual brakes, instead of the autobrake system, to reduce speed and avoid a runway excursion.

In each of the episodic interviews was possible to identify aspects that could be related to the selected CCs. Some examples were selected and are presented below. The Threat Data sections of the assessment forms are presented in Table 9.

Table 9: Threat Data section from episodic interviews in aviation

	Episodic Interviews			
Threat Data Sections Fields	**#1**	**#2**	**#3**	**#4**
Threat	Depressurization	Autopilot disconnection	Stick shaker activation	Deep landing
Classification of the Threat	Aircraft Malfunction	Automation Event or Anomaly	Aircraft Malfunction	Other Non-Operational Event
Was the Event Expected?	No	No	No	No
Possible Situation Escalation	Hypoxia and Fuel Shortage	Controlled Flight into Terrain	Loss of Control In-flight	Runway Excursion

[6] PAPI is a set of four lights on the side of the runway that indicates the right glidepath to the pilot.

Table 9: Threat Data section from episodic interviews in aviation (conclusion)

Phase of operation the threat was detected / Phase of Operation the threat occurred or would occur	Cruise Flight/Cruise Flight	Final Approach/Final Approach	Intermediate Approach/ Intermediate Approach	Landing/Landing

- Identifying Fragilities

During Event #2, the crew was performing a night landing near a mountainous area. Although the crew was aware of the presence of these mountains, they could not precise, exactly, where these elevations were. Added to that, the aircraft did not have the equipment that allows to precise the location of these elevations. These facts were interpreted, respectively, as non-available information and non-available resources.

Since the crew had the runway in sight, they felt pressured to continue the approach even without understanding what caused the malfunction. That fact, added to the necessity of not delaying the next flight, contributed to the pilots to continue the approach, and not performing a go-around maneuver. Both aspects were interpreted as goals conflicts. Finally, since elevations were present on the left side of final approach course and the crew was not able to precise the exact location of them, the flight path had to be from the center of the final approach course to the right. That was interpreted as a restriction in the operation.

- Managing Available Resources

On Event #3, the crew contacted the Maintenance Department of the company via radio. The two pilots and the maintenance personnel worked together to understand what was causing the malfunction and how to solve it. The contact was made via radio using a pre-determined specific VHF frequency. That is standard practice in the company. Then, the crew informed what happened and the Maintenance Department gave them instructions regarding on what to do to try to solve the malfunction.

The crew used the Maintenance personnel as a resource to try to solve the problem. This resource was identified based on operational procedures. Finally, the mobilization occurred via VHF radio, through which the communication occurred.

Finally, the utilization of this resource occurred as the crew was assisted with instructions given by the maintenance personnel.

- Adapting Plans and Procedures

During Event #4, the crew had to adapt the way they settled the aircraft to land. This was done via input made by one of the pilots. The information available for this adaptation was the position of the aircraft relative to the touchdown zone and the Vertical Speed of the aircraft. This two information provided the crew the understanding that the aircraft would touch the runway after the point where it was supposed to. Added to that, the copilot stated that, if the aircraft had flown farther than what occurred in the situation, he would have performed a go-around.

4.2.4.2 *Observation*

For the evaluation of the framework as an observation tool for aircraft cockpit environment, a flight was performed in an FTD. The flight route was between Bacacheri airport and Joinville airport, both regional airports in the south region of Brazil. The flight departed in Visual Meteorological Conditions[7] and, as progressed throughout the route, the weather started to deteriorate, culminating in an approach to land in Instrument Meteorological Conditions[8] with heavy rain.

The flight lasted 1h32min and several threats were identified by the expert throughout the simulated flight. Figure 8 shows the simulated flight session and the Threat Data sections of the Assessment Forms filled by the expert are summarized on Table 10.

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[7] Meteorological conditions that pilots are able to maintain visual references on the ground.
[8] Meteorological conditions that pilots are not able to maintain visual references on the ground and must rely on their instruments.

Figure 8: Simulated flight session

Table 10: Threat Data section from the observation in aviation

Threat	Threat Classification Category	Was the Threat Expected?	Possible Situation Escalation	Phase of operation the threat was detected / Phase of Operation the threat occurred or would occur
Fuel Selector in OFF position	Cabin Event/Distraction/ Interruption	No	Flight Cancellation	Pre-Departure/ Pre-Departure
Disorientation	Airport – Construction, Signage, Ground Conditions	Yes	Runway Incursion	Pre-Departure/ Taxi-Out
Before Takeoff Checklist not completed	Cabin Event/Distraction/ Interruption	No	Engine Failure	Before Takeoff/ Before Takeoff
Communicating with ATC before the checklist items were completed.	Cabin Event/Distraction/ Interruption	No	Loss of Control In-flight/ Controlled Flight into Terrain	After Takeoff/ After Takeoff

Table 10: Threat Data section from the observation in aviation (conclusion)

Thunderstorm Clouds	Adverse Weather	No	Loss of Control Inflight	Cruise Flight/ Cruise Flight
Thunderstorm Clouds	Adverse Weather	Yes	Loss of Control Inflight	Cruise Flight/ Before Descent
Autopilot Malfunction	Automation Event or Anomaly	No	Controlled Flight into Terrain	Initial Descent/ Initial Descent
Thunderstorm Clouds	Adverse Weather	No	Flight Diversion	Initial Approach/ Initial Approach
Go-around	Missed Approach	No	Flight Diversion	Approach and Landing/ Approach and Landing
Disorientation	Unfamiliar Airport	No	Runway Incursion	After Landing/ After Landing

In each of the system's response to the identified threats, the expert was able to identify aspects related to the selected CCs. These aspects are presented below.

- Identifying Fragilities

It was noted by the expert that the crew appeared to be confused regarding the identification of the taxiway they were supposed to be at the departure airport. This was related to the deficient signage of the airport. It was stated that the crew did not have the information about where they should turn left to enter the taxiway.

On another phase of the flight, this time during Initial Descent, the observer registered that the crew faced a malfunction with the Autopilot and this system stopped working. Because of that, the observer noted an increase in the crew's workload. This fact, added to an approach in a mountainous area was classified by the observer as a bottleneck in operation.

- Managing Available Resources

Before initiating the descent (*i.e.,* Before Descent phase of flight), the crew faced adverse weather conditions, in which multiple thunderstorms clouds were present along the flight route. Then, they requested to initiate the approach from a different place than the one prescribed in the procedure. The observer noted that this decision was based on the use of the weather radar once this equipment allowed the pilots to visualize the location of thunderstorms clouds. Therefore, the radar can be interpreted as a resource mobilized by the crew to respond to the situation.

After landing at the destination airport, the observer noticed that the airport was unfamiliar to the crew. The crew used the airport chart to identify the taxiway they were supposed to turn onto. They compared the chart with the layout they were seeing through the window. Therefore, the airport chart was identified as a resource used by the crew to respond to the identified threat.

- Adapting Plans and Procedures

Considering the threat identified prior descent (*i.e.*, Adverse Weather), by using the weather radar, the crew was capable to visualize where the thunderstorms clouds were in relation to the flight path of the aircraft. Having this information allowed them to adapt the approach procedure they were supposed to follow. In addition, the crew contacted the control tower of the destination airport to get information about the weather conditions. The information the controller passed to them can also be considered as information availability for the crew.

In a similar way, during Initial Approach the crew was also under adverse weather conditions. They tuned the Florianopolis ATIS[9], which was their alternate airport, to gather information about the weather at this region. The observer classified this weather information as information availability to the crew.

[9] Automatic messages transmitted via radio to inform the pilots of important aspects about the region of airports

4.3 FRAMEWORK INSTANTIATION IN OIL AND GAS OPERATIONS

4.3.1 Step 1: Capability Cards Selection and Adaptation

From the 13 CCs, each expert selected six of them. Table 11 presents the CCs selected by the experts.

Table 11: Selected Capability Cards by Oil and Gas experts

Capability Card	Expert #1 Choices	Expert #2 Choices
Sharing Information on Roles and Responsibilities Among Different Organizations		X
Enhancing the Capacity to Adapt to Both Expected and Unexpected Situations	X	X
Establishing Conditions to Adapt Plans and Procedures in Face of Events that Challenge Plans and Procedures	X	
Managing Available Resources Effectively to handle Unusual Changes in Demands	X	X
Noticing Brittleness	X	X
Identifying Sources of Resilience: Learning from What goes Well	X	X
Supporting Development and Maintenance of Alternative Methods of Working.	X	X

Only the CCs chosen by both experts were selected and adapted. The process of adaptation occurred similarly to the one in Aviation. Some considerations must be made regarding the CC Supporting Development and Maintenance of Alternative Methods of Working. This CC includes actions related to the identification of major system failures scenarios; the revision of working methods; and the dissemination of the information about these alternative methods. The actions presented in this CC are a product of the proposed framework. Besides, the core elements of this CC relate with other CCs (*e.g.*, Noticing Brittleness). Therefore, this CC and its elements were not included in the Assessment Form.

Moreover, the CC Identifying Sources of Resilience: Learning from What Goes Well is composed by actions related to the process of understanding the work-as-done by investigating how expected and unexpected conditions were handled. The authors argue that this is the very purpose of the proposed assessment framework. Therefore, this CC and its elements were also not contemplated in the Assessment Form. Table 12 presents the selected CCs and its adaptations.

Table 12: Selected Capability Cards and respective modification on Oil and Gas

Original Name	Modification
Noticing Brittleness	Identifying Fragilities
Enhancing the Capacity to Adapt to Both Expected and Unexpected Events	Field "Possible Situation Escalation" in Threat Data section
Managing Available Resources Effectively to Adapt to Change in Demands	Managing Available Resources

4.3.2 Step 2: Definition of the Threat Classification Categories

For illustrative purposes, the Threat Classification Category for the context of oil and gas operations was based only on literature. This choice was made since there is no official document listing possible threats in Oil & Gas operations. Moreover, there was no sufficient time in research to base this step on expertise from experts or on previous analyses using the framework.

Kvalheim and Haugen (2013) applied the Threat and Error Management framework in drilling operations. For that, they created two categories of threats that relates to operational environment: external and internal threats. External threats are environmental factors (*e.g.,* geology), equipment failure, last minute changes, and external error. On the other hand, internal threats are individual or team errors.

4.3.3 Step 3: Development of the Assessment Form

The Assessment Form layout was developed similarly to the aviation, considering the data collected in **Step 1** and **Step 2** of the ResPAF. The Header Section contained a field for the Assessment Identification Number. The Threat Data contained five fields: (1) Threat; (2) Threat Classification Category; (3) Threat

Expectedness; (4) Possible Situation Escalation; and (5) Phase of Operation the threat was detected/Phase of Operation the threat occurred or would occur.

At the Resilience Assessment section, the CCs Identifying Fragilities and Managing Available Resources were added. The fields to be filled related to Identifying Fragilities were: (1) Non-available information; (2) Non-available resources; (3) Goal conflicts; and (4) Bottlenecks/Restrictions in the operation. For the card Managing Available Resources, the fields were: (1) Identification; (2) Mobilization; and (3) Utilization. Finally, the System's Response Classification section was elaborated the same way in aviation, with the fields (1) Disarm; (2) Recovery; and (3) Adaptation. Appendix D presents the Assessment Form for Oil and Gas drilling operations.

4.3.4 Step 4: Assessment

4.3.4.1 *Episodic Interview*

Four episodic interviews explored four events that were challenging for workers in Oil and Gas domain. The events are as follows:

This first event occurred when the operators were removing the drill pipe from the well. This drill pipe was a combined column with two different sizes. Because of that, the handling equipment must be changed to match the size of the column. For some reason, that did not happen, and the handling equipment got stuck in one of the columns. The interviewee stated that, since they were in downtime, therefore not being paid, they tried three strategies to release the handling equipment, from the fastest to the safest. Finally, they decided to remove the drill pipe with the equipment stuck on it, laid it on the floor and remove it with another tool. That was a challenging situation because the interviewee never experienced something similar before and there was a risk of the pipe falling into someone.

The second event occurred during drilling operations. The interviewee noticed that some drilling parameters, when compared to the simulations, were different. However, all the other parameters seemed to be normal. The interviewee asked for the support of other specialists (*e.g.,* geologist) and realized that a leakage of drilling fluid through a hole in the pipe might be occurring. The drill pipe was then removed, and a hole of a cup-diameter sized was observed in it. This hole could have expanded and, consequently, sheared the column.

The third event occurred when the pipe connector, which is something attached to the pipe, fell into the well. Then, an operation called fishing was conducted to recover this part. This was a challenging event because, although fishing operations happens sometimes, fishing a pipe connector was never done before by the interviewee.

The fourth event occurred when operators were abandoning a well to initiate a sidetrack (*i.e.*, a horizontal diversion on the well) to drill a new well. For that, they had to remove part of the old structure of the well. This structure is composed by two concentric columns with the space in between partly cemented. They planned to remove a section of these two columns that had not cement in between. However, when they started the operation, they noted that the space in between the columns was all filled with cement. The operators had to pull the concentric columns off the well and remove the cement using a torch and a hammer. However, there were residual gas between these columns that could explode because of the use of the torch. Below are some examples of elements presented in the narrated events that relate with selected CCs. Table 13 presents the Threat Data of these events.

Table 13: Threat Data section from the episodic interviews in Oil and Gas

	Episodic Interview			
Threat Data Section Fields	**#1**	**#2**	**#3**	**#4**
Threat	Equipment Jam	Hole in the column	Tool Jam	Pipe Jam
Threat Classification Category	Equipment Failure	Equipment Failure	Equipment Failure	Equipment Failure
Was the Threat Expected?	No	No	No	No
Possible Situation Escalation	Dropped Object	Column Shear	Loss of another tool in the pipe	Explosion

Table 13: Threat Data section from the episodic interviews in Oil and Gas (conclusion)

Phase of operation the threat was detected/ Phase of operation the threat occurred or would occur	Drilling/Drilling	Drilling/Drilling	Drilling/Drilling	Completion/ Completion

- Identifying Fragilities

On Event #8, the drilling unit was combined with a production rig. During the operation to remove the cement from between the columns, they noticed that, during the day, they had to slow down this operation because they had more people of the Health, Safety and Environment (HSE) department observing them. However, during the night, they could increase the speed of the operation since there were less people watching. This was interpreted as a goal conflict.

During Event #6, the operators did not know how much weight the equipment they were using could support. That is because they were using it with a different purpose, adapting it to solve the problem they were facing. This was interpreted as non-available information. Moreover, they were in downtime period, meaning that, because they had to stop the operation to solve a problem, they would not get paid for that time. This was a goal conflict because they had to solve the problem quickly and safely.

- Managing Available Resources

When dealing with the tool jam situation on Event #8, the workers did not know, precisely, the way the tool was positioned inside the pipe. This information influences the equipment choice process to “fish” the tool that fell into the pipe. Then, they decided to use an equipment that works as a stamp. This equipment was sent down into the pipe and the position of the tool was marked on its surface. The identification of what tool should be used was based both on operational procedures and on the mark the tool that was inside the pipe left on the stamp. The adequate fishing tool was already present at the operational area and was utilized according to the fishing techniques.

4.3.4.2 *Observation*

The operation observed was conducted by the cargo handling team and consisted of moving an equipment that would be used by the drilling team. This equipment weighs, approximately, 2 tons and was moved to the drilling floor, the place in which the drilling team works. Since this operation involved delivering an equipment for the drilling team, members of this team helped to position the equipment in the right place, even though they are not trained in cargo handling operations.

Normally, the cabin of the crane used in these operations is about five meters above the level in which the cargo is lifted or settled. However, since the equipment was being moved to the drilling floor, which is higher than the places where the cargos are stored, the crane cabin was at the same level of the place in which the equipment was to be settled. Because of that, the crane operator could always visualize the signalman during the operation.

The spot in which the equipment was being settled was very near to the rig tower (*i.e.,* the place where the pipes are verticalized and connected). Because of that, the crane operator had to pay attention to whether the cable of the crane was hitting it. Besides, since the drilling team was helping to settle the cargo in the right place and they don't have experience in this type of operation, the positioning of these workers was also a concern for the crane operator. Figure 9 shows the drilling ship with the crane used in the operation (circled) and the rig tower (arrow) marked, Figure 10 shows an example of a cargo handling operation (not the one assessed), and Table 14 present the Threat Data of the Assessment Form. Below are some examples of what has been filled related to each of the selected CCs.

Figure 9: Drilling-ship in which the observation was conducted

Source: Commercial (2017)

Figure 10: Example of cargo handling operation

Source: Offshore Handling Systems Ltd (2022)

Table 14: Threat Data section of assessment form from observation in Oil and Gas

Threat	Threat Classification Category	Was the threat expected?	Possible Situation Escalation	Phase of operation the threat was detected/Phase of operation that threat occurred or would occur
Unsafe Positioning of Drilling Workers	External Error	Yes	Dropped object by the cable hitting the rig tower.	Cargo Lifting/Cargo Settlement

- Identifying Fragilities

The observer noted that, to help the cargo handling team, assistants of the drilling team proactively assisted on the process of settling the cargo on the determined spot. However, they had not participated on the pre-job planning meeting with the cargo handling team, nor they were trained in cargo handling operations. Thus, it was not possible to know whether they know how to properly handle the cargo. This was interpreted as non-available information.

- Managing Available Resources

Although the crane operator could see the signalman with no difficulty, the communication between them occurred through VHF radio. Since they were operating very close to the rig tower, the crane operator would be overloaded with visual information. He would have to pay attention to whether the cable of the crane was hitting the rig tower, to the positioning of the equipment being moved in relation to the cargo handling and drilling teams assistants that were helping to settle the cargo, and to the hand signals from the signalman. Therefore, the radio was interpreted as a resource that was used in this operation.

4.4 FRAMEWORK FINAL EVALUATION

Evaluating the artifact regarding its utility and usability aims at understanding to what extension it provides a satisficing solution to the identified problem and how easy is for people to use the artifact, respectively. Tables 15,16,17 and 18 present the answers of the experts who conduct the observations regarding these two dimensions and a summarization regarding to what extent these aspects were addressed by the framework

Table 15: Aviation's expert answers regarding artifact's utility

Questions	Answers
Do you think this protocol helps understanding how work-as-done is performed? How?	"I believe so. As far as I could see, we have many elements in the protocol. For instance, the threats, its classification, fragilities, etc. All these elements were put in a logical way. During the observation, I noticed we could really understand how the work was performed, its difficulties, the management, etc. It was very easy to observe these aspects in the video record. I don't know whether my previous experience as a LOSA observer contributed to that, but I felt very comfortable, it was not difficult to interpret. So, it really allowed to understand how work was performed."
Do you think the aspects addressed in the protocol are pertinent?	"For sure, the aspects were pertinent. All the elements in the protocol are worth as an analysis object. For me, the protocol was very interactive."
Can you envision an applicability for the data collected using this protocol?	"Yes, for sure. A lot of data was collected regarding human factors, how the pilots interacted with each other and how they handled the situations. Based on this information we can look for a pragmatical solution. We can quantify these data and look for a mitigation"

Table 16: Oil and Gas' expert answers regarding artifact's utility

Questions	Answers
Do you think this protocol helps understanding how work-as-done is performed? How?	"Yes. Because it correlates risks and their classification, helping to identify possible failures to adopt the necessary resources to keep the activity under control. Another very positive element is the final analysis of the system performance."
Do you think the aspects addressed in the protocol are pertinent?	"Yes, the aspects of the protocol are very pertinent and related in a direct and objective way."
Can you envision an applicability for the data collected using this protocol?	"Yes, mainly in the cause-and-effect relationship."

Table 17: Aviation's expert answers regarding artifact's usability

Questions	Answers
Were you able to assess the elements in the protocol with your current knowledge?	"It is a tool different from the LOSA. It has similar aspects, but some aspects go beyond what is assessed on LOSA. I believe there is no need of an advanced knowledge to use the artifact. However, I would suggest that the observer have some basic training in human factors, since there are some technical terms. The tool is very easy to use, but my background as a LOSA observer may have influenced that."
Do you think you would be able to conduct the assessment without the aid of the researcher?	"I think the person must have contact with the artifact in a training exemplifying with practical examples how the tool must be used. Then, the guidance of a researcher would no longer be necessary."

Table 18: Oil and Gas’ expert answers regarding artifact’s usability

Questions	Answers
Were you able to assess the elements in the protocol with your current knowledge?	“Yes, I was able to clearly assess the aspects present in this protocol through my knowledge”
Do you think you would be able to conduct the assessment without the aid of the researcher?	“Yes, I think I would be able to apply this protocol without the immediate help of the researcher, however, I think there should be support in case there is any doubt because of some particularity in resource management. “

5 DISCUSSION

5.1 PRAGMATICAL PROBLEM AND PROPOSED SOLUTION

Assessing resilience has been a topic explored by many researchers. In complex sociotechnical systems, a resilient response emerges from the interactions between the multiple elements that constitute these systems (BERGSTRÖM; DEKKER, 2014). Therefore, assessing resilience is about understanding how work-as-done is performed and how local adaptations contribute to the overall performance of the system.

A proposed solution to address this necessity is the Resilient Performance Assessment Framework (ResPAF) developed in this study. It aims at providing a structured manner to shed light and understand how these interactions occur in face of a situation that threatens the system during an operation. This framework focuses on aspects that the other methods developed in the field of RE are limited to address.

When compared to RAG, the ResPAF deepens the understanding on how local interactions originated a resilient performance. Differently from the former, the proposed solution is theoretically founded on guidelines that were developed in a bottom-up approach based on the expertise of experts in crisis management (DARWIN, 2018). This constructivist approach contrasts with the normative one that RAG is based on (*i.e.,* the cornerstones of resilience), which has been criticized for lacking further literature references for their development (DEKKER, 2019; HOPKINS, 2014).

On the other hand, the ResPAF and the FRAM can be used in a complimentary manner. The fact that the performance of complex sociotechnical system emerges from the interactions raises the necessity of having a functional model of the system (DISCONZI; SAURIN, 2022). The main goal of FRAM is modelling work-as-done and analyzing how different variabilities may combine and resonate through the system. Thus, its units of analysis are the couplings between these functions. Since the ResPAF deepens the understanding of how variabilities were present in work-as-done, it can be used to improve the analysis conducted on FRAM. For instance, Bueno et al. (2021) applied FRAM to identify functions that present resilient performance. By using the ResPAF, it is possible to deepen the analysis of these functions, understanding how the overall performance of the system emerged from these functions.

5.2 EXTENDING DARWIN RESILIENCE MANAGEMENT GUIDELINES APPLICABILITY

Complex sociotechnical systems range from a group of workers interacting with artifacts to a whole society, comprised by a myriad of social elements and artifacts. Resilience in these systems is present at different spatial scales (BERGSTRÖM; DEKKER, 2014). The DARWIN Resilience Management Guidelines were developed with the goal of improving the response of infrastructure and social structures in face of expected and unexpected crises (DARWIN, 2018). Thus, it focuses on improving resilience at higher levels in sociotechnical systems.

The instantiations of the ResPAF comprised a different application of the DRMG in a distinct spatial scale than the one initially proposed on project DARWIN. By using the aspects that are present in the CCs to base assessments of activities at different sociotechnical levels, the ResPAF offers a structured way to assess how and to what extent some interventions proposal, related to each CCs, contributed to the system’s response. Thus, extending the original applicability.

5.3 UTILITY OF THE PROPOSED FRAMEWORK

5.3.1 Understanding Interactions and Relationships Among System Elements

Assessing resilience in complex sociotechnical systems shall occur by understanding how work is performed (work-as-done) and its inherent variabilities (HOLLNAGEL, 2012). These systems, in a daily basis, must adapt their functioning to cope with its inherent complexity and uncertainties. Its resilient performance (or its absence) emerges from the interaction between the various social and technical elements of the system, not only from the inherent characteristic of these elements (CILLIERS, 2005).

The data collected using the ResPAF allowed to understand how different elements that compose both the dimensions of complex systems (*i.e.,* socio and technical) interacted to deal with a threatening situation in ways that were not predicted beforehand in manuals or procedures. For instance, during the observation in Oil and Gas domain, the use of the radio as the primary mean of communication allowed to reduce the crane operator’s visual information load. That was only possible because, due to previous experience, the cargo handling team knew that, when the cargo operations are being conducted to attend another drilling-ship team's demand, the workers from that team try to help with the settlement of the cargo. These data shed light on the interactions that contributed to an operation happening near to the rig tower and with the presence of people from another team ended well.

Another example is the night landing in mountainous area narrated in one of the episodic interviews in aviation. According to the pilot, he was able to continue the approach avoiding the mountains by using the navigation display in Map Mode that provided him the track information of the aircraft. Also, he knew that these mountains were on the left side of the aircraft track. The comprehension of how these different elements interact with each other and with the environment matches with the necessity stated by Bergström and Dekker (2014) regarding focusing on the interactions and relationships to understand how the system performed (or not) resiliently.

Due to the non-linearity of complexity and the impossibility to predict the effect of a cause in a direct way, decisions made at one level of the system has the potential to influence how decisions are made in another level of it (LEVESON, 2011; RASMUSSEN, 1997). The assessments based on the episodic interviews and observations allowed to identify influences from other levels of the system. For instance, the fact that the supervisor, during the observation in Oil and Gas, classified the presence of members from the drilling team as a threat reflects his knowledge regarding the probable absence of appropriate cargo handling operations training for these members.

Another example of these influences can be noticed on the episodic interview #5. During this event, the handling tool jammed in one of the columns and the period that the drilling team was trying to solve the problem was not counted as working-hours. The interviewee stated: "In this case, as we were in downtime, the other thing that comes into consideration is the time to execute each of these options. It's no use for someone to say: "I have an option here, which is the safest of all, but it takes 3 days". Considering that the establishment of a downtime period is not decided by the drilling team, this interview fragment shows how the framework aids at identifying these influences in the system.

It is important to note that, although the elements assessed in each of the domains were considered pertinent by both experts, they were originated in **Step 1** of the framework. This implies that the assessment is dependent on how **Step 1** was conducted. In this study, for the aviation domain, a consensus was reached between the authors. However, the process conducted for Oil and Gas (*i.e.,* interviews) originated two sets of selected CCs. It was chosen to select only those CCs that both experts selected. However, this process limits the influence of expertise from the experts on the choice of the CCs. It is probable that a focus group with the experts may provide better results since would allow the experts to clarify their ideas regarding the topic (KITZINGER, 2006).

Besides, the process was mediated by the author of this study. This suggests that the way the author presented the rationale of each CC was influenced by his perceptions and previous experiences both as pilot and as a RE researcher. For example, the CC Supporting Development and Maintenance of Alternative Working Methods deals with actions from the organizations to support alternative working methods. However, it may have been interpreted by the Oil and Gas experts that selected it that this CC is about the alternative working methods itself. A solution for that is that the selection and adaptation of the CCs be made by experts who studied the DRMG. This would improve the process in **Step 1**.

5.3.2 The Assessments and the Hawthorne Effect

When collecting data, several aspects may influence the results. One of these influences was noted in studies conducted to increase productivity in the Western Electrical Company's Hawthorne in Chicago during the first decades of 20th century. It was observed that any change in working conditions would increase productivity (MCCARNEY *et al.*, 2007). This effect was associated, not with the changes itself, but with the awareness of people being observed or having behavior assessed, causing distortions in the data collected and was named Hawthorne effect (MCCAMBRIDGE; WITTON; ELBOURNE, 2014). Therefore, any assessment based on data collected in a context that people know that are being assessed is susceptible to the Hawthorne effect.

Considering that the ResPAF aims at understanding the interactions between people and artifacts through episodic interviews and observations, the Hawthorne effect may distort the data collected. That would occur because, in case of interviews, people may distort the narrative or, in case of observations, people may change the way they interact with each other and with the artifacts. However, the author argue that the way the framework was developed and is intended to be used, the Hawthorne effect could, if not eliminated, be reduced.

First, this effect was noticed in groups of workers who were observed by managers conducting a research program (MCCAMBRIDGE; WITTON; ELBOURNE, 2014). This implies that there was a hierarchical difference between these two groups, especially during the 1920's and 1930's, when these studies were conducted. On the other hand, the assessment in the instantiations were conducted by experts whose work activities occur at the same hierarchical level of the people working. The supervisor in Oil and Gas act as the leader of the cargo handling team and it is directly involved in the operations. For instance, he sometimes performs as a signalman or helps positioning the cargo during its settlement. It is believed that this mitigates the Hawthorne effect. This can also be achieved in the interviews by selecting interviewers that works at the same organizational level of the interviewees.

Second, the focus of the studies conducted on the Hawthorne Electrical Company was to identify what changes must be made to shape human behavior for better productivity. Therefore, the workers knew that the unity of observation from those studies was their behavior. Conversely, the focus of the assessments in this study is understanding how different elements of a complex system interacted and originated a system-level behavior capable of coping with a certain situation. Adopting the interactions of the system as the unit of observation and analysis represents a systemic approach to understand work-as-done, rather than a behavior-based one.

5.4 USABILITY OF THE PROPOSED FRAMEWORK

5.4.1 Required Level of Knowledge

To achieve its objectives, it is important that the artifact be developed considering who is going to use it and the level of knowledge required for that. Considering that, the proposed artifact in this study must be used by someone who has experience in the activity being assessed. That is because experts have more mental models and are capable of identifying the interactions and relationships that occurs during an activity (KLEIN; CALDERWOOD; MACGREGOR, 1989). However, the study showed that the required level of knowledge varies whether the assessment is being conducted through interviews or observations.

For interview-based assessments, a semi-structured guide was followed based on the Assessment Form. This allowed data to be collected in the Oil and Gas domain even without the interviewer being an expert in the domain. The difference between an expert and a non-expert in this case relies on the former being capable of elaborating further questions to deepen the understanding about the interactions that occurred in the event. Besides, it is possible that the interviewee will be more comfortable narrating the event to a domain-peer, providing more details about the event. This was noted in some interviews, which the interviewees used analogies to explain to the main author what happened in the event. This may have caused details from the situation to be missed or distorted.

On the other hand, observation-based assessments conduct by non-experts would impose several limitations to the assessments. This is related to the direct nature of data collection based on observations and the contextual aspects that must be contemplated in it. Subtle cues in the context are only readily detected by experts (CRANDALL; KLEIN; HOFFMAN, 2006). Thus, the author suggest that observations conduct using the proposed framework be performed by experts.

5.4.2 Assessor Training and Discriminant Validity

An important aspect of any performance assessment is the accuracy of what is being assessed. This accuracy is influenced by how distinguishable the variables being assessed are from each other. This distinguishment is called discriminant validity (FARRELL; RUDD, 2009; LIEVENS, 2001).

An aspect that influences discriminant validity on assessments is the assessor training. Training assessors regarding on what should be assessed, added to a pre-determined structure of observation, provides higher discriminant validity (LIEVENS, 2001). Considering that assessments conducted using the framework proposed in this study is based on pre-determined categories (*i.e.,* the Capability Cards), it is argued that a training in relation to framework would be beneficial for the assessment.

Since none of the observers received a training regarding the framework, some issues involving discriminant validity occurred. For instance, in the observation-based assessment conducted in Oil and Gas, the expert mentioned, in Managing Available Resources: “The radio was used for communication between the crane operator and the signalman, although they were seeing each other, as the crane operator needed to be aware of the proximity of the crane boom to the rig tower, the crane ball and cable near the suspended basket and to crane equipment." In this fragment, the expert noted the use of a resource (*i.e.,* radio), but considered the proximity to the rig tower also something that should be mentioned at the Managing Available Resources fields. It is argued that this aspect represents a restriction in the operation and, therefore, should be mentioned in Identifying Fragilities field.

Moreover, the aviation expert mentioned that he had no difficult in using the Assessment Form, but this may relate to his experience as a LOSA observer. He also noted that, based on his experience, takes some time until the assessors get used to the assessment process. Thus, discriminant validity tends to increase as the assessors gain familiarity with the assessment process.

6 CONCLUSION

This study aimed at addressing a gap that have being discussed in the field of Resilience Engineering and it is crucial for its evolution: assessing resilience. Assessing resilience is not about understanding the individual characteristics of the elements in a reductionist approach but understanding how system's performance emerged from the interactions and relationships between these elements. For that, the following research questions was established: **how to assess resilience in everyday operations?**

Complex sociotechnical systems are only capable of achieving its objectives due to their capacity of dealing with threats and opportunities that occur. Without this capacity, they would collapse in face of situations with disruptive potential. The fact that successes and failures arise from the variabilities in everyday work makes crucial to understand how they occur so to engineer resilience in these systems.

Although some methods were developed aiming at addressing this necessity, they present limitations in relation to understanding how everyday work occurs and how resilience emerges from the variabilities present in it. For being an easy-to-use tool, RAG is largely used to assess the cornerstones of resilience adopting a question-answer rationale. However, this rationale is also what limits its applicability to understand how system level behavior emerged from local adaptations, since it does not explain how different elements interacted. Similarly, although focusing on defining the couplings between different activities performed during everyday work, FRAM is not, *per se*, an assessment tool. Rather, it provides a model of how work is conducted and how variabilities may aggregate with each other.

By adopting Design Science Research as methodology, a framework, called Resilient Performance Assessment Framework (ResPAF) to assess resilience, based on the DARWIN Resilience Management Guidelines was developed. The choice for this theoretical foundation is justified by the bottom-up approach through which these guidelines were developed. The assessments conducted using this framework are interview and observation-based and focus on understanding how local adaptations occur, considering the interactions and relationships between the elements of the system, rather than on the behaviors of the workers involved in the activity being assessed.

ResPAF is composed of four steps: (1) Selecting and Adapting the Capability Cards; (2) Defining Threat Classification Categories; (3) Development of an Assessment Form; (4) Assessing. Steps 1 and 2 provides information for the development of the assessment form that should be used; Step 3 develops an Assessment Form to guide the assessments with fields to be part of a database in organizations; and Step 4 is the assessments itself. The framework was instantiated in two industries (*i.e.,* aviation and oil and gas) and provided a deeper understanding of how a resilient performance emerged from interactions and relationships between elements of the system.

Organizations may leverage from this framework by using it in programs of structured assessments of their activities. Like LOSA in aviation, these programs may provide data collected using the framework to feed training programs and risk management activities. This allows these organizational activities to contemplate the complexity that is present in their operations and to understand how macro-behaviors of the system emerged from local adaptations.

There are many complex sociotechnical systems with uncountable activities being performed. The steps of the framework were developed so assessments can be conducted at different sociotechnical levels and in different domains. Therefore, further applications of the framework may result in data similar to the ones collected in this study. Besides, considering that time was a constraint in this study, studies replicating the framework in other domains may benefit from more elaborated ways to conduct the steps proposed in the framework.

This research presented some limitations. Since it was conducted mainly through the Covid-19 outbreak, the development process of the framework was delayed due to restrictions to instantiate the framework naturalistically during the first 18 months of the study. It is possible that, without this constraint, the final version of the assessment form layout might have been tested. A second limitation is the maturity of the Capability Cards. The DARWIN Resilience Management Guidelines were developed in 2018 and still need further studies and developments.

6.1 FUTURE STUDIES

6.1.1 The Assessment Form as a Briefing Tool

The capacity of a system to adjust its performance when facing possible threats relates to knowing whether its actual configuration is adequate to possible arising demands (WOODS, 2011). Anticipating the consequences of actions that might be taken in complex systems is facilitated by considering the resources and the constraints added to the understanding how adjustments on the performance might occur (HOLLNAGEL, 2014b).

Based on the results and the feedback provided by the experts, it is suggested that the utility of the framework extends beyond the one initially proposed by this study, serving also as a briefing tool. The Assessment Form originated in **Step 3** would allow to, projectively, identify interactions and relationships between the system's elements that would contribute to deal with expected threats in the activity. In fact, the Oil and Gas expert who assessed the cargo handling operation stated that he could certainly use it with his team before operations. Thus, it is suggested that studies using the ResPAF with the purpose of developing a briefing tool be conducted.

6.1.2 The Framework and Scenario-Based Simulations

Training for operations in complex systems is a topic of interest, especially in safety-related activities. For simulation-based trainings, scenario-based trainings are being used to train operators decision making. Scenario-based trainings simulate ambiguities, scarcity of resources, and time pressure situations that are characteristics of an everyday environment in complex systems (CANNON-BOWERS, 2008). Determining the success of a training program is directed linked with the capacity to assess and provide feedback regarding operator's performance (MARCANO *et al.*, 2019)

Although there is always a difference between work-as-trained and work-as-done (PATRIARCA *et al.*, 2021), it is possible that the proposed framework be used both as an assessment and as a debriefing tool in scenario-based simulations. Assessments are feasible since scenario-based trainings simulate scenarios in which the adaptive capacity of the system is tested. Thus, it is expected that interactions that occur in real situations also occur during scenario-based trainings. In addition, using the assessment form as a way to structure the debriefing of scenario-based simulation allows the participants to shed light, in a more systemic way, on how elements interacted during the operation conducted in the simulation.

Finally, it is suggested that the ResPAF allows the creation of scenarios for this type of trainings. By collecting data and understanding how interactions occur in everyday work, it allows to elaborate a more trustworthy scenario for the simulation. Moreover, it is also possible to use the Assessment Form developed in **Step 3** to guide the establishment, *a priori*, of how the interactions between the elements of the system may interact during the simulation, even that these interactions were not observed yet in the operational environment.

Finally, the instantiations showed several other applications regarding the framework. Training programs could be benefited since the framework allows assessing scenario-based trainings and the creation of the scenarios itself. Moreover, although being an artifact initially for job assessments, the framework can be used as a briefing and a debriefing tool. Therefore, some studies to evaluate the utility and usability of the framework are suggested:

(1) Evaluate the framework in training programs;

(2) Evaluate the framework in activities briefings;

(3) Evaluate the framework in debriefings after activities; and

(4) Evaluate the framework to assess resilience in other organizational levels.

The present study was a first attempt to develop a resilience assessment framework based on the Darwin Resilience Management Guidelines. The results discussed showed feasibility of its initial application in Aviation and in Oil & Gas industry. However, due to the cross-sectional nature of this study, further studies must be conducted to validate the framework and prove its extensibility in other domains and in real work practices.

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APPENDIX A – Semi-structured CDM interview guide

Introduction

Thank you for agreeing to participate in this interview. The purpose of this interview is to, based on a challenged event experienced by you, understand how different elements interacted to the outcome of the situation. All data collected here will be de-identified and, if it is ok, I would ask you permission to record this interview.

The interview will start with you narrating a challenging event that you experienced. Please, try to mention as many details as possible. Then, I will ask you a series of questions to deepen the analysis regarding some aspects.

Are there any questions you would like to ask?

Threat Data Section

Thank you for narrating the event. Now, I am going to ask you some questions to deepen the analysis of this event.

- Was this threat something expected during the operation or not?
- What was the possible escalation to this event?
- In what phase of the operation the threat was detected?
- In what phase of the operation the threat occurred or would occur?

Identifying Fragilities:

Now, we are going to explore how fragilities were identified in this event.

- What information that you considered important for this event, but you didn’t have back then?
- What resources, being human or technical, were not available during the event?
- Were there any goal conflicts during the event? Which ones?
- Was there any sort of restriction in the operation?

Managing Available Resources

Now, we are going to explore how the resources were managed during the event.

- How the resources used in the event were identified?
- How the resources used in the event were mobilized?
- How the resources used in the event were utilized?

Adapting Plans and Procedures (only for aviation domain)

Regarding adaptations made in Plans and Procedures, here are some questions:

- How inadequacies or ambiguities in plans and procedures were identified?
- What information were available to adapt these plans/procedures in the way it was?
- What courses of actions were established in this event?

System's Response Classification:

Finally, I want you to classify the system's response to the experienced threat. We say that the response was a Disarm when the threat was anticipated, and actions were taken to avoid the threat. We say that the response was a Recovery if it was not avoided, but the response employed was able the operation to the normal state that was before the threat. Finally, we say the response was an adaptation if the threat was avoided, a response was employed, but the operation is now in a new normal state, which is different from the state before the threat. Based on that, I ask you:

- Which one best describes the system's response?

APPENDIX B – Interview guide for selection of Capability Cards

Introduction

Thank you for agreeing to participate in this interview. The objective of this interview is to select some guidelines that I will present to you, and that you judge as operationalizable in XXX operations. These guidelines were developed by a project in European Union and, whether implemented in a system, contribute to a resilient performance.

Interviews with experts are necessary because these guidelines contemplate various levels of a system. For example, some guidelines are about dealing with community people. Is this related to activities performed aboard a drilling ship? This is the objective of this interview. So, I am going to present the guidelines, the core ideas of it and action to operationalize it. Then you judge whether these guidelines are operationalizable in the context of XXX operations.

Promoting common ground for cross-organizational collaboration in crisis management

To have an effective collaboration during a crisis, the different people involved must be aware of their common goals, expectations, capabilities, and operational procedures. This card includes actions related to, for instance, the organization of periodic exercises to promote inter-organizational common ground.

Do you think actions like that are present in the work of people in XXXX operations?

Establishing networks for promoting inter-organizational collaboration in the management of crises

An effective response to a crisis event requires coordinated actions between multiple organizations. For this, the identification of relevant stakeholders is essential. This card deals with actions aimed at identifying these stakeholders and establishing a relationship of trust between these organizations

Do you think actions like that are present in the work of people in XXX operations?

Sharing information on roles and responsibilities among different organizations

Knowing the roles and responsibilities of those involved in a crisis situation is critical to a resilient response. This knowledge is intra and inter-organizational. This card deals with actions such as identifying organizations or sectors with shared responsibilities during a crisis, organizing periodic coordination meetings, drawing up a checklist containing joint actions, etc.

Do you think actions like that are present in the work of people in XXX operations?

Enhancing the capacity to adapt to both expected and unexpected events

Emergency situations occur suddenly, and it is sometimes necessary to adapt the way tasks are carried out to deal with the event as quickly as possible. This card deals with actions related to the identification of possible emergency situations and uncertainties; and the definition of someone responsible for coordinating the response to the event.

Do you think actions like that are present in the work of people in XXX operations?

Establishing conditions for adapting plans and procedures during crises and other events that challenges normal plans and procedures

Crises often challenge existing plans and procedures. As a result, margins to adapt plans and procedures are necessary. This card addresses actions related to recognizing the adequacy of plans and procedures and about the availability of information for the person in charge to make these decisions.

Do you think actions like that are present in the work of people in XXX operations?

Managing available resources effectively to handle unusual changing in demands

Resource availability is crucial for an effective response to system-challenging events. For this, these resources must be identified and mobilized to be used. This card deals with actions related to identifying and mobilizing these resources.

Do you think actions like that are present in the work of people in XXX operations?

Assessing community resilience to understand and develop its capacity to manage crisis

Assessing and monitoring community resilience before, during, and after crises occur allows policymakers to establish interventions and plans in collaboration with community leaders and members. This card deals with actions related to establishing contact with community members.

Do you think actions like that are present in the work of people in XXX operations?

Noticing brittleness

Having the ability to identify weaknesses in the system allows corrections to be made so that the system does not collapse. This card deals with interactions related to identifying goal conflicts; setting priorities under time pressure; and identification of situations where resources or information may become scarce.

Do you think actions like that are present in the work of people in XXX operations?

Identifying sources of resilience: learning from what goes well

One of the goals of Resilience Engineering is to learn from daily performance and successful operations, not just from lessons learned after failures. In line with this, identifying sources of resilience means investigating the mechanisms by which organizations successfully deal with expected and unexpected conditions. This card addresses actions related to the learning process with events that went well.

Do you think actions like that are present in the work of people in XXX operations?

Increasing the public's involvement in resilience management

Systematic management of policies

Policies are a form of statements of intent and are often used to guide decision making at all levels of operation in public and private organizations. Policies are not static documents but evolve with the organization and therefore must be managed. This card involves actions to involve different stakeholders in the elaboration of policies

Do you think actions like that are present in the work of people in XXX operations?

Communication strategies for interacting with the public

The response of the general public that is potentially affected by a crisis, or may be helpful in resolving a crisis, has an impact on the outcome of crisis response work. Therefore, organizations need to develop and implement communication strategies for interacting with the public that can help facilitate beneficial crisis responses and crisis response efforts. Communication and interaction with the public during a crisis will be facilitated if day-to-day communication strategies and regular interaction with the public are already well established. This card addresses actions of communication and audience interaction.

Do you think actions like that are present in the work of people in XXX operations?

Increasing the public's involvement in resilience management

Understanding community needs in crisis situations has a major impact on how to respond to an event. Integrating the organization into a network of relevant actors and agencies (community members and local companies that do not normally carry out crisis management) is of paramount importance. This card addresses actions related to increasing the organization's ability to respond to the needs of both the organization and the local community in times of change and emergency.

Do you think actions like that are present in the work of people in XXX operations?

Supporting Development and Maintenance of Alternative Working Methods

System failures are when a certain component essential for the functioning of the system is lost or starts to operate in a degraded way. To deal with this, alternative working methods are needed. This card deals with actions related to the identification of scenarios where a System Failure is occurring, the definition of alternative working methods, the dissemination in the organization about these methods; etc.

Do you think actions like that are present in the work of people in XXX operations?

APPENDIX C – Assessment Form for Aircraft Cockpit Operations

Assessment No:			
Threat		**Threat Classification Category**	
Was the threat expected?	**Possible Situation Escalation**	**Phase of operation the threat was detected/ Phase of operation the threat occured or would occur**	
( ) Yes ( ) No		/	
Situation Description:			
Identifying Fragilities			
Non-available Information	Non-available Resources	Goal Conflicts	Bottlenecks/Restrictions in Operation
Managing Available Resources			
Identification	Mobilization		Utilization
Adapting Plans and Procedures			
Recognition of Inadequacies/Ambiguities	Available Information		Alternative Courses of Action
System's Response Classification		( ) Disarm ( ) Recovery ( ) Adapt	

APPENDIX D – Assessment Form for Oil and Gas Offshore Operations

<table>
<tr><td colspan="4">Assessment No:</td></tr>
<tr><td colspan="2">Threat</td><td colspan="2">Threat Classification Category</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Was the threat expected?</td><td>Possible Situation Escalation</td><td colspan="2">Phase of operation the threat was detected/ Phase of operation the threat occured or would occur</td></tr>
<tr><td>( ) Yes ( ) No</td><td></td><td colspan="2">/</td></tr>
<tr><td colspan="4">Situation Description:</td></tr>
<tr><td colspan="4">Identifying Fragilities</td></tr>
<tr><td>Non-available Information</td><td>Non-available Resources</td><td>Goal Conflicts</td><td>Bottlenecks/Restrictions in Operation</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Managing Available Resources</td></tr>
<tr><td>Identification</td><td colspan="2">Mobilization</td><td>Utilization</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">System's Response Classification</td><td colspan="2">( ) Disarm ( ) Recovery ( ) Adapt</td></tr>
</table>

ANNEX A – Capability Cards and its rationales and triggering questions

High Level Themes	DRMG Topics
Supporting coordination and synchronization of distributed operations	• **Promoting common ground for cross-organizational collaboration in crisis management** Promote periodic cross-organizational dissemination exercises to increase organizations mutual awareness of other motives, perspectives, terminologies and working practices. In turn, this can support improved collaboration at the time of crises, because first responders are more aware of the behavior to expect from staff of other organizations. **Triggering Questions:** *Identification of gaps in mutual understanding* • What is our understanding of the mission, culture and operating methods of other organizations with whom we need to collaborate in crisis management? • What is the level of understanding of our mission, culture and operating methods by other organizations with whom we need to collaborate in crisis management? *Information-sharing workshops* • Are there opportunities for organizing workshops with one or more of the organizations collaborating with us in crisis management and for sharing presentations about our respective mission, culture and operating methods? • If such workshops were already organized in the past, is there a need to repeat such experiences to take into account relevant changes in each organization and the turnover of our respective staff members? *Visit to other organizations* • Are there opportunities for organizing visits of our staff members to the facilities of other organizations collaborating with us in crisis management and vice-versa? • If such visits were already organized in the past, is there a need to repeat such experiences to take into account relevant changes in each organization and the turnover of our respective staff members? *Joint drills and crisis preparation exercises* • Are there opportunities for organizing joint drills and crisis preparation exercises with other organizations collaborating with us in crisis management? • Do we use specialist terminologies that may be unclear or ambiguous to the teams of other organisations and should be addressed in joint crisis preparation exercises? • Can we think of possible sources of joint activity breakdowns that should be addressed in crisis preparation exercises? • Can we envision the presence of conflicts in resource usage that should be addressed in joint crisis preparation exercises? • Can we think of potential synergies between our organization and other organizations that should be addressed in joint crisis preparation exercises?

- **Establishing networks for promoting inter-organizational collaboration in the management of crises**

Establishing pre-crisis relationships between the organizations that may be jointly involved in managing a crisis paves the way for more effective collaboration and communication during crisis and post crisis responses across organizations.

Triggering Questions:

Identifying the organizations to include in the network
• When thinking of a specific type of crisis, are there organizations that may be involved together with us in the management of it. Among these organizations, are there any with whom we do not have any collaboration yet in place?
• If there is no collaboration yet in place, would it be worth establishing it?
• When thinking of new possible collaborations, are we considering all relevant levels, including the local, regional, national and international level?

Specifying the rationale for collaborating with an organization
• What type of collaboration do we expect to have with an organization we have decided to include in our network?
• What do we expect to achieve from the collaboration?
• Which communication modalities do we want to adopt in order to interact with such organizations?

Approaching the organizations to include in the network
• Do we know with which person/s should we get in touch in order to activate the collaboration?
• Do we know if there are interpesonal relationship already established in previous activities that may be exploited to facilitate this process?

Establish Memorandum of Understanding
• Have we clearly defined why we need to collaborate?
• Have we clarified what we expect to achieve from the collaboration?
• Have we defined the specific way we intend to collaborate?
• Have we discussed and agreed with the other organization about possible extensions of the scope of our collaboration in future?

Establish a Framework for Collaboration
• Have we defined how often we should get in touch with the other organization to review reciprocal roles and responsibilities in the management of crises?
• Have we defined shared activities to improve the common ground among us and the other organization in the management of crises (e.g. common training sessions)?
• Have we developed inside our organizations a documentation to record the status of our collaboration with the other organization?

	• **Sharing information on roles and responsibilities among different organizations** Stakeholders involved in resilience management need to have clear idea of roles and responsibilities who may be involved in the management of a potential crisis. Each organization should have an adequate knowledge not only of its own roles and responsibilities, but also of those of other organizations they may be required to collaborate with during a crisis. This is vital in order to identify gaps and cooperate before, during and after a crisis. **Triggering Questions:** *Involvement of organizations* • Does a shared procedure exist among different organizations required to manage jointly a specific type of crisis? • Is there a need to involve new organizations in the coordination activities about shared roles and responsibilities for the management of a crisis? • Is there a need to create a new network of organizations for the management of a specific type of crisis? (see CC Establishing networks) *Coordination mechanism* • When a shared procedure among different organization exists, is there one organization clearly appointed to activate and arrange periodic coordination activities with other organizations? • Within our organization, is a calendar of periodic coordination activities already established, to check roles and responsibilities with other organizations? *Impact on other organizations* • Did we recently experience within our organization changes of roles and responsibilities that could affect emergency procedures shared with other organizations? • Are these changes sufficiently significant to require a communications to other involved organizations? *Internal dissemination of changes* • Are we providing adequate information and training on relevant changes of roles and responsibilities in other organizations to the personnel potentially involved in the management of crisis? • Can we develop a ‘quick reference guide’ to help the personnel of our organization to promptly identify shared roles and responsibilities with other organizations during a crisis? • If we already have a ‘quick reference guide’, do we need to update it to include recent changes of the procedure shared with other organizations?

Managing Adaptative Capacity	• **Enhancing the capacity to adapt to both expected and unexpected events** Emergency situations occur suddenly and without warning. Therefore, organizations must be prepared and adapt their functions to respond to emergency events as quickly as possible. Among those situations, some of the events are expected while others, could be unexpected with different nature. Roles, training, strategies, and procedures must be in place to provide such capacity, using an all-hazards approach which considers the common denominator of emergency situations in different areas, building generic response plans that can be adapted to a specific event. **Triggering Questions:** *Classify and analyze potential emergencies* • What variables/data are monitored to assess whether there is a crisis? What is the underlying rationale for the monitoring efforts and what limitations does this approach have? What crisis information is difficult to capture in variables/data? • Could we classify emergencies according to their nature? • Do we identify mutual component of different types of emergencies? *Build a mechanism for response plans* • Do we have an actor who will be in charge of, coordinate or synchronize crisis management planning and response? • Do we design the response plans based on everyday manner? Do we use known resource to handle unexpected situations? • Do we have appropriate equipment to the first stage of the emergency? • How are such managers trained to recognize when unexpected events occur that challenge the current organisational structure and processes? • How do we define potential relevant partners to coordinate with in case of expected and unexpected 0073ituations? • Are lists of “good-to-have” contacts available in case unexpected situations occur that may require contacting actors outside of established communication channels? • Do we (re-)develop response plans based on new experiences? • Do we have response plans as well as training such as exercise and drills? • Do we model protocols to promote a common approach? • How do we create communication channels and networks between partners so that they can adaptively coordinate and cooperate when unexpected situations occur? • Can the adaptive re-allocation and deployment of resources within and between organisations be supported by building in slack in appropriate places in the network to meet unexpected demands?

- **Establishing conditions for adapting plans and procedures during crises and other events that challenges normal plans and procedures**

Often, crises challenge the plans and procedures in place. As a result, organizations need to support and maintain a clear and legitimate space of maneuver relative to normative plans and procedures. Such space is important for actors engaged in crisis response in order to adapt to unusual (unanticipated) circumstances. After training or real events, investigating why these adaptations occur can feed the processes of revision of checklists, procedures and policies.

Triggering Questions:

Nature of Plans and Procedures
• Are plans and procedures in place for all operators?
• Are they rehearsed regularly?
• Is there flexibility for operators to adapt when situations are unexpected?

Authority Issues
• What roles will be in charge of abnormal situations?
• Will they be in a capacity to quickly make informed decisions if such a situation occurs?
• Would other roles be in a better position to make decisions?
• Do these roles have the authority to do so?

Capability Issues (skills, expertise)
• Are operators trained on unusual situations for which plans and procedures are limited?
• Does training include situations in which they need to solve problems or make trade-offs?
• Do they experience situations in which they need to show initiative, outside of the regular line of command, in order to act quickly?

Learning Process (normal operations vs. crises)
• How regularly are training programs reviewed and revised?

	• **Managing available resources effectively to handle unusual changing in demands** To better handle the unusual and changing demands of crisis situations and achieve critical objectives, organizations need to be able to use available resources effectively, sometimes creatively, and potentially to bring in additional resources. For the purposes of this card, resources refer to human resources, such as personnel in various roles and divisions of an organization, as well as to material or immaterial resources, such as equipment and tools. In other words, to anything that is necessary or useful in order to accomplish the tasks at hand. **Triggering Questions:** *Establishing conditions to use resources* • Are we have aware of human resources that can potentially be shared with other organisations or departments of our organisation? • Can we distinguish between human resources that can be shared with other organisations and human resources who cannot be shared in any circumstance? • Do we know who should be consulted to receive authorisation to take advantage of the human resources of another organisation or department? • To take advantage of the human resources of another organisation or department are we sufficiently aware of their level of training, skills and competences?
Assessing Resilience	• **Assessing community resilience to understand and develop its capacity to manage crisis** The assessment and monitoring of community resilience prior to, during and after the occurrence of crises allows policy makers to establish interventions and plans in collaboration with community leaders and members, in order to ensure communities will be better able to manage and recover from future events. **Triggering Questions:** *CR assessment tool* • Is there an accepted tool for measuring community resilience? *CR assessment process* • Is the study population representing all population strata, including vulnerable population with special needs? • What is the aim of the assessment? To create a baseline? To measure the impact of intervention plan? *CR assessment results* • How do we translate the study results to intervention plans? • How could the organisation (from the whole business/CI sector) be involved in strengthening the community resilience in accordance with the assessment's results?

	• **Noticing brittleness** The interventions proposed here aim to support organizations to identify sources of *brittleness* in order to invest in their correction. Brittleness is experienced in situations of goal conflicts and trade-offs, or when there is a competition for resources and a need to establish priorities under time pressure. Other difficulties emerge when an organization struggles to manage *functional interdependencies* between different parts of the same organization, or when there is insufficient *buffer capacity* to provide additional resources. Noticing brittleness also means observing *operational variability* and comparing *work-as-done* with *work-as-imagined*, so to reveal how the system might be operating riskier than expected. In addition, brittleness manifests itself when the organization is unable to learn from past events, such as near misses and accidents. **Triggering Questions:** *Lack of Resources (human, technical, material)* • Are there situations in which the resources we expect to have to respond to a crisis/emergency may not be available? • What can we put in place to relieve, lighten, moderate, reduce and decrease stress or load? • Where could we easily add extra capacity to remove stressors? *Lack of Information* • Can we anticipate situations in which we will lack the necessary information to handle a certain event? • Do we have a protocol in place to gather the missing information? • Can we anticipate situations in which we may experience uncertainty based on the history of our operations? • Which processes and/or plans are insufficiently defined and may represent a source of uncertainty? *Goal Conflicts* • What goal conflicts and trade-offs may arise or increase? • In such situations, will we be able to establish priorities? • Can some goals be temporarily relaxed or sacrificed to reduce the trade-offs? *Constraints and Bottlenecks* • What constrains us in our ability to execute? • What conditions may push our system towards its limits? • Who will be most heavily loaded/stressed? • Can we anticipate situations in which our operations will be constrained by other organisations? • Can we anticipate situations in which our operations act as a constraint for other organisations managing a crisis? *Difficulties to adjust* • Do we have the capacity to reallocate existing resources if needed. What may prevent us from reallocating them? • Do we have a policy that allows us to modify normal operations when needed? • Do we expect that major mismatches between official procedures and actual practices may occur? *Limits of mitigation plans* • If we have safety/emergency plan, what can go wrong when applying the planned mitigation actions? • What could prevent us from applying some of the mitigation actions?

- **Identifying sources of resilience: learning from what goes well**

One of the aims of Resilience Engineering is to learn from the everyday performance and from successful operations, rather than by only through lessons learned after failures. In line with this, identifying **Sources of Resilience** means investigating the mechanisms by which organizations successfully handle expected and unexpected conditions. Such mechanisms (e.g., strategies, processes, tools) allow the organization to adapt, perform and deliver required services in spite of the variability and complexity they experience in their operations. This *adaptive capacity* can be recognized by looking at the **work-as-done**, both in daily operations and unusual or exceptional scenarios, in order to identify sources of resilience and to **learn from what goes well**.

Triggering Questions:

Adaptive capacity:
• Which strategies (e.g. working methods or contingency procedures) can be used to handle a sudden loss of capacity and/or increase in demands?
• For which events is there a response ready?
• How and when can existing roles and tasks be reorganized in response to such events?
• Is the personnel exposed to unusual situations as part of the training?

Operational Margins:
• Which margins are available in everyday operational situations that can be used to handle suddenly increased demands?
• Which margins have been defined and anticipated beforehand?
• How is it possible to increase existing margins?
• When is it necessary to negotiate this increase with other actors? With which actors?
• Are there criteria to establish when it is possible to revert to the original margins?

Resources:
• How and when can additional resources (human, technical, material) be allocated/called in to integrate existing ones?
• What back-up (incl. legacy) resources and working methods are available? Is personnel (still) familiar with these in order to readily use them?
• What kind of coordination with other actors needs to be established for additional resources?
• Are there criteria to establish when it is possible to revert to the original set of resources?

Monitoring:
• Which roles in the organization can monitor the margins/resources available, both during and after an unexpected increase in demands?
• How are margins/resources monitored?
• Which monitoring mechanisms are put in place by the organization to anticipate and assess possible threats that may occur in the future?

Goal trade-offs:
• During the management of everyday operations or crises, are there different goals that may come in conflict (e.g. ensuring
adequate safety margins vs. minimizing economic losses)?
• How do operators succeed in meeting conflicting goals and finding appropriate balance among them?

Dependencies and interactions:

	• What strategies (could) foster a smooth coordination among actors and minimize constraints and bottlenecks? • Where do more efforts need to be spent to understand the potential for small variations in conditions and performance outcomes to combine, propagate, and amplify across organizations (so-called “cascading”, “butterfly” or “snowball” effects)? • What do operators (need to) know about the other parts of the system that they are interacting with? • How are formal and informal networks nurtured that are useful in handling crises?

Developing and Revising Procedures and Checklists	• **Systematic management of policies** Policies are a form of statements of intent and are often used to guide decision making throughout all levels of operation within in both public and private organizations. Policies are not static documents but evolve with the organization and must thus be managed. The purpose of Systematic management of policies is to support structured development and management of policies for dealing with emergencies and disruptions characterized by occurrence of emerging risks and threats. The aim is to achieve adaptive and holistic policy management involving policy makers and operational personnel, both within public and private organizations. Note, that when this capability card is used by operational personnel, it rather refers to systematic management of plans, procedures or checklists. **Triggering Questions:** *Policy Management Process* • Reflect on the policy management process o How are emergent risks and threats identified and described? o How are identified risks and threat used in the policy management process? o How well is the cross-domain, cross-organizational or cross-border perspective included? • Involve operational personnel in the policy management process o Are operational personnel included and invited to participate and provide expertise and experience in the processes involved in policy making? o Are bottom-up organizational processes provided to encourage dialogue between policy-makers and operational personnel? o How do these processes support establishment of common ground, understanding and trust between policy-makers and operational personnel? • Design policies for flexible use o Can policies be designed so that their parts (items, sections, etc.) can be used flexibly and as inputs to decision making in specific situations, rather than sequentially procedures to strictly follow? *Policy Assessment* • Identify and evaluate existing policies o How many and which policies are operational personnel expected to work by? o Have conflicts between these policies been analysed (between different roles and organizations)? o Have conflicts between policies of operational personnel of different organizations following different policies been analysed? o Are there situations where operational personnel would need support but policies do not apply? o Is operational personnel supported sufficiently by the existing policies? • Identify weaknesses in application of existing policies o Are policies easy to understand in various situations? o Are policies too constraining to deal with actual situations or too general to give concrete guidance? o Have operational personnel developed alternative ways of working, compensating strategies, or work-arounds during their actual use of policy? Why? o Has this actual use of policy in terms of difficulties of application, alternative ways of working, compensating strategies, or work-arounds been analysed with the purpose to understand them (instead of counting and condemning "violations")? o Have gaps between policies and reality been analysed and identified?

	• Assess policies as part of the whole context, rather than individual policies o Has a joint validation of purpose and underlying intent of policies been performed? o Have sets of policies been evaluated together in order to assess their joint applicability, complexity, overlaps, bureaucratization, and conflicts? o Have different roles' and organizations' perspectives and views on the same policies been included in assessments? o Have the amount of policies and expectations on policy-driven actions versus actions that cannot or should not be covered by policies been addressed and put into context? o Has the need for support for interpretation of policies, pre-authorizing exceptions, and handling exceptions been identified and addressed? o Can policies that have low fitness-for-purpose be redesigned or removed? *Policy Training and Implementation Support* • Impose strategies or mechanisms for communication, training, and support o Is a communication strategy in place on how information on new, modified, redesigned, or discontinued policies will be communicated to relevant actors (both policy-makers and operational personnel)? o Is a training strategy developed on when and how operational personnel will be trained on policies? o Are supporting mechanisms put in place to provide support to operational personnel when applying policies during response operations? • Consider implementation aspects of new or revised policies in the planning of policy revision activities o Are preparations and processes established for how to provide guidance to operational personnel on when to apply policies and when policies are known not to be applicable in some situations? o Are preparations and processes established for making policy-makers available during response operations? o Are preparations and processes established for resolving policy conflicts during response operations? o Are processes in place for tracing policy changes over time and following-up the effect of these changes?

Involving the Public in Resilience Management	• **Communication strategies for interacting with the public** The response of the general public that is potentially affected by a *crisis*, or could be helpful in resolving a crisis, has an impact on the outcome of the crisis response work. Therefore, *organizations* need to develop and implement communication strategies for **Interacting with the public** that can help facilitate beneficial responses to crises and crisis response efforts. Communication and interaction with the public during a crisis will be facilitated if daily communication strategies and regular interaction with the public is already well established. The recommendations presented here are aimed at both public and private entities at all levels that are involved in crisis management, in particular crisis managers and roles within the organizations related to design, development and evaluation of communication plans and strategies. Even though not all personnel involved during a crisis or incident needs to communicate directly with the public, being aware of communication strategies aimed at the public and the need of communication *competencies* can be of use. **Triggering Questions:** *Adequacy of the Plan* • Do we have a communication strategy or crisis communication plan that gives guidance on who and how to communicate? • Are relevant roles aware of their responsibilities with regard to communication? • Is our communication plan sufficiently coordinated with other relevant authorities/organizations? • Do we have mechanisms to prevent misalignment or conflicts regarding communication among both different organizations and/or different parties of the same organization (e.g. through an appointed common spokesperson)? *Capability to guide effective crisis response by the public* • Does the communication plan include adequate information on how to guide crisis response by the public? • Are we making sure the information shared with the public does not cause unnecessary alarm or distress? • Does the communication plan include information to the public on how to avoid using resources that may be needed by others during a crisis? • Do we provide information on crisis management also during normal/ordinary situations? • Have we prepared standard public messages or information blocks for use during crises? • How do we communicate the individual responsibility to increase public preparedness, avoiding an overreliance on authorities? *Communication Channels* • Through what kind of channels are we able to communicate? • Do we use communication channels that people already use every day? • Are the communication channels sufficiently up-to-date? • Does the selection of our communication channels take into account the needs or routines of the public in target? • Is there a risk of our communication channels being overloaded? *Adequacy of Competencies* • Are we proficient at using the available communication channels? • Are relevant roles trained, educated, and exercised using this strategy/plan? • Are we using the appropriate terminology for communication with the public (consider, for instance, different demographics)? • Do we have access to the appropriate competences (subject matter experts, domain experts etc.) while developing communication strategies/plans?

	• Does the communication officer/s have the appropriate (technical) domain knowledge in order to understand, and respond to, information requests from the public (and thus have the ability to work independently)? *Clarity and Accessibility* • Are people aware of where they can access the information? • Have we considered in which languages the information needs to be communicated? • What processes or routines do we have to fact-check/quality-assure before we communicate it? • Do we clearly communicate responsibilities of individuals, as well as of the agencies involved in crisis management? *Acceptability and Trustworthiness* • Does our communication strategy adequately encourage trust and acceptance by the public? • Is our information presented in a way or place that makes it trustworthy? • Is our communication avoiding any expression of blame culture, which could be seen as unhelpful or counterproductive scapegoating? • Are we adequately communicating the benefits of being prepared in case of crisis and not just prescribing how to be prepared? *Prevention of Misinformation* • Do we have procedures to monitor and react to misinformation spread by non-official communication channels? • Do we have a strategy to counter misinformation and rumours? • Do we have adequate technical information security in order to prevent misuse or manipulation of our social media/web channels (i.e. prevent hacking and spoofing in order to distort or change official information)? *Ability to listen and collect feedback* • Are we able to engage with the public in order to understand and recognize the diversity of local communities, the local needs, and the available or lacking resources? How? • Are we able to integrate information from the public or other sources into our communication? How? • How do we seek feedback from the public? • What capability do we have to respond to information requests or other interactions with the public? • How do we communicate the need for people to be self-reliant to a certain degree? *Capability to trigger public engagement* • Does our communication strategy/plan facilitate public participation? How? • How do we ask for help/resources that corresponds to actual *needs*? • Are we prepared to communicate in a timely manner (i.e. do we have prepared messages, websites or other forms of communication)?

	• **Increasing the public's involvement in resilience management** To integrate the organization in a network of relevant actors and agencies (community members and local business that typically don't conduct crisis management). The integration is aimed at enhancing the organization's ability to respond to the needs of both the organization as well as the local community in times of change and emergency. **Triggering Questions:** • Assuming cellular communication fails, are people aware of where landlines are located? • How can the elderly population be trained as a resource for emergency situations? • If infrastructures are cut off, does the specific organization (form the business sector, for example) have special means that could deliver emergency supplies?

Managing System Failure	• **Supporting Development and Maintenance of Alternative Working Methods** The card supports the development and the maintenance of Alternative Working Methods (AWMs) in case of system failure. System failures are situations in which an essential component to ensure continuity in the service offered by the organization is either lost or functioning in a degraded mode and there is no backup, emergency or contingency solution available by design. Applying an AWM means performing one or more activities within the organizations in a way which is remarkably different from what described in existing procedures or practices, in order to bypass the constrain created by the system failure. It may imply following different steps in the way to perform the activity, using different tools or cooperating with different people (or all of the above) with respect to what is normally done without the system failure. **Triggering Questions:** *Identification of System Failures* • What kind of system failure has the potential to compromise the continuity of the service offered by our organization? • Can we think of an unprecedented system failure with the potential to compromise the continuity of the service offered by our organization? • Can we think of a system failure for which there is no straightforward backup, emergency or contingency procedure identified by design? • For which kind of system failure the identification of an AWM represents a priority for our organization? *Review of Existing AWMs* • Is our personnel aware of the AWMs we identified for specific system failures • Did we verify if the AWMs we identified for specific system failures are still applicable and fit for the purpose? Did the last check occur too long ago? • Did we check if the tools necessary to support the identified AWMs are still usable? • Did we check if the tools necessary to support the identified AWMs are still accessible to the personnel? • Are the skills and competences of our personnel adequate to apply the AWMs if needed? *Consideration of Older Working Methods* • Can we revert to ‘old school methods’ that existed before the system affected by the failure was available in the organization? • Would the older working methods be capable of managing the complexity of the process that we previously supported with the system affected by the failure? • What is the level of obsolescence of the tools used as part of older working methods? • Do we maintain the tools formerly used in older working methods in a way that would allow us to reuse them in case of system failure? • Can we make adaptations to the tools used as part of older working methods to compensate for their obsolescence? • Are we periodically refreshing the skills and competences that would be needed by the personnel to reuse the older working methods? • Does the cost to rebuild skill and competences to reuse older working methods exceeds the expected benefits? *Definition of New AWMs* • What kind of physical redundancy we may use to compensate for the system failure?

	• What kind of functional redundancy we may use to compensate for the system failure? • What kind of human backup we may use to compensate for the system failure? • Can we provisionally use a tool to compensate for the system failure in a way different from what originally intended in its design? *Limitations of Selected AWMs* • Is the AWM we have identified expected to reduce the level of safety of operations until the system failure is not repaired? • Does the AWM we have identified rely on the same infrastructure that has caused the failure of the main system? • Does the AWM we have identified rely on resources of other organizations on which we do not have full control? • Is the AWM we have identified at risk of causing undesired side effects on other organizations with whom we collaborate? *Dissemination and training on AWMs* • Did we inform properly all the relevant personnel in our organization regarding the identified AWMs? • Do we need to organize a dissemination campaign in order to make sure the relevant personnel in the organization is aware of the identified AWMs? • Do we need to inform the point of contacts of other organizations of the AWMs we have identified? • Do we need to develop training modules to make sure the relevant personnel in our organization have the necessary competences and skills to master the identified AWMs?

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