Agile Response Capability (ARC) best practices

Rogier Woltjer, Björn J.E. Johansson (FOI), Barry Kirwan (ECTL)

Future Sky Safety is a Joint Research Programme (JRP) on Safety, initiated by EREA, the association of European Research Establishments in Aeronautics. The Programme contains two streams of activities: 1) coordination of the safety research programmes of the EREA institutes and 2) collaborative research projects on European safety priorities.

This deliverable is produced by the Project P5: Resolving the Organisational Accident. The European aviation system has become increasingly inter-connected in order to be more efficient. However, the current degree of complexity and coupling means that events and failures in one location can rapidly affect other parts of the European system. Furthermore, dramatic events such as the Volcanic Ash Crisis, and the possibility of coordinated terrorist attacks mean that the European aviation system needs to be better able to respond in a coordinated and effective manner. One area that could make emergency response more effective is agility, which has been developed in the military for some time. This report explores the challenges facing European aviation, what is already in place today, and how agility could help in the near future.

Programme Manager	Michel Piers, NLR
Operations Manager	Lennaert Speijker, NLR
Project Manager (P5)	Barry Kirwan, EUROCONTROL
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Contributing partners

Company	Name
FOI	Rogier Woltjer, Björn J. E. Johansson
EUROCONTROL	Barry Kirwan
AIRBUS	Corinne Bieder
NLR	Sybert Stroeve
KLM	Arthur Dijkstra
ENAV	Alessandro Boschiero, Paolo Marzano, Giuseppe Esposito
LSE	Tom Reader
TCD	Tiziana Carmen Callari

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Prepared by: *(name)*	**Company**	**Role**	**Date**
Rogier Woltjer	FOI	WP5.4 Lead	15-01-2016
Checked by: *(name)*	**Company**	**Role**	**Date**
Beatrice Bettignies-Thiebaux	EUROCONTROL	Quality Assurance	18-01-2015
Approved by: *(name)*	**Company**	**Role**	**Date**
Barry Kirwan	EUROCONTROL	Project Manager (P5)	18-01-2015
Lennaert Speijker	NLR	Operations Manager	27-01-2015

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Acronyms

Acronym	Definition
ANSP	Air Navigation Service Provider
ARC	Agile Response Capability
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Transport System
ATSU	Air Traffic Service Unit
C2	Command and Control
CFMU	Central Flow Management Unit
CODA	Central Office for Delay Analysis
CT	Contingency Team
DG MOVE	Directorate-General for Mobility and Transport
DG SANTE	Directorate-General for Health and Food Safety
DMO	Duty Manager Operations
EACCC	European Aviation Crisis Coordination Cell
EASA	European Aviation Safety Agency
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
ECHO	European Commission's Humanitarian Aid and Civil Protection
ENAV	Italian Air Navigation Service Provider (ENAV S.p.A)
ESA	European Space Agency
EVITA	European crisis Visualisation Interactive Tool for ATFCM
FRAM	Functional Resonance Analysis Method
ICAO	International Civil Aviation Organisation
KLM	Koninklijke Luchtvaart Maatschappij N.V. (Royal Dutch Airlines)
MTO	huMan- Technology and Organisation
NATO	North Atlantic Treaty Organization
NGO	Non-Governmental Organisation
NM	Network Manager
NMOC	Network Operations Management Centre

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NOP	Network Operations Portal
NOTAM	Notice To AirMen
NSA	National Supervisory Authority
NSP	Network Service Provider
OAR	Operational Analysis and Reporting
OC	Operations Controller
OJT	On the Job Training
RE	Resilience Engineering
RAG	Resilience Analysis Grid
SAS	Systems Analysis and Studies (NATO research panel)
SESAR	Single European Sky ATM Research
STAMP	Systems-Theoretic Model and Processes
STATFOR	Statistics and Forecast Service
STO	Science and Technology Organization (NATO research organization)
SyRes	Systemic Resilience Model
VAAC	Volcanic Ash Advisory Centre

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EXECUTIVE SUMMARY

Problem Area

Aviation is a highly inter-connected system of systems. This means that a problem in one area may not be confined to the local system. Instead it may cause effects in other countries or parts of the Air Transport System (ATS), for example a fire in an airport area may lead to the shutdown of the airport, and if it is a major hub, this can cause disruption over a large part of Europe. Additionally, there is the potential for massive system-wide events such as volcanic ash. The immediate response to volcanic ash was uncoordinated and even chaotic. Volcanic ash was a natural event, but the possibility of coordinated terrorist events must increasingly be taken into account. How would the European aviation transport system respond to a 9/11-style coordinated attack in several European capitals?

What is needed in such situations is not only rapid coordination, but an agile response, fast and effective. This requires a new approach for aviation. Agility refers to the ability to cope with dynamics and complexity in a flexible manner by adjusting and/or adapting performance and/or the organization of work to better fit changing demands, both pro-actively as a way of preventing unwanted events and re-actively as a way of coping with unwanted events. Agility, according to the final report of the research group NATO SAS[1]-085, consists of six capabilities, or enablers: Responsiveness, flexibility, versatility, resilience, adaptiveness and innovativeness. NATO SAS-085 developed a conceptual framework as to how organisations (in particular command and control/crisis management organisations) may develop and display agility. The current work aims to apply agility to safety management in organisations within the ATS.

As indicated by the inclusion of the capacity of resilience in this list of agility capabilities, the concept of agility for safety management will be linked to recent developments in Resilience Engineering as a new perspective to address systemic approaches to safety and safety-critical business management. Resilience Engineering aims to understand, devise, and amplify strategies and systemic emergent properties in operational and organizational processes in order to adjust and adapt to expected and unexpected disturbances and varying conditions. Resilience Engineering emphasizes further understanding of why these processes usually go right, or vary as part of everyday performance, whereas traditional safety approaches focus on how these processes (can) fail. The integration of four key capabilities of anticipation, monitoring, responding, and learning is seen as essential for resilience. Recently Resilience Engineering has been applied to air traffic management, an approach that will be broadened and extended with

[1] Systems Analysis and Studies.

agility concepts in the current project. The resulting approach is to provide ATS organisations with an agile response capability.

Description of Work

This document reports best practices from military and resilience theory for the development of Agile Response Capability (ARC). The work was performed using a literature review supplemented by expert input during two workshops and two interviews, resulting in a documentation of principles and similarities and differences between civil and military task and environment characteristics that could affect ARC operation.

Specifically, the theory and best practices of military research and development into agile command and control have been studied. Two important aspects to be developed according to agile response are the **endeavour space**, or the parameters that play an important role in developing and applying an appropriate response, and the **approach space**, or the parameters that can be varied in the organization of the response in terms of information dissemination, allocation of decision rights and interactions within the response organisation. The work that this deliverable reports has particularly focused on aspects that determine the endeavour space of the Air Transport System. Through workshops and interviews, the most challenging factors that the agile response approach should be sensitive to have thereby been identified.

Results & Conclusions

The results encompass an overview of agile response and resilience. Agile response lessons from the military have been derived and preliminarily applied to the parameters that characterize crises in the Air Transport System.

Applicability

The results show that the agility concept seems to have a general applicability to the Air Transport System to the extent that it warrants further development of the endeavour space and approach space of the ATS, in order to define guidance for Agile Response Capability during the continuation of the project.

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TABLE OF CONTENTS

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

LIST OF FIGURES

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

LIST OF TABLES

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1 INTRODUCTION

This document is the first deliverable produced by WP 5.4 "Agile Response Capability" within P5 "Resolving the organisational accident" of the Future Sky Safety programme. This introduction section starts with a brief description of the Future Sky Safety programme and the context of Project P5 and its WP5.4. Thereafter, the research objectives, approach, and structure of this document are presented.

1.1. The Programme

Future Sky Safety[2] is an EU-funded transport research programme in the field of European aviation safety, with an estimated initial budget of about € 30 million, which brings together 33 European partners to develop new tools and new approaches to aeronautics safety, initially over a four-year period starting in January 2015.

Future Sky Safety contributes to the EC Work Programme Topic MG.1.4-2014 Coordinated research and innovation actions, targeting the highest levels of safety for European aviation in Call/Area Mobility for Growth – Aviation of Horizon 2020 Societal Challenge Smart, Green and Integrated Transport. Future Sky Safety addresses the Safety challenges of the ACARE Strategic Research and Innovation Agenda.

Future Sky Safety, established under coordination of EREA, is built on European safety priorities around four main themes, each consisting of a small set of Projects:

Theme 1 (New solutions for today's accidents) aims for breakthrough research with the purpose of enabling a direct, specific, significant risk reduction in the medium term.

Theme 2 (Strengthening the capability to manage risk) conducts research on processes and technologies to enable the aviation system actors to achieve near-total control over the safety risk in the air transport system.

Theme 3 (Building ultra-resilient systems and operators) conducts research on the improvement of Systems and the Human Operator with the specific aim to improve safety performance under unanticipated circumstances.

Theme 4 (Building ultra-resilient vehicles) aims at reducing the effect of external hazards on the aerial vehicle integrity, as well as improving the safety of the cabin environment.

1.2. Project context

[2] See https://www.futuresky-safety.eu/ accessed 15JAN2016.

The objective of Project P5 "Resolving the organisational accident" is to reduce the likelihood of organisational accidents in aviation via development and implementation of a Safe Performance System. P5 answers to Future Sky Safety Theme 3, which aims at strengthening the resilience to deal with current and new risks of the humans and the organizations operating the air transport system.

The Air Transport System (ATS) is a system-of-systems, wherein each subsystem (airport, airline, air navigation service provider, etc.) is complex and inter-connected, operating as an open, global 24/7 macro-system that is also in a state of constant evolution. By definition, systems-of-systems are not easy to analyse, nor is their behaviour easy to predict. Resolving the organisational accident in such a domain therefore cannot be achieved by a single 'silver bullet' solution. To resolve the organisational accident, all of the key safety components need to be activated and coordinated across the entire ATS: executive safety intelligence at the top and middle management layers of the organisation, as well as the political layer above; safety culture throughout the organisation; safety mindfulness at the operational layer; and an agile response capability to ensure robust response to crises with varying time dynamics. These solutions must be bound together into an agile organisational safety system that is more in the hands of the operational division running an organisation's business. In this way, safety will emerge in day-to-day operations, every single day, 24/7 – as a Safety Performance System. Safety will not be something separate, but will be inextricably bound with other business imperatives.

We need to understand how organisations can work together to detect and respond to crises, with various time dynamics, from major system events or 'surprises' (which can never be fully designed out) towards risks and crises that change at a slower pace with longer-term dynamics. This includes how such events are detected and communicated, and how distributed parts of the aviation system can respond to resolve them. This will create an Agile Response Capability for the entire ATS.

1.3. Research objectives

This document has as its objective to present Agile Response Capability (ARC) best practices from military and resilience theory, in order to outline the theoretical foundations and best practices of these novel approaches to handling unexpected and expected events that the ARC will be based on.

1.4. Approach

The work reported here is based on the following activities:

- A literature overview has been performed describing theory and best practices regarding agility and resilience.
- Identification of the parameters that play an important role in developing and applying an appropriate response, through workshops and interviews, resulting in a preliminary

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description of the so-called **endeavour space** for the Air Transport System. This endeavour space thereby identifies the most challenging factors that the agile response approach should be sensitive to.

1.5. Structure of the document

Chapter 2 outlines the literature related to agile response, including agile command and control and resilience engineering. Chapter 3 applies part of the literature of Chapter 2 to the Air Traffic System. Chapter 4 outlines the focus of Agile Response Capability and Chapter 5 outlines the work that the project aims to perform during the remainder of the Future Sky Safety programme.

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2 CONCEPTS RELATED TO AGILE RESPONSE

Research on agility and C2 (Command and Control) agility has primarily been conducted in the military domain, although some exceptions can be found such as business management, complexity theory and organizational theory (Dyer & Schafer, 1998; Holsapple & Li, 2008; Spaans, Spoelstra, Douze, Pieneman, & Grisogono, 2009). Resilience, as defined in resilience engineering, has on the other hand mostly focused on safety, and the theoretical heritage comes from human factors and risk or accident analysis. A common theme in both agility research and research on resilience engineering is the problem of coping with uncertainty and risk, although the origin of uncertainty and risk differ greatly between military endeavours (which are inherently risky) and for example industry, where risk largely can be mitigated. In this report, we have focused primarily on the ability of an organization or a collective of organizations (as in the case of the ATS) to monitor and respond to unwanted or unexpected threats.

This chapter contains an overview of literature that was found to be relevant for understanding the respective fields of agility and resilience engineering. First, the concept of agility is outlined based on military and crisis management literature. Second, Resilience Engineering theory and applications are described. Third, the use of the term resilience in crisis and disaster management is outlined. Fourth and last, the concept of drift is discussed.

2.1. Control of complex dynamic systems

Cybernetics, or the science of control, has been influential in both of the theoretical strands that this report explores, i.e. agility and resilience. Ashby (1956) used the term 'essential variables' for the variables that are to be kept within assigned limits for a system to be able to function, or for a system to be able to retain control. "The state of a system at a given instant is the set of . . . values which its variables have at that instant" (Ashby, 1960, p. 16, numerical values in original). Systems behave in the sense that their state changes over time. A system that changes state over time is called a dynamic system (Ackoff, 1971). To control a dynamic system in cybernetic terms means to steer the behaviour of that process, i.e. to steer the behaviour of its essential variables.

One of the most fundamental principles of control and regulation in cybernetics is the law of requisite variety, which states that "only variety can destroy variety" (Ashby, 1956, p. 207). This means that the controlling system needs to have at least as much variety (behavioural diversity) as the controlled system has variety, for the controlling system to be able to control the controlled system. Systems are said to behave in terms of a continuous series of actions, in terms of a process. Thus there are two processes going on in process control: The process to be controlled and the process of controlling. One process is used to control another process (Brehmer & Allard, 1991).

Agile response may be phrased in cybernetic terms as assuring that the response and the variety in behaviour of the system and processes involved in the response aims to meet the variety and dynamics of the controlled processes so that its essential variables are kept within acceptable limits. Typical dynamics in the ATS are changing weather, new regulatory laws, the economy, and human and technological variations in performance, often occurring in unpredictable combinatorial and emergent ways (see Hollnagel, 2004). For the ATS, losses in lives and material are generally regarded as essential variables to be minimised (e.g., from the definition of what constitutes an accident). For an aircraft and its crew, the aerodynamic flight envelope, minutes of flight delay, fuel consumption, or passenger comfort, may be essential variables. For an airline, the passenger load factor would be an example. For air traffic controllers, aircraft separation is an example essential variable. For any commercial company (such as an airline, aircraft manufacturer, or ANSP), quarterly or yearly profit, the company's market value, or its image in the eyes of the customer, may be examples of essential variables. Thus, essential variables may be more or less easy to measure and defined for various (systems of) systems. Research on agility and resilience in cybernetic terms may be said to investigate how a system (e.g. an individual, team, or organization in the ATS) retains requisite variety in the face of (potentially) adverse events, for example by changing the organizational structure or organizational processes, in order to retain acceptable values for essential variables.

2.2. Agility in military and crisis management

Agility as a concept was developed from the point of view of command and control, which is characterised by time pressure, uncertainty, and risk, in the face of complexity. Similar to the development within industry, aviation and society in general with an increased level of complexity and interdependence between systems, military operations have become so complex that effective command and control and performance in military operations should be described as emergent properties of the behaviour of MTO-systems (Man-Technology-Organization), rather than simple cause and effect relationships. Similarly to Resilience Engineering, agility is about "maintaining success in light of changed or changing circumstances" (Alberts, 2011, p. 66). It includes both passive–active and reactive–proactive components.

The concept of agility is related to the concept of resilience in the sense that there is a common focus on adaptation of the management/organisation of command and control (C2) and/or crisis management processes not only after a certain disturbance or event but also in a proactive manner. The primary focus is on agility and C2 agility as defined by and in connection to the NATO STO[3] SAS task-groups (SAS-065, 2010; SAS-085, 2013) whereas other definitions and uses of the term exist. In the non-military context, *organisational agility* (Johansson & Pearce, 2014; Dyer & Schafer, 1998) has been used to describe how business organisations adapt to changes in the

[3] Science and Technology Organization

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market. From this point of view a dualistic relationship exists between *agency*, the ability to respond to changes with flexibility and acuity, and *structure*, the process constraints and functions that organise work in terms of coordination and cooperation. The organisation thus must provide the necessary structure for work while giving the members of the organisation the freedom to be creative and take advantage of opportunities as they appear (Johansson & Pearce, 2014; Dyer & Schafer, 1998). Holsapple & Li (2008) propose a similar view of organisational agility by pointing out that the organisation must be able to recognise opportunities and challenges (both internal and external to the organisation) and respond using resources in a timely, flexible, relevant and affordable manner.

In the military context, Alberts proposes the following definition: "Agility is the ability to successfully effect, cope with, and/or exploit changes in circumstances" (Alberts, 2011, p. 190) and (SAS-085, 2013, p. 54).

In the agility concept developed by Alberts and the SAS-085 group, agility is a multi-faceted concept which includes the following components: *responsiveness, versatility, flexibility, resilience, innovativeness,* and *adaptability* (Alberts, 2011, p. 204).

- *Responsiveness* is a reflection of the timeliness of the intervention(s). The efficacy of the intervention is a function of all six of the components of agility.
- *Versatility* is the passive component of agility that enables an entity to maintain an acceptable level of performance without having to take action or change oneself.
- *Flexibility* is having more than one way to achieve a desired result. Having options becomes important if the preferred way cannot be exercised, does not work given the circumstances, or becomes prohibitively costly. In theory, the more options one has, the more likely it is that one will have a good option available whatever the circumstances. As the number of options in one's tool kit increases, the marginal contribution of each additional option gets smaller (the law of diminishing returns) (SAS-085, 2013).
- *Resilience,* in the SAS-085 definition, refers to the ability to cope with changes in circumstances that limit, damage or degrade entity performance. Being resilient involves an ability to maintain performance within acceptable bounds despite suffering damage[4].

[4]). Apart from the adversary as an obvious source of perturbations in a military environment, acts of nature and inevitable results of complexity are also mentioned as sources, providing overlaps with the disaster management and resilience engineering fields respectively. Resilience is in this description however more in line with resilience as described in for example physics, meaning the ability to bounce back to an earlier performance level after a disturbance, essentially a passive capacity. In contrast, some authors in the Resilience Engineering and disaster management field, see pro-active adaptability in anticipation of degradation as part of resilience. Adaptability is another overlapping theme, although here it is seen as a part of agility that is related to but separate from resilience.

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- *Adaptability* refers to making changes to oneself. In the case of agility, it is not what one does (choose an alternative course of action) that needs to change, but what one is and how one operates. Thus, adaptability involves changes to organization, policies, and/or processes.
- *Innovativeness* involves creating something new, e.g. a new way of accomplishing something when current practice does not provide options with adequate performance. While flexibility refers to having more than one choice, innovativeness adds new ways and means to the toolkit. Hence, Innovativeness enhances Flexibility.

Alberts (2007) builds upon the NATO STO SAS work and explains the need for agility based on the limitations in the dominant form of command and control as a hierarchical approach focusing on control of internal processes. Agility is motivated by the need to think about new approaches by: (1) the nature of operations and the environment in which they are undertaken; (2) the capabilities of adversaries; and (3) opportunities provided by advances in technology, particularly information technologies).

Agility can in part be achieved by being command and control agile, meaning that the actual C2 (systems, organization) is rearranged in order to better fit the current or foreseeable future situations. The NATO STO SAS defines command and control agility (C2 agility) as the ability the organization(s) must have to monitor own behaviour in relation to the ongoing situation (SAS-085, 2013). Also, the organization(s) must have the ability and willingness to adjust its current way of working. This is explained in detail in section 2.2.1 below.

From an analytical point of view, agility can be divided into *potential agility* and *manifest agility* (SAS-085, 2013). Potential agility is the degree of agility that can be assessed or expected from an entity or a collective of entities. Manifest agility is the agility actually manifested during an event, something that can be judged in for example an accident analysis or a case study. These are differentiated, as having potential agility does not assure that this potential actually is manifested in an actual event.

2.2.1. Command and control approach space

The most important conceptual tool developed in the NATO STO SAS work is the *command and control approach space* (see Figure 1), a three-axis model presenting an organization's[5] approach to C2 (C2 approach) in terms of "information dissemination" (who gets to know what?), "allocation of decision rights" (who has the mandate to take action) and the "interactions" (who is interacting with who?) (NATO STO SAS-065, 2010). Hierarchical, formal bureaucratic organizations with limited capability to disseminate information will position themselves on the "lower" end of the

[5] Or *entity*, using the language of the SAS-groups.

dimensions while more networked, distributed organizations with a high degree of allocation of decision rights will position themselves further out on the axes. The positioning of different approaches should not be interpreted as one being "better" than another. Instead, the appropriateness of a C2 approach can only be evaluated in the light of the situation and problem in which it is applied. For some situations/problems a formal bureaucracy may be a good choice, while other situations demand other approaches to command and control/crisis management.

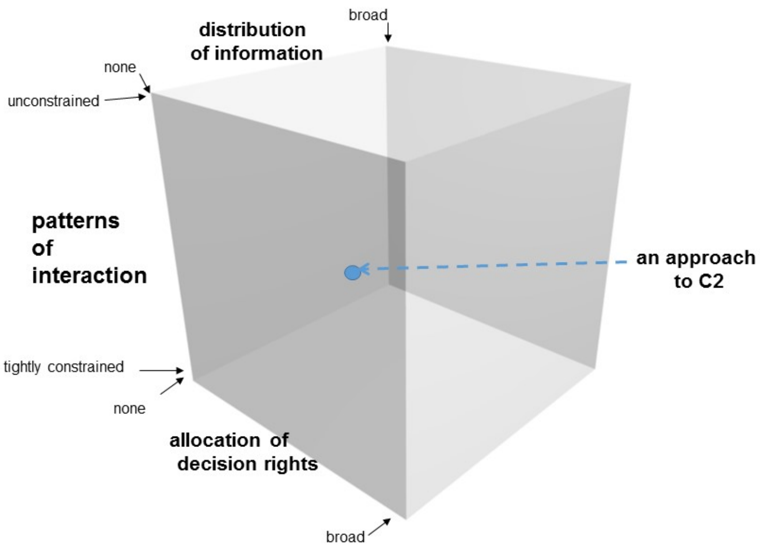

Figure 1. The C2 approach space (SAS-085, 2013).

The SAS-065 (2010) report suggests five archetypical approaches to command and control that can be found along the diagonal going from the lower left corner of the cube towards the upper right corner on the opposite side of the space. Two C2 approaches that are often used as extreme cases to illustrate this are traditional, hierarchical organizations with stove-piped communication and centralized control, versus fully networked organizations with complete access of information for all participants and full allocation of decision rights to all members. The following archetypical C2 approaches are described (SAS-065, 2010, see Figure 2):

- *Conflicted C2* represents a lack of coordination of action between the involved entities. Each entity acts on its own accord and does not consider or respect the act of other entities. No information sharing exists between entities and no entity has decision authority over another entity. Surprise, duplication of work, poor resource management

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and even potential risk (especially in the military context where friendly fire incidents may occur) is common.

- *De-conflicted C2* is signified by basic coordination, such as dividing an area of operations into different sectors that the entities are restricted to, or by functional division of work. Decision rights are usually centralised and information is only disseminated on a need-to-know basis. Continuous coordination does not take place, making the approach inflexible and unable to adapt to sudden changes.
- *Coordinated C2* represents an approach where the involved entities actively coordinate their efforts. Planning may still be centralised and the internal organisation of the entities may be hierarchical, but some degree of joint planning and resources management exist. At least, the involved entities must seek mutual support for their actions. This demands a certain degree of information sharing to make sure that the involved entities are aware of each other's actions. Technical systems must not necessarily be interoperable between entities as long as the commanding nodes of each entity can exchange information with other command nodes.
- *Collaborative C2* demands active collaboration between the entities involved and also a collaborative planning and goal formulation. A common intent, a single shared plan, must exist within the collective of entities. Such an approach demands interoperable systems on several levels so that local coordination can take place between parts of different entities. Entities employing a Collaborative C2 approach accept symbiotic relationships and are interdependent. Very frequent interactions, indeed approaching continuous interactions between/among identified individuals/organisations, involving richer and more extensive interchange of information.
- *Edge C2* is an envisioned approach to C2 that is based on highly networked interactions where all entities share a common intent and the allocation of decision rights are established in its broadest sense. Work is coordinated by self-synchronisation. The patterns of interaction are dynamic and reflect the confluence of mission and circumstances. The resulting distribution of information is emergent as a function of the emergent decision-related and interaction related behaviours.

While the de-conflicted, hierarchical organization demands centralized coordination of all action, the edge organization is almost completely based on self-synchronization. Most real-world organizations will be somewhere between these two extremes, positioning themselves towards the middle part of the C2 approach space, and not necessarily along the diagonal axis. Results from the studies performed in SAS-085 (2013) suggests that organisations that seemingly have adopted one of the archetypical approaches actually position themselves far off the diagonal axis.

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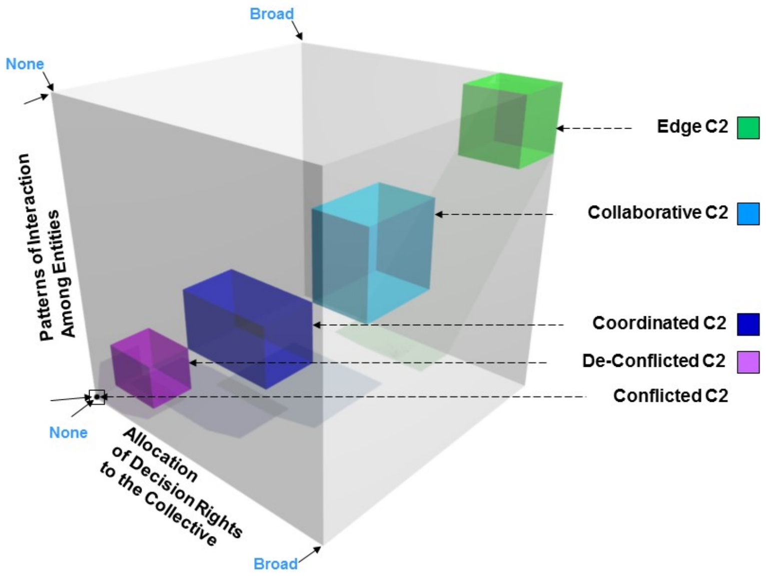

Figure 2. The archetypical approaches to C2 (SAS-085, 2013).

In military operations, actual approaches resemble a coordinated approach to C2 where entities coordinate their activities and share information to a certain extent, or perhaps adopt a collaborative approach to C2 where significant synergies are established by negotiating and establishing collective intent, making roles explicit, coupling actions and increasing shared awareness by increasing information dissemination. Similar observations can be made in crisis management/response. For example, the EACCC function (see Section 3.1.1) is basically organized according to the coordinated approach to C2, although the degree of information dissemination is somewhat unclear from official description.

2.2.2. Command and control agility

A fundamental hypothesis presented in the work conducted by SAS-085 is that each type of situation/problem/mission has a corresponding "best choice" of C2 approach (position in the command and control approach space). No approach is thus perfect for all kinds of situations/problems/missions. The situation in which the organization operates is referred to as the *endeavour space,* using the NATO STO SAS terminology.

"C2 Agility is an entity's capability to successfully accomplish C2 functions over the entire Endeavour space" (NATO STO SAS-085, 2013, p. 79).

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However, no explicit model like the C2 approach space, describing the basic dimensions of the endeavour space has been published within the NATO STO SAS research groups.

The term *command and control maturity* (SAS-085, 2013) refers to the ability of the organization/organizations to function at different positions in the C2 approach space. It should be observed that there is a difference between C2 *maturity* and *C2 manoeuvre agility*. C2 maturity only tells what parts of the C2 approach space an organization/entity can occupy. Having C2 manoeuvre agility means that the entity also has the ability to recognize when it should perform such a movement and do so. This is partly founded on the agility components *adaptability* and *innovativeness*, but mostly on the ability to self-monitor, which will be further discussed below (see Figure 6.). To be C2 agile is thus a function of what parts of the C2 approach space that an organization/entity or a collective of such potentially can occupy (the C2 maturity), and the ability to position itself appropriately in relation to the endeavour space (the C2 manoeuvre agility). Figure 3 illustrates how a change in mission circumstances suggests the need to adapt a different C2 approach.

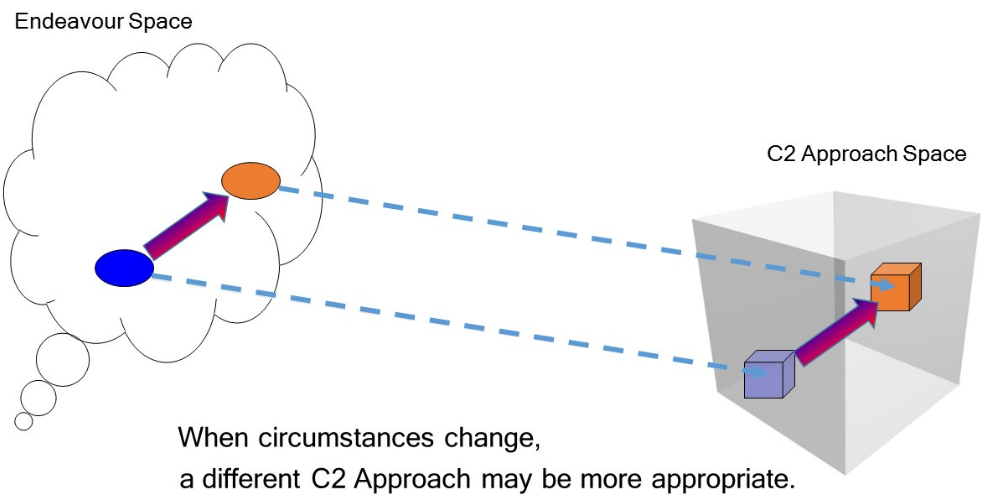

Figure 3. Adapting a different C2 approach as a function of changes in the endeavour space (SAS-085, 2013).

Being C2 agile thus means to be able to recognize that the current C2 approach is inappropriate in relation to the current situation, understanding what approach would be appropriate, and, finally, to have the ability to make a transition from the current C2 approach to the desired one. Naturally, this will, in many cases, require a fundamental change in thinking about organizational design as such an approach demands that an organization or a collective of organizations not only focus on one way of organizing and performing. This stands in contrast to most current approaches where one way of working is assumed. Admittedly, crisis management/response organizations are

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sometimes less formalized in their processes than other types of organizations, but the most agile organizations today are probably found in business rather than military or crisis management/response organizations. A crisis will however often challenge pre-conceived views of how things should be done, promoting flexible approaches to C2/management.

It should also be noted that the need for being C2 agile can emerge as a consequence of the composition of a crisis response organization (the collective, using the terminology of the SAS-groups). For example, as pointed out in Section 3.1.1, different organizations may be called upon by the EACCC depending on the situation at hand. This in turn means that the various organizations that are to collaborate/coordinate during a crisis must adapt their ways of doing so to the partners in the collective effort. This will directly affect all dimensions of the C2 approach space as the principles for working together (if any) prescribe interactions and decision authority (allocation of decision rights) and the technical possibilities, as well as juridical and practical, and set the boundaries for the possibility of dissemination of information. So, even if an individual organization has a C2 approach that is positioned close to the "edge" archetype, it may very well be forced to work on "coordinated" when taking part in a larger collective of organizations. Lack of technical interoperability or technical failure may even degrade an operation to de-conflicted or even conflicted C2, at least if the participating entities are located far from each other in terms of physical distance. Individual agility is thus not a guarantee for collective agility (see Figure 4 and Figure 5).

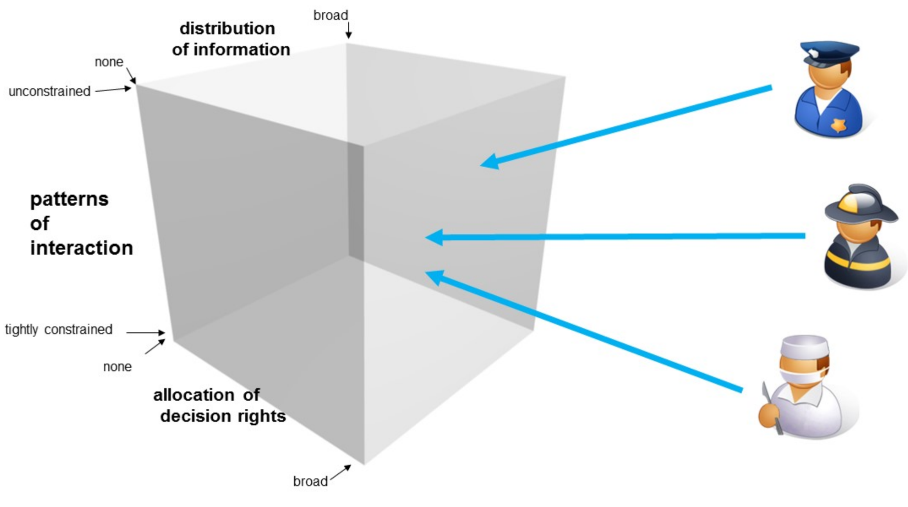

Figure 4. Different emergency response organisations position themselves differently in the C2 approach space.

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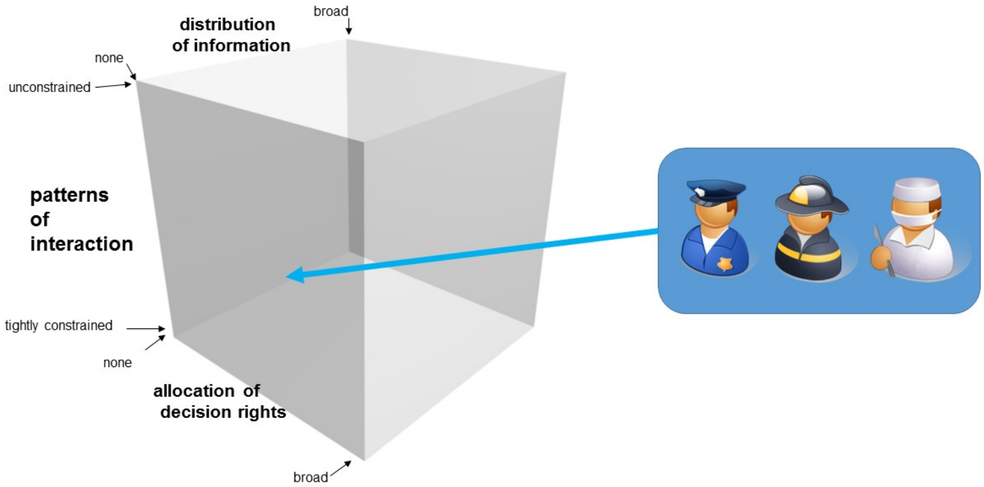

Figure 5. When working as a collective, for example during a crisis, the emergency response organisations may occupy a different region than their individual in the C2 approach space.

Likewise, the C2 maturity and C2 manoeuvre agility of a collective can differ greatly from the capacities of the individual participating organisations/entities. The C2 approach of the collective may also change during the course of a crisis. Several case studies have shown such movements in the approach space. Movements may be initiated pro-actively, based on an understanding of what is likely to happen in the future, or re-actively, based on an understanding of the current situation (see Figure 6).

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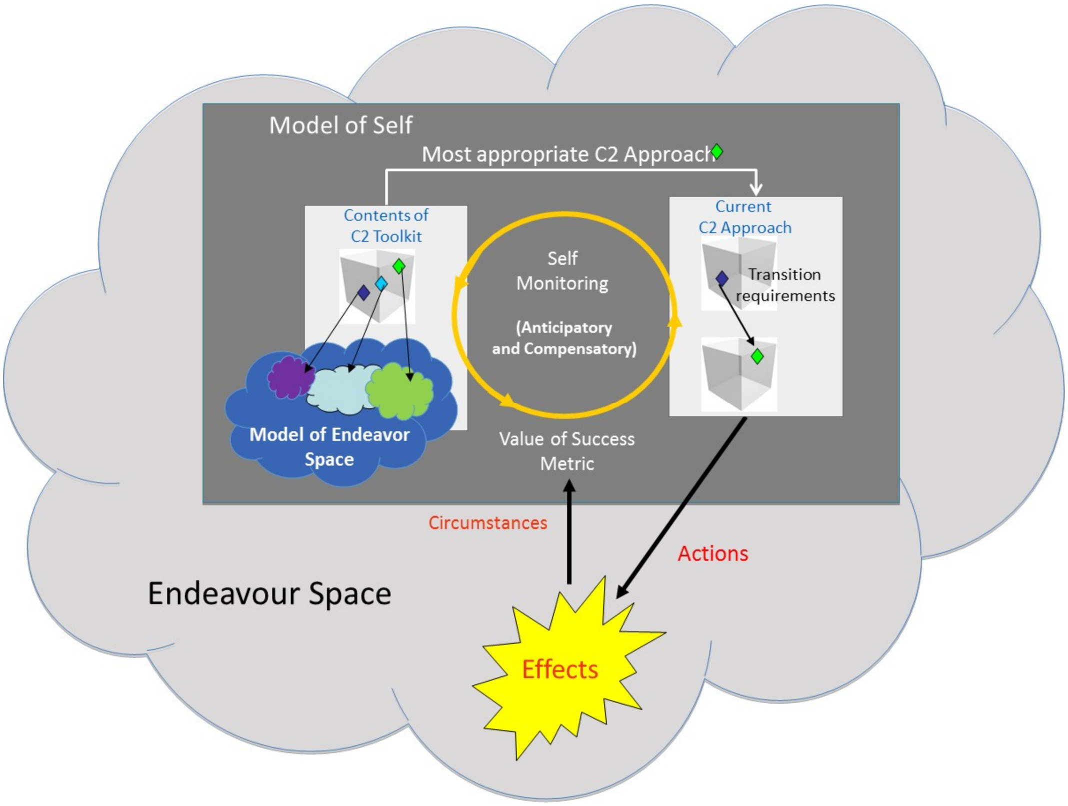

Figure 6. Conceptual model of C2 manoeuvre agility (SAS-085, 2013).

As can be seen in the model above, a "self-monitoring" function is needed in order to assure that an appropriate C2 approach is utilized in a specific situation. The self-monitoring function may be designed into the organization/collective, or simply be a consequence of the realization that the current way of organizing and conducting C2 is insufficient. In the latter case, it is most likely reactive in its nature. The task of the self-monitoring function is essentially to fulfil the requirements of C2 manoeuvre agility - to monitor the progress of operations and reflect upon the appropriateness of the current C2 approach in relation to the progress. If a mismatch is detected, the self-monitoring function should assess what kind of movement in the C2 approach space would be needed to achieve a better fit.

2.2.3. Application of C2 agility

The conceptual model shows that self-monitoring is necessary for successful C2 agility, but it does not provide guidance on how to implement these concepts. Some preliminary answers can be found in a document published by the CCRP (Command and Control Research Programme; CCRP, 2014). According to this "handbook", the selection of C2 approach should be part of operational planning. It suggests a three-stage process by addressing three questions: *What prevents us from*

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going where we want to go (the problem)? , *What should we be doing*? and, *What are we doing – is it working?*

The first stage involves an effort to understand what the mission/problem looks like and the "C2 linkages" that need to be established (both internal and external) to achieve a certain C2 approach. The C2 linkages are the connections between entities in a specific operation. Many of these would exist prior to the operation, but some new may have to be established. The purpose of establishing these links is to achieve certain C2 activities, such as preparation, planning, prioritization, risk management, coordination etc. C2 activities are the means through which the C2 approach is realized – different C2 approaches will be more or less suitable for achieving these functions depending on the circumstances. The "Handbook" (CCRP, 2014) is intended to be used in a military context, specifically aimed at US military, but it makes a distinction between Joint C2 tasks and C2 activities that may be helpful in the crisis management domain. There are examples of joint C2 tasks, being performed on the level of a collective of organizations, and the C2 activities needed to perform these Joint tasks, see Table 1.

Table 1. Joint C2 Tasks and Exemplar C2 activities (from CCRP, 2014, pp. 15-16).

Establish, organize, and operate a joint force headquarters:

- Operational Design

Command subordinate forces:

- Decision Authorities Matrix

Prepare and, when required, modify plans, orders, and guidance:

- Mission Analysis
- Orders Process
- Plans Synchronization Boards
- Transition Mapping Workgroup
- Joint Planning Groups (deliberate, crisis action, and adaptive planning processes)

Prioritize and allocate resources:

- Synchronization Workgroup
- Critical Path Synchronization Meeting
- Various Utilization Boards
- Intelligence Collection/Synchronization Workgroup
- Medical Workgroup
- Logistics Coordination Workgroup

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- Aviation Deep Operations Working Group
- Joint Transportation Board
- Cyber-Electromagnetic Activities Working Group

Manage risk:

- Risk Assessment Workgroup
- Develop Commander's Critical Information Requirements
- Force Protection Working Group

Communicate and maintain the status of information:

- Battle Update Briefings
- Commander's Update Assessment
- Commander's Azimuth Check
- Chief of Operations Synchronization Huddle
- Staff Update Briefing
- Shift Change Turnover Briefing
- Information and Knowledge Management Workgroup
- Information Operations Workgroup

Assess progress toward accomplishing tasks, creating conditions, and achieving objectives:

- Assessment Boards
- Decision Support Matrix

Coordinate and control the employment of joint lethal and non-lethal capabilities:

- Deliberate and Dynamic Targeting Processes
- Targeting Workgroups
- Targeting Boards

Coordinate, synchronize, and, when appropriate, integrate joint operations with the operations and activities of inter-organizational partners:

- Operate various centres and cells
- Civil-Military Workgroup
- Manage Visitors' Bureau
- Strategic Communications Workgroup

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As can be seen in Table 1, not all joint C2 tasks and C2 activities can be transferred to the ATS or crisis management domains, but the approach may still be useful for understanding how activities relate to joint tasks. Further, the handbook provides guidance on how to determine what C2 approach to apply in a situation. Table 2 presents sample questions to identify an appropriate position in the C2 approach space.

Table 2. Guiding questions for identifying an appropriate C2 approach (CCRP, 2014, pp. 18-19).

- What are we seeking to understand, how does this understanding relate to current or planned operations (relevant yet missing aspects of the circumstances and supported decisions), and how is it related to decision making?
- What then are the informational needs? *Distribution of information*.
- Who might have the needed information or where do we expect to find it? *Patterns of interaction* and *Distribution of information*.
- What relationships exist with those that have or are expected to have the needed information? *Patterns of interaction*.
- Do new relationships need to be established in order to gain the needed information? *Patterns of interaction*.
- What types of information will need to be exchanged and how exactly will the exchang e be accomplished? *Distribution of information*.
- Do we have release authority to share this information in the manner expected? Do other entities have the authority to share with us? *Decision rights*.
- Are communications established and tested to ensure information can be shared in the manner expected? *Distribution of information*.
- How will this new information be compiled and presented to meet the informational and decisional needs? *Distribution of information*.
- How will this information support decisions necessary to enable current or future operations? *Decision rights*.

These questions must be addressed in order to understand how communication and information sharing shall be established between the involved organisations in the collective. Decisions are probably the most important products of crisis management organisations, because they guide the force toward objectives and goal accomplishment. Naturally, decision makers do not need only information to make these decisions, but also knowledge and understanding. However, to provide information, C2 linkage must be established.

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When establishing C2 linkage, certain questions must be answered (CCRP, 2014, p. 21):

- Who is responsible for establishing the linkage?
- A description of the linkage (what should the linkage look like physically? Not all need be or can be electronic).
- When is the linkage necessary?
- What types of information are expected to be exchanged? While it is not possible to predict in advance all the data that will be needed, enabling discovery is key. More specifically:
    - What do we need from the entity?
    - What will the entity need from us?
- What restrictions, if any, may limit the exchange of information (e.g. access to classified information)?
- How will this information be provided to the new entity?
- Which entity has authority to make key decisions based upon new information?
- The means and frequency (how often) for reporting the status of this linkage (e.g. command communications/assessment update)

As can be seen, establishing C2 links directly affects the C2 approach of a collective. Furthermore, the ability to establish such links (or the preparation of links) affects what positions in the C2 approach space a collective potentially could occupy. It is not the only pre-condition, as training, processes and juridical aspects also may constrain the C2 maturity of the collective, but without the necessary C2 linkages, some approaches are beyond reach.

Once an appropriate C2 approach has been established, the collective/organizations still have to keep on monitoring the appropriateness of that C2 approach as the situation evolves through the "self-monitoring function". The handbook provides some aspects for performing such an assessment on the macro (collective) level. They are as follows:

Is the C2 approach working? Is the approach enabling both the operational approach as a whole and its individual lines of effort? This can be assessed by bottom-up reporting of information flows, collaborations and if decision and action can be performed in a timely manner.

What has changed or could change in the operational environment that will/could impact the C2 approach? It is not possible to present a comprehensive list of what could change as each mission and operational environment are likely to be different, but examples could be changes to the mission itself, changes to the organization (within the collective or in other organisations that have significant impact on the operation), changes in the number of involved organisations/actors, changes in the actual operational environment (such as a major change in weather or changes in public opinion or political ambitions), or communication disruptions (technical failures, security issues, etc.).

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What indicators would illuminate change in the operational environment and how can they be monitored? How can such indicators be implemented? What kind of intelligence must be gathered and from what sources? Who is responsible for monitoring those information sources?

What are the most important changes to address first? The C2 approach could be altered along the dimensions of the C2 approach space, but different changes comes at different costs, and may also be more or less feasible depending on the situation and the current composition of the collective. Urgency and risk must be compared.

How will the most important changes impact the C2 approach? In what way will the implemented changes affect the C2 approach? What adjustments are required to achieve this?

The above presented aspects were taken from CCRP (2014). As can be seen, the literature provides some guidance on how to select, assess and monitor the appropriateness of a C2 approach. However, few, if any, organizations today have implemented these concepts in their organisations/collectives, at least not with the level of flexibility suggested in the agility literature in mind. Within the SAS-085 work, a number of case studies were performed to investigate the appropriateness of the concepts and terminology. They are briefly presented below.

2.2.4. C2 agility case studies

The SAS-085 final report (SAS-085, 2013) and related literature (Banbury, Kelsey & Kersten, 2011; Farrell, Jobidon & Banbury, 2012; Meijer, 2012; Henshaw, Tetlay & Seimeieniuch, 2013; Farrell, Baisini, Belanger, Henshaw, William & Norlander, 2013) present a number of case studies aiming to identify key concepts, components, constraints and behaviours related to C2 agility. The conducted studies utilized a shared case study template which was designed to make the different cases comparable (SAS-085, 2013). The case study consists of 10 parts that should guide the researcher with respect to what data to collect and how to analyze it by defining what kind of content each part should consist of. The template comprises the following parts:

1. *Executive summary* describes the events studied, focusing on aspects relating to C2 to give the reader an understanding of the case and how the analysis was performed.
2. *Identify the focus of and the boundaries of the case study* identifies the level of analysis, temporal phases, and other boundaries.
3. *Describe the challenge or opportunity that gave rise to the need for C2 approach and C2 manoeuvre agility* briefly summarizes the situation that would give indications about the appropriateness of a particular C2 approach and the observed C2 agility, if any.
4. *What would have been the consequences of a failure to act in a way that demonstrates C2 approach agility and C2 manoeuvre agility?* Focuses on the consequences if an appropriate C2 approach was not adopted or if C2 agility were not manifested.

5. *Was C2 approach agility and C2 manoeuvre agility manifested?* Encapsulates high-level statements on whether C2 approach agility and C2 manoeuvre agility were manifested in the case.
6. *Which enablers and inhibitors of C2 approach agility were observable?* Presents the evidence found to support the agility assessments.
7. *What C2 approaches were relevant (i.e. did different situation complexity levels require a corresponding different C2 approach?)? How can C2 manoeuvre agility be inferred from what was reported or observed?* Recounts any interesting vignettes from the case that might clearly illustrate C2 approach agility, C2 manoeuvre agility, or both.
8. *What interesting and important vignettes are included or can be derived from the case study to help create illustrative stories?* Can be used to compile account that can be used to illustrate phenomena that are useful for describing C2 or C2 agility-related events that have been identified in the case study.
9. *Case study assumptions and limitations* is a discussion of the assumptions and limitations that frame the case study.
10. *Bibliography* contains references to publications used as data sources for the analysis.

The case studies presented were gathered from different domains so that a meta-analysis could be performed (reported in SAS-085 2013 and Farrell, 2013). The meta-analysis aimed to find evidence for C2 agility across multiple studies and to revise the case study template.

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Table 3 presents the SAS-085 case studies.

Table 3. Case studies reported in the SAS-085 final report (SAS-085, 2013).

Complex battlespace • Helmand Province 2010/2011 • Comprehensive approach in NATO operations **Peace-keeping and personal agility** • Rwanda genocide 1994 **Cyber Warfare** • Estonia Cyber attack 2007 • Georgia Cyber attack 2008 **Natural disasters** • Garda Earthquake 2004 • Haiti Earthquake 2010 **Major Events** • Munich Olympics 1972

The case studies are generally organized in at least three phases, an initial phase, an "operations" phase and a "stabilization" phase. Some of the cases, such as the 1972 Munich Olympics terrorist attacks and the Rwanda genocide in 1994 consist of more phases. In some cases movements in the C2 approach space based on the complexity of the situation (C2 manoeuvre agility) was observed between the phases (Helmand Province, Garda Earthquake and Rwanda genocide). The Georgia cyberattack case and the Haiti earthquake case reports describe movement in the C2 approach space, but these movements do not seem to match the actual development of the situation. They may thus have been intentional, but too late. Five out of nine case studies indicated Self-monitoring. Out of these five case studies, only Helmand Province demonstrated intentional movements in the C2 approach space that actually matched the conditions of the mission (C2 manoeuvre agility). The Garda Earthquake yielded C2 Manoeuvre Agility but gave no evidence for Self-monitoring. A possible explanation is that the concept of Self-monitoring was added to the C2 Model long after the Garda Earthquake case study was finalized. SAS-085 (2013) presents some general findings from the case studies, of which the following are found to be relevant to this report:

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Anticipation, in terms of learning, training and exercises can be seen as a part of the potential agility of an organization or a collective.

The *size of the collective* and how it fluctuates also affect which C2 approach can be adapted. Although no specific size can be pointed out from the observations made in the case studies, the studies indicate that smaller collectives are more likely to achieve edge-like C2 approaches, as in the case of the Helmand province and the Garda earthquake (SAS-085, 2013).

The *homogeneity of C2 approach* amongst organisations/entities in the collective enables agility while collectives whose entities adopt different C2 approaches seem to be less able to manifest agility. This was particularly apparent in the Rwanda genocide case study.

Some organizations/collectives tend to adopt a *comfortable C2 approach* meaning that they show reluctance to changing C2 approach even when circumstances suggest so.

The Garda earthquake case study showed that *trust* and *interpersonal relationships* are key variables related to agility and C2 agility. Oppositely, the Munich 1972 Olympics case showed that lack of trust can lead to a lack of agility or C2 agility. Without a sufficient degree of trust between the participating organizations/entities, it will be difficult to achieve even basic forms of collaboration and coordination. Information exchange is based on trust.

A more general observation that is hard to label is that, in some cases, the C2 approach was imposed upon the collective by external influence in the sense that the way of conducting C2 and exchanging information was prescribed already at the beginning of the operation. This is not a problem as long as the selected C2 approach fits the problem at hand in the sense that it allows for achieving a sufficient variety to cope with the problem.

The case studies support the work conducted in this D5.3, although no case study has been based on studies performed within the ATS so far. The phenomena and findings described are general enough to be applicable to many domains that are signified by having to establish a complex C2 organisation to cope with dynamic and complex situations.

2.3. Resilience Engineering

Resilience has been defined as “the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions.” (Hollnagel, 2011a, p. xxxvi). This definition reflects the need to not only reactively adjust after disturbances are observed but also when they are anticipated to occur. Adjusting performance with respect to disturbances but also subtle changes is essential, as fluctuations in working conditions may coincide and combine to hazardous situations due to complexity and intractability. Resilience Engineering (RE) emphasises the need to see the multiple goals that the core business aims to achieve, which is hardly only safety but often also productivity, security, environmental sustainability, etc. RE recognizes that not all conditions can be expected and prepared for beforehand, and that unexpected conditions will at some point occur. In order to achieve resilience, four interrelated and interacting abilities have been suggested: anticipating (knowing what to expect), monitoring (knowing what to look for), responding (knowing what to do), and learning (knowing what has happened) (Hollnagel, 2011b).

Articulating the importance of unexpected conditions in Resilience Engineering, another definition focuses on the situations that go beyond what the organisation or system has prepared for: ”the ability to recognize and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies and coordination” (Woods, 2006) (p. 22). Recently, Woods outlined four uses of the concept of resilience: as rebound, as robustness, as graceful extensibility when surprise challenges boundaries, and as a network architecture that can sustain the ability to adapt to surprise (called Resilience-1 to 4 by Woods, 2015).

Resilience Engineering and Safety-II (EUROCONTROL, 2013; Hollnagel, 2012a) are concerned not only with understanding the relatively few cases of incidents and accidents and reducing what goes wrong, but even more so to learn from normal, daily operations in ultra-safe systems, of which the potential data set is many orders of magnitude larger, thereby increasing the number of cases that go right (EUROCONTROL, 2013). Adopting this view creates a need for an approach that can represent the everyday performance variability and emergent properties of safety-critical huMan-Technology-Organisation (MTO) systems. Emergent properties are properties of complex socio-technical systems that arise at higher levels of complexity out of relatively simpler processes or interactions, and are the result of system components and processes (people, procedures, and equipment) working together or impacting each other. Resilience Engineering attempts to understand and manage performance variability and address safety, efficiency, and resilience as emergent properties.

The perspectives of Resilience Engineering and Safety-II aim to understand why everyday performance succeeds. In this context, safety is understood as the ability to succeed under varying conditions (EUROCONTROL, 2013). Varying conditions are always under-specified. Individuals and organizations must therefore adjust what they do to match current demands and resources. Because resources and time are finite, such adjustments will inevitably be approximate. Performance variability is defined as the ways in which individual and collective performances are adjusted to match current demands and resources (EUROCONTROL, 2013).

Descriptions of procedures and the use of technical systems cannot fully be specified for the actual situations that will be met during everyday operations, because the conditions of work cannot be fully specified. Thus, operators necessarily have to make approximate adjustments of their performance to the context, and their performance has to be variable, to be able to cope with unexpected situations and conditions. Performance variability and approximate adjustments by

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complex socio-technical systems are necessary, inevitable, and useful, and the reason why everyday work is safe and effective, but at the same time they can play a role in why unexpected or undesired outcomes occur (EUROCONTROL, 2013; Hollnagel, 2004). Unexpected outcomes can result from everyday processes that interact in unexpected ways. Thus, all outcomes are due to everyday performance variability and approximate adjustments. Categorizations of outcomes (such as positive/negative, success/failure) are judgements of value rather than objective binary categories.

The appreciation of performance variability and trade-offs leads to a view that adaptations are simultaneously well-adapted and under-adapted (to various sets of situational variations and organisational pressures) and maladapted (or brittle, with respect to unanticipated or unprepared-for events) (Woods & Branlat, 2011). In this context it is also relevant to consider the extent to which a MTO system is able to anticipate, monitor, respond to, and learn from (Hollnagel, 2011a) different kinds of threats. One classification (Westrum, 2006) distinguishes between regular threats (that are predictable and expected), irregular threats (that are unexpected, but not perceived as impossible or unimaginable), and unexampled events (that are outside collective experience envelope). The processes for handling each of these are argued to be fundamentally different. From the point of view of agile response, it must be acknowledged that the response system must be designed in such a way that it supports response to both foreseeable (regular) and irregular/unexpected events. This does however call for different approaches, as response to regular events usually can be optimized, and irregular/unexpected events only can be coped with by creating flexible response organizations with a high degree of redundancy (Johansson & Lundberg, 2010).

A recent effort to include resilience engineering and safety-II principles in risk assessment is a method developed for the air traffic management (ATM) research and development programme SESAR Woltjer, Pinska-Chauvin, Laursen, & Josefsson, 2015). This approach developed resilience engineering guidance for safety assessment of functional changes in air traffic management MTO systems. Eight principles were derived originating from resilience engineering concepts and transposed into ATM operations. These principles are the foundation for a method incorporating resilience engineering into an existing framework for safety assessment used in SESAR, and for providing guidance for various design processes in ATM. The principles address work-as-done, varying conditions, signals and cues (anticipation, monitoring, response), goal trade-offs, adaptive capacity, coupling and interactions, timing, pacing, and synchronization, and under-specification and approximate adjustments.

Within RE, several methods are suggested that can provide guidance on how to improve the resilience of a system. These methods are typically based on either a systemic approach or a functional approach, or a combination thereof.

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The Systems-Theoretic Accident Model and Processes (STAMP) is a systemic model for accident analysis and hazard analysis (Leveson, 2004, 2011). STAMP develops a control-theoretic perspective on mapping constraints and organizational interactions and suggests an analysis approach that takes blunt end – sharp end (from governmental regulations to operator behaviours) into account.

The Functional Resonance Analysis Method (FRAM) is a method based on four principles: the equivalence of failures and successes, the central role of approximate adjustments, the reality of emergence, and functional resonance as a complement to causality. The method utilizes a functional perspective, suggesting that a system should be defined in terms of what it does (function) and, in line with functional modelling, the pre-requisites for achieving different functions should be described in order to understand how variability can propagate between functions and lead to unwanted outcomes (Hollnagel, 2012).

The Resilience Analysis Grid (RAG) is a method for assessing the resilience of a system (or organization), departing from the ability to respond, the ability to monitor, the ability to anticipate and the ability to learn. The outcome of performing a RAG analysis is a resilience profile, based on ordinal scale rating performed by experts (Hollnagel, 2011b).

2.4. Resilience in crisis and disaster management

The emergency and disaster management literature has acknowledged the importance of the concept of resilience and the ability to respond swiftly to disturbances for some time (Manyena, 2006). Modern crises may be characterised by an increase in coupling and complexity, which makes prevention, mitigation, and preparation very challenging (Boin et al., 2010). A definition of resilience in the disaster management strand of research is: “Resilience is the capacity of a social system (e.g., an organization, city, or society) to proactively adapt to and recover from disturbances that are perceived from within the system to fall outside the range of normal and expected disturbances” (Boin, Comfort, & Demchak, 2010, p. 9). Besides similarities in proactivity, a tension can e.g. be found between the inclusion of expected events and the restriction of resilience to the unexpected and not-prepared-for, as in Boin et al.’s (2010) as well as Woods’ (2006) definitions of resilience. Agility and C2 Agility on the other hand acknowledges both themes as military operations are inherently risky and expected as well as unexpected events must be coped with or even exploited to derive benefit (SAS-085, 2013).

Research tensions and challenges for the definition of resilience in disaster management in relation to related disciplines have been described in three aspects (Boin et al., 2010): (a) the moment of resilience (response/recovery after the event and/or adaptation beforehand); (b) to which event severity it applies; and (c) the state of return that resilience applies to (returning to a situation similar to before the event, make the system function again, or making it stronger than it was before). A similar stance is taken by Lundberg and Johansson in the Systemic Resilience Model

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(SyRes), which describes resilience in crisis response as a series of events that may or may not be handled depending on the ability of a set of functions to cope with them (Lundberg & Johansson, 2015). According to the SyRes model, a number of "core resilience functions" must be maintained, otherwise the system will become increasingly vulnerable. The core resilience functions in SyRes are: Anticipate, Monitor, Respond, Recover, Learn and Self Monitor. As in the case of Boin et al. (2010), the SyRes approach does not assume that a system can walk unharmed from all events. Instead, it assumes that the ability to recover should be planned for in advance and that learning and self-monitoring is crucial as to improve the resilience of the system to better cope with future threats.

2.5. Drift-into-danger and related concepts

The "organizational accident" is an example of a blunt end failure, which in most cases is difficult to detect before the accident, or even trace after something has happened. It typically involves a large number of interacting factors in a complex socio-technical system on different organizational levels that makes it difficult to understand the factors that have contributed to the outcome or could contribute to an unwanted outcome. "Weak signals" can sometimes be detected given a thorough understanding of the system under scrutiny. Such signals may, for example, be a reduced amount of training for coping with emergency situations, gradually increased service intervals, subtle increases in demands for profitability, or decreases in incident and accident reporting or analysis. Two metaphors that aim to integrate the dynamics and multiplicity of complex socio-technical systems are "migration toward boundaries" and "drift toward failure". Rasmussen (1997) proposes a model of how variable system performance is likely to migrate towards boundaries under the influence of various pressures. In this model, boundaries are put up by economic and workload constraints, and perceived and functionally acceptable (safe) performance define the space of possible action. The system exhibits variation in performance, while being pushed towards the various boundaries by pressures of management for efficiency, of safety-improvement initiatives, and a tendency of minimizing effort. A hierarchical modelling philosophy and several analysis techniques describing organizations in various levels are associated to this model, enforcing constraints down the hierarchy and communicating information about the enforcement of constraints upward (Leveson, 2004, 2011; Rasmussen, 1997; Svedung & Rasmussen, 2002). Amalberti has developed Rasmussen's model further as a model of ecological safety, or the model of migration and transgression of practices (Amalberti, 2001; Amalberti et al., 2006; Polet et al., 2003).

The concept of drift toward failure has been suggested as a similar metaphor for describing a system that slowly develops more risk-filled behaviour and eventually breaks down, while all looked well during the process at the decisive operational or managerial levels. It provides a metaphorical description of this phenomenon, which has many similarities to the migration toward the boundaries model discussed above. Dekker (2004) calls drift toward failure "the greatest residual risk in today's sociotechnical systems", and describes its features as being

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generated by normal processes of reconciling conflicting goals under uncertainty, incremental decisions over long time spans, and normalization of signals of danger aligning operational observations with organizational goals.

Both space shuttle accidents have been called examples of drift. Starbuck & Milliken (1988, p. 319) describe organisations such as NASA before Challenger as "interpreting past successes as evidencing their competence and the adequacy of their procedures, and so they try to lock their behaviours into existing patterns", to "evolve gradually and incrementally into unexpected states", and to "fine-tune the odds". Vaughan (1996) describes NASA organisational behaviour before Challenger as "normalization of deviance".

Woods (2005), in describing lessons learned from the Space Shuttle Columbia accident, charts the drift toward failure in this particular accident by identifying points in time where the evaluation of risks related to debris strikes shifted or could have shifted. Along with three shifts, he identifies five general patterns in the period up to the Columbia accident (Woods, 2005), illustrating the processes involved in the drift toward failure: (1) defences eroding in the face of production pressures, acute efficiency goals gradually taking precedence over chronic safety goals, (2) gaining confidence from past success instead of investing in anticipating the changing potential for failure, (3) fragmented distributed problem solving clouding the "big picture", no person had a complete and coherent view of the problem and cross-checks were missing, (4) failure to revise assessments as new evidence accumulates, not capturing and displaying indicators of safety margins, and (5) breakdown at the boundaries of organizational units, lacking effective overlap.

The understanding of "organisational drift-into-danger" is here regarded as a difficult problem that is relatively ill-understood and a research area in itself. It is mostly addressed in connection to safety management and a range of overarching organizational processes, related to agile response but also to other themes of Future Sky Safety (FSS) Project P5, such as leadership, culture, and mindfulness in relation to safety and other organizational goals. Although it is important to be aware of the notion of drift and the detection of weak signals, the actual explicit development of such capabilities is beyond the scope of the Agile Response Capability (ARC) developed in FSS P5 WP5.3. As will be described in Chapter 4, the scope of ARC here primarily focuses on adverse events and the organization of the processes involved in handling such adverse events, where the rate of development over time and ease of detection of the phenomena that constitute the adverse event may be regarded as some of the factors that characterise the adverse event (i.e. they part of the endeavour space).

2.6. Agility and resilience definitions compared

The concepts of agility and resilience have a similar bearing on the management of complex safety- and security-critical operations in terms of adaptability of operations in the face of change and unforeseen circumstances that are not fully avoidable. Both fields have emerged as a reaction

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to earlier, mechanistic/Tayloristic attempts to safeguard against failure. As described above in chapter 2, agility is a term used in the literature on organizational theory (Holsapple & Li 2008; Spaans, Spoelstra, Douze, Pieneman & Grisogono, 2009) military command and control (Alberts, 2007, 2011; SAS-085, 2013) and crisis management (Farrell, Baisini, Belanger, Henshaw, Mitchell & Norlander, 2013). Resilience as used in Resilience Engineering (RE; Hollnagel, Pariès, Woods, & Wreathall, 2011; Hollnagel, Woods, & Leveson, 2006; Woods, 2015) has its basis in cognitive systems engineering (Hollnagel & Woods, 1983, 2005), human factors, and safety science. Disaster management literature has also used the concept of resilience for some time (Boin, Comfort, & Demchak, 2010; Manyena, 2006). Several common definitions of the concepts are at least partially overlapping, yet they stem from rather different conceptual backgrounds and problem areas. The approaches do however share that they have emerged as a consequence of growing complexity and unpredictability in the type of stakeholders' activities.

Both resilience and agility consider adaptive capacity as the primary way to cope with the kind of events that emerge from the complexity of today's challenges. They both consider learning as an important source for improving the ability to cope with challenges, but they also recognise the need to be able to cope with what cannot be anticipated. However, there are some important distinctions too. Firstly, resilience engineering, and safety in general, does not cope with an intelligent enemy and therefore does not need to "exploit changes in circumstances" in that sense – it is enough to "sustain required operations". However, an issue that is more prevalent in aviation, and that military is affected by but in a less distinct manner, is the economic pressure in the highly competitive aviation environment. The "exploit changes in circumstances" aspect of agility could provide a contribution here, linking business continuity and interactions of these aspects with crisis management and safety management aspects in aviation stakeholders. Also, the expectation of flexibility in the ATS clearly points to the need for exploitation of operational opportunities, for example in order to provide efficiency in traffic flows.

Further, agility focuses largely on adaptive capacity in terms of C2, which would translate to "organization" or "management" in the aviation domain. Resilience engineering is not specific in its view on organization/management and lacks a commonly accepted theoretical construct for discussing how management and organization can or should adapt to changing circumstances. Resilience from the agility perspective described seems to be most related to "rebound" or "recovery", and is thus a distinctly different from how resilience is used in Resilience Engineering and disaster management.

Possibly due to Resilience Engineering's roots in mainly cognitive systems engineering and reactions to traditional human factors and safety, the debate of how Resilience Engineering can contribute to these operational practices often focuses on discussions as reactions to traditional safety and human factors paradigms. This report has aimed to discuss how a number of concepts and ideas developed under the labels agility and C2 agility may contribute to improving operational realities in ways congruent to the ambitions of resilience engineering. In particular,

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these concepts may broaden the discussion of resilience from safety to business continuity concepts such as seizing opportunity and exploiting circumstances, and clarify the multifaceted concept of adaptability of organizational features.

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3 SCOPE OF AGILE RESPONSE CAPABILITY

The ATS operates with a very high level of reliability and safety, but the goal of increasing the capability to respond swiftly and agile should always be pursued. By identifying links between different organizations and functions that need to operate as a joint system during a crisis event, the pre-conditions for agile response can be improved. Different kinds of crisis events will obviously call for different constellations of actors in the response system, which also creates demands for having flexible structures that can be re-arranged depending on the type of event to be managed, in line with both C2 agility theory as well as resilience engineering.

This chapter describes the major types of organisations considered in the development of the Agile Response Capability, thereby outlining the system boundaries for ARC, as well as a high-level comparison of the Air Transport System (ATS) to military systems in order to identify the generalisability of agility research from military to ATS.

3.1. System boundaries for Agile Response Capability

The ATS can be seen as a system-of-systems where each component (which may be an organisation, authority, function or even a technical component) contributes with an important competence or information source that is needed for providing timely, reliable and safe operation. As a system-of-systems, the ATS is also vulnerable to disturbances as variations in performance in one system easily propagates to other systems and hence has the potential to hamper the performance of the entire system. Widespread external disturbances such as the ash cloud in 2010 effectively shut down the ATS in a large part of Europe, even if most functionality of the ATS in itself was operational. A coordinated terrorist attack targeting core components of the ATS could likewise effectively cause a shut-down in the ATS, even if a very small part of the system was targeted.

There are naturally specific linkages within the ATS that are crucial for its performance, especially when facing disturbances. Below follows a description of the core functions for managing crisis situations for the main actors that are participating in this project. These are the Network Manager (EUROCONTROL) and its European Aviation Crisis Coordination Cell (EACCC), Air Navigation Service Providers (ANSPs), aircraft manufacturers, and airlines. Other stakeholders are mentioned but not part of the mapping of capabilities as such.

3.1.1. Network Manager and its European Aviation Crisis Coordination Cell (EACCC)

In May 2010, the European Commission (EC) and Network Manager EUROCONTROL jointly established the European Aviation Crisis Coordination Cell (EACCC) (source: EUROCONTROL website) to coordinate the management of crisis response in the European ATM network. The main role of the EACCC is to support coordination of the response to network crisis situations impacting

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adversely on aviation, in close cooperation with corresponding structures in States. This includes proposing measures and taking initiatives to coordinate a response to crisis situations, and in particular, acquiring and sharing information with the aviation community (decision makers, airspace users and service providers) in a timely manner.

This section further describes the EACCC composition and steps taken in case of crisis, example tools that are made available, as well as EUROCONTROL guidelines for contingency planning, as well as Network Manager functions of forecasting, monitoring, and analysis.

3.1.1.1. EACCC composition

In accordance with the Network Manager Implementing Rule EU 677/2011, the EACCC composition includes:

- a representative of the EU Member State holding the Presidency of the European Council,
- a representative of the European Commission,
- a representative of the EASA,
- a representative of EUROCONTROL (Chairperson),
- a representative of the military,
- a representative of the ANSPs,
- a representative of airports, and
- a representative of airspace users.

The composition of the EACCC may be augmented on a case-by-case basis by experts, depending on the specific nature of the specific crisis.

External interactions are mainly relevant State focal points from national supervisory or regulatory agencies. Sharing information and linking national contingency plans with those established at the network level, as well as coordinating a response and mitigation actions are essential parts of the EACCC role in establishing a consistent approach across Europe.

3.1.1.2. EACCC Steps taken in the event of a crisis

In the event of a crisis:

- the EACCC chairperson contacts the relevant State Focal Points and those at risk at the beginning of any crisis, as well as relevant expert organisations, depending on the type of crisis (e.g. VAAC, ESA, etc.).
- the EACCC is convened via meetings or teleconferences.
- the remaining State Focal Points are contacted.
- a crisis-mitigation policy is discussed, agreed and approved by the EACCC. The relevant State Focal Points provide a link with internal structures at the national level and, where

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appropriate, coordinate the response and mitigating actions at the national level in accordance with national procedures.

When the crisis is resolved, the EACCC is deactivated.

A debriefing EACCC session is held to address the lessons learned and remaining actions.

The EACCC gathers, prepares and shares any relevant information with the entire aviation community, ensuring that consistent messages are issued.

To achieve this, the EACCC prepares factual assessments of the situation for communications purposes. Through a nominated communications focal point, the EACCC ensures that consistent information, based on the factual assessment of the situation made by the EACCC, is transmitted to EC/EASA/EUROCONTROL as Network Manager, the civil and military authorities of affected States and corresponding NSAs/ANSPs, airlines and airports.

3.1.1.3. Example tools

NOP

The Network Operations Portal[6] (NOP) is designed for ATM professionals and provides real-time information on air traffic operations. It provides a single human-machine interface bringing together various EUROCONTROL tools and services, presenting the current and expected European air traffic situation. Journalists and the general public can also consult the portal for information on delays and the number of flights in real time.

The NOP serves two main purposes:

1. monitoring the real time status of traffic, airspace and air traffic flow and capacity management measures, and
2. planning pan-European operations in a collaborative way from the strategic to the tactical phases, thus optimising the use of available ATM capacity.

The NOP enables partners to anticipate or react to events, enables users to increase their respective knowledge of the ATM situation, from the strategic phase to real time operations. Operations planning and performance monitoring and reporting functions of the Network Manager are built on the NOP.

[6] Source: http://www.eurocontrol.int/articles/tools-available accessed 03MAR2015.

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EVITA

EVITA[7] (European crisis Visualisation Interactive Tool for ATFCM) is a collaborative online tool which allows users to visualise the impact of a crisis on air traffic and on the available air traffic network capacity in Europe, supporting decision making in times of crisis and providing the principal communications channel during major crisis situations for airlines operating in Europe. It is one of the NOP's features.

EVITA supports the sharing of information between airlines, state regulators and air navigation service providers, in particular through the functionality that allows airlines to identify which of their flights may be impacted by ash. The tool, originally created to monitor ash concentration levels, could be used for other crises such as nuclear emergency, pandemics or security risks.

In the event of a volcanic ash event, EVITA:

- displays ash concentration data received from VAAC London and VAAC Toulouse on the NOP map;
- displays the coordinates of Danger Areas, as declared by States via NOTAM, on the NOP map;
- displays local areas defined by aircraft operators;
- detects sectors, aerodromes and flights impacted by either ash concentration data or Danger Areas, or areas locally defined by aircraft operators.

[7] Source: http://www.eurocontrol.int/articles/tools-available accessed 03MAR2015.

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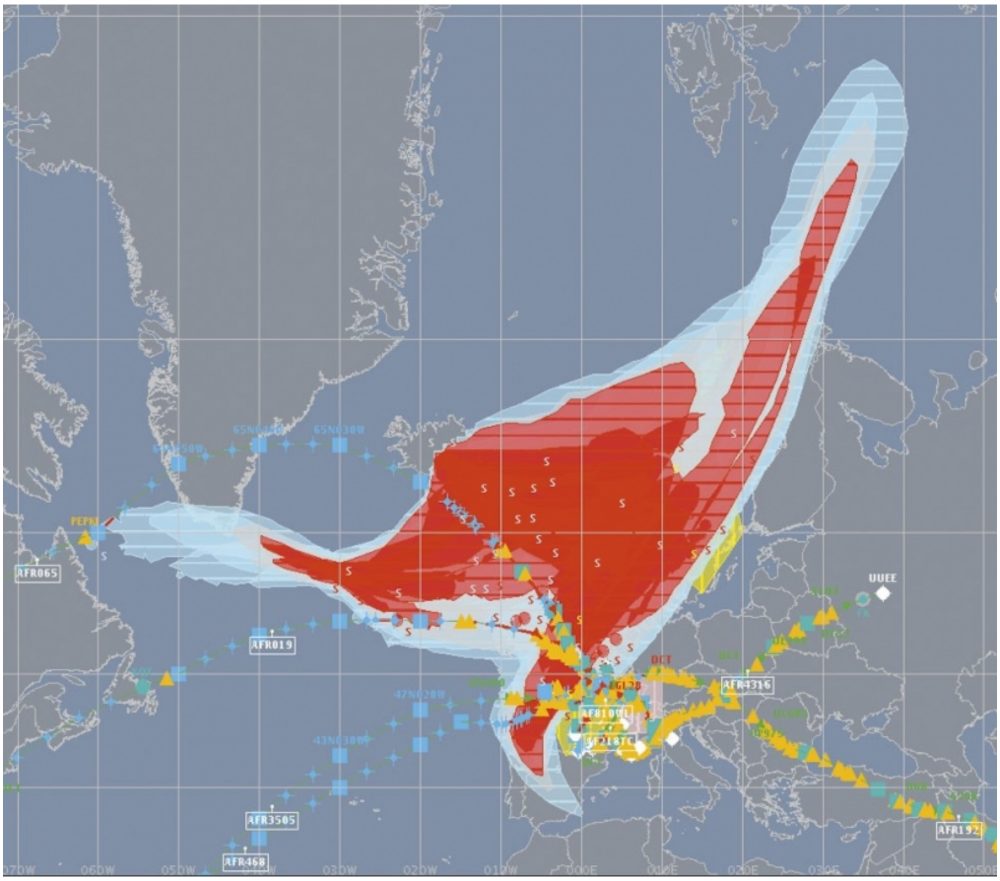

Figure 7. Example screenshot of an EVITA visualisation (source: EUROCONTROL).

3.1.1.4. Guidelines for Contingency Planning for Air Navigation Services (including Service Continuity)

The ATM industry has developed general guidance for contingency planning and service continuity (EUROCONTROL, 2009). A contingency plan outlines actions, including their associated timing and responsibilities, to be performed following the declaration of any of the contingency modes shown in the contingency life-cycle, which in turn includes the following modes: emergency situations, degraded modes of operation, service continuity, and recovery to normal operations.

The guidelines are organised in such a way that they are to be applicable to all parts of the ATS and in all phases (Normal operation, Emergency Situation, Service continuity, Recovery to normal operations, and Normal operation). The guidelines state that:

"The overall objective remains to support ANSPs and State authorities so that the whole ATM community benefits from confirmed best practice and maintains the capability to continue with the provision of air navigation services whatever the circumstances." (ECTL, 2009)

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The document also describes how different organisations should interact in the event of a crisis, what their responsibilities are, and what an operational concept of coping with a crisis event should look like. Therefore, for further details on the various actors' responsibilities and capabilities, we primarily refer to this document.

3.1.1.5. Forecast, monitoring & analysis

The Network Manager[8] (NM) provides traffic and delay forecasts and analysis to support the global performance of the European aviation network, in line with the European Commission's 'Implementing Rule'. The NM:

- continuously assesses the performance of the network functions and has established pan-network processes of monitoring, analysing and reporting on all network operational performance aspects
- recommends measures and/or takes the actions needed to ensure the network performance
- compares these performance against the objectives established in the NSP, NOP & Performance Plans identifying gaps and proposing remedial actions

In this way NM provides a consolidated and coordinated approach to all planning & operational activities of the network.

Three activities feed into this, as well as into the decision-making of the 'NM Performance Plan' and 'Network Strategy Plan':

- Statistics and Forecast Service (STATFOR): The STATFOR forecasts are used as direct inputs into the NSP, NOP and the Network and local Performance Plans as required by the NMF IR. These forecasts are also a prerequisite for the establishment of the unit rates used to calculate the route and terminal charges. Traffic forecasts are also used by an extensive number of planning departments of airlines, ANSPs, airports, government authorities, etc. for general planning.
- The Operational Analysis and Reporting (OAR): The Network Manager annual report describes the implementation of the Network Strategy Plan and the Network Operations Plan, and the performance of all aspects of the network compared to the performance targets and performance plans. A comprehensive set of more detailed reports covering all operations, performance and compliance aspects of the network are also published.
- The Central Office for Delay Analysis (CODA): In addition to monitoring and reporting on the performance of the ATM network in terms of delays from flow management regulations

[8] Source: http://www.eurocontrol.int/forecast-monitoring-analysis accessed 03MAR2015.

the Network Manager provides a monitoring and analysis function for all delay reasons (ATFM, airline, airport, etc.). This enables correlation between airline and network reported delays, and is used in schedule and turnaround planning, enabling better punctuality.

3.1.2. Air Navigation Service Providers (ANSPs)

During workshops and interviews in the project the following main information on ANSP crisis management was established. Air Navigation Service Providers typically have Safety and Security Management Systems in place for the daily management of safety and security issues, devised at corporate level, with a number of roles defined, which could include a crisis manager, responsible for press during crisis, etc. Usually the responsibility for handling crisis on the operational level will be with the responsible manager for each Air Traffic Service Unit (ATSU). For Area Control Centres (ACCs) there usually are a number of Watch Supervisors and Team Leaders in place that have the operational responsibility. Extra resources in terms of additional ATCOs or technical or management functions may be allocated on short notice, for which standard mechanisms are in place. Contingency plans and procedures and plans for degraded modes are typically readily available to be deployed. ANSPs can typically decide how traffic is run and notify traffic flow (capacity) restrictions to the Network Manager, through EUROCONTROL Central Flow Management Unit CFMU and Network Operations Management Centre NMOC, in Brussels. The main external operational interactions with other stakeholders are with aircraft crew, between ATSUs of the same or adjacent ANSPs, and on a more tactical or strategic basis with the national supervisory and regulatory agencies.

3.1.3. Airline Operations Centres (KLM)

An interview with an operational expert at KLM's Airline Operations Centre (AOC) served to give an indication of airline crisis processes. The interview subjects were the types of events that the organisation distinguished, the main roles and responsibilities of the AOC, the use of procedures, and which characteristics of the events to be handled were most challenging (see Section 4.2).

The information that decisions on "crisis" status is based on is mainly delay. To determine the extent and impact of a delay, a computerized tool is used that applies a complex function of several factors, considering for example the cost of delay for the airline (aircraft and crew scheduling) and passengers, possibilities of rebooking or repurchasing of flights, effects on connecting flights, etc. The tool thus provides decision support in terms of determining the impact of a flight's delay, and the overall impact of delays in the airline's network. Different criteria for the assessment of a flight delay's impact may be used, depending for example on whether flights are domestic/European/intercontinental.

Situations that may be characterized by the average delay of all flights in the network of up to 1 hour (fixed precise boundary), expected to be resolved within one day, are handled by Operations Controllers (OC). Operations controllers learn by doing and on-the-job training (OJT), they develop

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their skills by resolving delays and taking action for handling individual flights on a day-to-day basis, there are no strict standard operating procedures for this role. This is because these situations are difficult to judge, there is currently no definition of the "optimum" solution is because it is a multidimensional/hard problem. However, it is important that if procedures would be described for OC skills and tasks, that this does not restrict the freedom of action for resolving flight delays to fit the solution to the specific problem.

At a higher level of crisis, with an average delay of more than 1 hour, or in other words with so much delays that it can't be resolved within one day, flights need to be cancelled, with the aim of getting again back to a situation of an average delay below 1 hour so that OCs can handle the situation. This situation is handled by the Duty Manager Operations. Duty Manager Operations (DMO) does this according to a procedure and checklists, based on how much time can be gained by cancelling flights. The aim is to have normal operations again by the next day, so flights are cancelled in order to be in a good position for the next day's operations. This role used to be performed in different ways by various DMOs but has now been standardized.

The next and highest level of crisis is roughly the situation where the crisis lasts more than 1 day, or is roughly expected to last more than 1 day (not a very precise boundary). In this case a Contingency Team (CT) is formed. Various management functions are called in to the CT and a policy and strategy will be formed for the event and decision makers at this level. There are no procedures for crises at this level but certain high-level management policies are in place to inform the CT on the airline's general policy. The head of the OC leads the CT.

A main challenge is to estimate when the crisis is going to be resolved, as this determines many aspects of how the crisis is handled, who needs to be involved, how to communicate to the passengers and public, etc.

Aircraft accidents are highly regulated more or less independent of this crisis management structure above, every airline needs to have this in place. The handling of the accident is isolated from the rest of the operations, and is handled by a dedicated team. Spin-off effects can though occur that have a network impact, for example a runway contaminated with aircraft parts.

3.1.4. Aircraft manufacturers (Airbus)

Typically the aircraft manufacturers have substantial crisis management organizations in place, consisting of crisis managers in different functions. For the purpose the project, the partner that was interacted with is Airbus. To give a general introduction to the crisis functions of Airbus crisis management, some core functions are mentioned, derived from an interview with an Airbus operational expert that focused on crisis organization and the main types of crisis handled, as well as which characteristics make crises challenging (see Section 4.2).

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Airbus[9] is a part of the Airbus Group[10]. Airbus has its own crisis response organization, with its head reporting to the corporate secretary, member of the Airbus Executive Committee. Airbus crisis response organization is located in Toulouse, with crisis response rooms in France, Germany, UK, Spain, US, and China. These crisis rooms can be activated when necessary. There is a crisis management liaison officer in each country responsible for taking care of crisis on location.

Within the global crisis management organization, another organization called Family Care has been set up. Composed of volunteer Airbus staff who did follow specific training, its goal is to provide support to Airbus staff who were involved in a major event (and/or their families).

In total about 2500 persons (including crisis team and Family Care volunteers in France, Spain, Germany, and UK) can be activated if a crisis is declared.

There are several checklists that are to be used in case of a crisis. These include both processes of which steps to take and lists of personnel that can be summoned. The crisis response team that would be activated in case of a crisis would be comprised of several functions. There is a core team and other persons/functions are activated depending on the needs of the core team. If needed an on-location team (consisting of up to six persons) can be sent out on short notice. There are recurrent international drills held in the crisis room.

The basic crisis types:

- Corporate crisis
- Local crisis
- Family care

Airbus makes a distinction between a crisis involving personnel (or people that Airbus have a responsibility for; in the three types above) and an incident/accident where an aircraft built by Airbus is involved. The former concerns business continuity in terms of ability to deliver (for example, if personnel central to production are injured or deceased). This is a concern since a lot of employees are transported daily between different Airbus locations in Europe. The latter case concerns aircraft accident investigators.

3.1.5. Other actors

Regulatory agencies and National Supervisory Agencies (NSAs) are the formally responsible stakeholders for the management of airspace and certifications of ANSPs and airlines. This means that these authorities are responsible for the closing of airspace (e.g. in the case of a volcanic ash

[9] http://www.airbus.com/

[10] http://www.airbusgroup.com/int/en.html

cloud) and the permission of airspace users and ANSPs to use the airspace. State focal points that interact with the EACCC are usually allocated as part of these agencies.

At the European level the regulatory and supervisory agency is the European Aviation Safety Agency (EASA). EASA's main activities include safety strategy and safety management, the certification of aviation products and the oversight of approved organisations and EU Member States. In case of crises that require coordination on a European scale, EASA will play a role in handling a crisis depending on its effects and context, possibly with EU Directorate Generals that typically have dedicated crisis management roles, such as the Directorate-General for Mobility and Transport (DG MOVE), Directorate-General for Human Resources and Security (HR), Directorate-General for Migration and Home Affairs (DG HOME), European Commission's Humanitarian Aid and Civil Protection department (ECHO), Directorate-General for Health and Food Safety (DG SANTE), and European Centre for Disease Prevention and Control (ECDC).

Other actors that may play a role in the handling of a crisis that may be considered for consideration of the Agile Response Capability not further investigated here are airport authorities, maintenance organizations, interactions with military coordination in case of civil crisis situations, national airspace policy bodies, MET offices, and actors representing business and general aviation.

3.2. The ATS compared to military systems

Comparing the ATS with a military system is not straight forward as there are fundamental differences in terms of purpose, the view on risk and the organization of the respective systems. However, if we view both as complex socio-technical systems, some comparison is possible. A system may be called complex if the components of a system are tightly coupled and may interact in unexpected ways (Perrow, 1984):

Coupling refers to:

- the time-dependency of a process,
- the flexibility of action sequences,
- the number of ways to achieve a goal, and
- the degree of operational slack in resources.

Complexity of interactions refers to:

- the number of variables and causal relations in the system's processes and interconnected subsystems,
- limited substitutions, and
- interactions in unexpected sequences that are not easily observed or understood.

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By firstly looking at the time dependency of the involved processes involved, we find that both ATS and military are similar in the sense that time dependency is high in both. The flexibility in action sequences are less dynamic in the ATS than the military domain. In the latter, flexibility may be high in certain situations, but very low in other. The flexibility of the ATS is usually less dynamic, but disturbances may affect it. Goal achievement is usually clearer and less dynamic in ATS normal operations than in the military case, as military goals usually are more multi-faceted and may have large political implications if not achieved. Operational slack in resources is likewise probably more context-dependent in the military case than in civil ATS. Also, military organisations may have a higher degree of acceptance concerning losses if those losses can be attributed to the achievement of a goal. Also, military operations may include contradicting goals, especially in large joint operations where different nations in the same coalition. This may naturally be the case also in an ATS where competing businesses still need to coordinate to achieve acceptable safety levels.

Regarding interactions, the ATS is probably once again more predictable than the military domain where communication may need to be initiated with a number of actors during a military endeavour. On the other hand, military communication and information sharing is often subject to heavy restrictions as only certain kinds of communication links may be used and procedure and hierarchy in many cases restrict the possible interactions. This contradiction often puts pressure on military C2 and coordination with external actors such as NGOs. Interaction sequences may also become unpredictable in military endeavours as planning cannot always be performed with sufficient detail. In the ATS, most activities are planned in detail long before they are executed. Military operations often require rapid re-formulation of plans or action based on high-level goal formulations, such as “mission command”. A summary of the comparison of complexity in military and air transport systems is provided in

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Table 4.

Table 4. A comparison of complexity in military and air transport systems.

Complexity aspect	Military systems	Air Transport System
Time dependency, variables and causal relations	High	High
Flexibility in action sequences	High	Moderate
Goals	Dynamic	Pre-defined in normal operations, more dynamic in crises
Resources	High variability in slack and substitutions, context-dependent	Limited slack and substitutions
Risk acceptance	Context-dependent, inherently risky	Very low
Interactions	Restricted, partly unpredictable, context-dependent	Mostly open, planned, and predictable

It thus makes sense to observe and gather information from the military domain as it is in many ways more complex than the ATS and therefore has looked to approaches and theories for coping with that complexity. At the same time, the ATS system is getting more complex and needs new concepts like agility to be able to cope with complexity.

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4 FOCUS OF AGILE RESPONSE CAPABILITY TO BE DEVELOPED

This section outlines the focus of the ARC to be developed in P5 Wp5.4. It starts with applying the definitions outlined in Chapter 2 to the scope of the ARC described in Chapter 3, and discusses the characteristics of the event types that are the focus of ARC.

4.1. Definitions, discriminability, and applicability to ATS Agile Response Capability

This section discusses some of the components of the definitions outlined above from military and crisis management to identify research questions for aviation. First, the need for aspects of agility and resilience may be identified as part of the International Civil Aviation Organization (ICAO) definition of Air Navigation Service (ANS) expectations, which are highlighted to make the point that the concepts seem to suit well to the ANS operational environment.

As an example of how central and important the presented concepts are to ATM, the expectations of ANS flexibility, and capacity have bearing on agility and resilience. *"Flexibility* addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times, thereby permitting them to exploit operational opportunities as they occur." (ICAO, 2005, p. D-2). The expectation of flexibility thus includes exploiting opportunities, a central concept in agility. The expectation of *Capacity* expectations addresses resilience explicitly and links several high-level expectations to each other: "The ATM system must be resilient to service disruption and the resulting temporary loss of capacity" (ICAO, 2005, p. D-1). Improving the ability to exploit opportunities and be resilient to service disruption are thus in the interest of the aviation system, and theoretical frameworks that enhance these abilities may be employed to do so.

As a step in this direction, Table 5 includes a number of the concepts as part of the agility and resilience literature and their definitions, and identifies applied aviation research questions for further research. It should be noted that these concepts are not mutually exclusive. Instead, they should be seen as complementary and pre-requisites for the emergence or an agile response system.

Table 5. Agility (A) and resilience (R-n) concepts, with research questions applied to aviation.

Concept	Definition	Aviation agility/resilience research question examples
Responsiveness (A)	The ability to react to a change in the environment in a timely manner (SAS-	How can a change be detected by different stakeholders and roles at different levels? What response is required? What are the *criteria* for a successful response (e.g. separation maintained, safe

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Concept	Definition	Aviation agility/resilience research question examples
	085, 2013, p. 204)	landing, minimize economic loss), and *how* (indicators) and *when* (immediate, delayed) can these be assessed? How does response at the *sharp end* (pilots, controllers (ATCOs), maintenance engineers) and *blunt end* (safety/crisis managers, middle/top management) interact and how are they interdependent? Is a collective response by stakeholders (several ANSPs, several airlines, ANS Provider-airport-airline, etc.) expected/beneficial?
Versatility (A)	The ability to maintain effectiveness across a range of tasks, situations, and conditions (SAS-085, 2013, p. 205)	How are competencies and tasks distributed among operators (e.g., controllers being certified on various clusters of area control sectors, or both tower/terminal control; pilots with multiple type ratings; engineers with crisis management roles)? Note that multiple roles must be based on actual competence – experience from the crisis management sector suggest that assigning responsibility for crisis management to personnel that normally have other obligations can hamper response and performance of the crisis response organisation. How can resources be made available and shared so that stakeholders' task coordination is facilitated (e.g., airline and manufacturer sharing crisis facilities)?
Flexibility (A)	The ability to employ multiple ways to succeed and the capacity to move seamlessly between them (SAS-085, 2013, p. 203)	Which alternative courses of action can be taken to achieve goals (e.g., are several procedures available so that the choice of procedure is not obvious)? How do alternative courses of action intertwine? How do operators know when to switch strategy (e.g., how can ATCOs and pilots be prepared generally to identify when a procedure in an unusual situation is taking too much time to complete)?
Resilience (A)	The ability to recover from or adjust to misfortune, damage, or a destabilizing perturbation in the environment (SAS-085, 2013, p. 204)	What strategies and resources are necessary and available to recover to a normal state? How much "slack" exists in the system? Can core functions for maintaining resilience within the ATS be protected? What is the normal state to recover to (e.g., in terms of flight delays, re-routings, ANS capacity levels)? Similar to Rebound (R-1), below.

Concept	Definition	Aviation agility/resilience research question examples
Innovativeness (A)	The ability to do new things or the ability to do old things in new ways (SAS-085, 2013, p. 204)	How can operators be encouraged to come up with new ways to achieve goals? Are alternative resources available to use in innovation of ways of working (e.g., particular expertise, maps, break-out rooms, simulation resources)? When are new approaches necessary and how do operators identify this? Does training and exercises encourage or supress innovativeness? Does the culture in the "system" encourage innovativeness in the event of disturbances?
Adaptability (A)	The ability to change the organization and/or work processes. SAS-085, 2013, p. 199)	What mechanisms are in place for changing organization and/or processes (e.g. prepared crisis-mode organization responsibilities and communication channels/C2 links)? How can different levels of the organization be prepared for unexpected and new changes in work processes? Do physical structures (buildings, infrastructure) support "crisis response mode", i.e. can for example a boardroom be turned into a crisis response centre?
Resilience cornerstones	Monitor, respond, learn, anticipate	Questions on the four cornerstones (from the Resilience Analysis Grid RAG; Hollnagel, 2011b) include: Anticipate: How, by who, when, and how often are future threat and opportunities assessed? How are these assessments communicated or shared within the organisation? What is the (common?) time horizon? Monitor: How, by who, when and concerning which goals are indicators defined, evaluated, and revised? How are 'leading,' 'current,' and 'lagging' indicators combined? (See also the framework on goals and indicators by Woods et al, 2015). Respond: Is there a list of events for which the system has a prepared response? How, by who, and when are events and responses defined and revised? Learn: Which events are investigated and which are not? Does the organisation try to learn from what is common (successes, things that go right) as well as from what is rare (failures, things that go wrong)?
Rebound (R-1)	Rebound (Woods, 2015)	See Resilience (A) above, as resilience from the agility perspective is defined as recovery from perturbation.

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Concept	Definition	Aviation agility/resilience research question examples
Robustness (R-2)	"increased ability to absorb perturbations" (Woods, 2015, p. 6)	Woods (in press) argues that robust control works for well-modelled and well-understood situations, but that increasing robustness may decrease resilience (R-3/4). Thus it is relevant to ask which situations are modelled and handled using the processes and system designs in place. For example, safety assessment techniques in both air traffic management and aircraft manufacturing model a large number of risks. R-3 and R-4 (below) would ask how to cope with the surprise situations that are not covered by these methods, rather than relying on that all these anticipatory processes fully specify all future situations.
Graceful extensibility (R-3)	"resilience as the opposite of brittleness, or, how to extend adaptive capacity in the face of surprise" (Woods, 2015, p. 7)	This perspective on resilience asks "how do systems stretch to handle surprises?" (Woods, 2015, p. 7). Thus it is relevant to ask what aspects of a situation are regarded as surprises, how do controllers and pilots identify surprise, and what strategies can be identified that operators and organizations use to adapt (see Rankin et al. 2013, for a discussion of surprise and control in flight crews, and roles and strategies of pilots and controllers in Rankin et al. 2014, and Stroeve et al., 2015), as well as extend that adaptive capacity.
Network architectures for sustained adaptation (R-4)	"the ability [to] manage/regulate adaptive capacities of systems that are [and are part of] layered networks […] to produce sustained adaptability" (Woods, 2015, p. 8)	The air traffic system arguably develops more and more towards increased interdependency between nodes in a layered network. ATM units and aircraft become more interconnected (e.g. through trajectory management) and aviation stakeholders are more linked than ever before (e.g. through collaborative decision making). Questions from this perspective (Woods, 2015) ask how architectures of these networks, and design principles and techniques can support adaptation at and between layers over time, and how this property can be assessed (see Woltjer et al., 2015, for a design and assessment method in ATM based on principles of Resilience Engineering).

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4.2. Event Types

4.2.1. Event characteristics – ATS Endeavour space

Expert input was obtained during two workshops and two interviews, as described in Sections 3.1, 4.2.2, and 4.2.3, and one EACCC exercise planning meeting that was observed, resulting in a documentation of characteristics of the ATS crises to form the basis of an endeavour space for the Air Transport System.

- Number and variety of stakeholders (multi-national):
    - Change/escalation in stakeholders;
    - Competing priorities;
    - For who and in what way is the event a crisis for stakeholders;
- Dynamics of the triggering event and the subsequent effects:
    - Time to detection/acknowledgement of event as a crisis (in/outside own ”ecosystem”);
    - Duration of triggering event after crisis is declared;
    - Reach/knock-on effects (throughout ATS stakeholders, geographic areas, people affected, industries, parts of society, economic effects);
    - Escalation in severity, non-linear effects (relatively “minor” triggering events having “major” consequences in proportion);
    - Duration of consequences, time to return to normal operations;
    - Combination of several unusual or adverse events or crises, timing and combined effects as emergent phenomena (see also non-linear effects);
    - Short-term vs long-term effects, time horizon;
- Uncertainty aspects:
    - Degree of novelty for the stakeholders involved;
    - Degree of uncertainty of information;
    - Predictive ability, uncertainty of duration;

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  - A general challenge in crisis situations is uncertainty, on the development of the circumstances around the crisis (e.g. weather) or on the resources that other actors may or may not have (e.g. runway capacity);
- Degree of visibility, sources of pressure (public, media):
  - Media coverage of the events, consequences to market image aspects for stakeholders involved;
- Degree of external knowledge needed:
  - Expertise needed to assess or handle the event and whether tis expertise is in-house or externally available;
- Degree of regulation of handling event:
  - Applicability of laws and regulations to the event dictating its management;
- Clarity in definition of crisis, possibly at different severity degrees:
  - Whether the stakeholders' definitions of declaring a crisis (which may be defined for varying levels of e.g. severity) are readily applicable. These definitions could for example be based on extent (number) and categories of passenger, aircraft, or traffic impact.
- Situations where there is an optimum solution, vs. situations that do not.
  - Availability and reliability of tools for complex unified assessments of the situation (e.g., delays, costs, for various stakeholders) and the situations where a tool is of particular value and where it loses its significance because assumptions that the tool is based on are no longer met.
- Difficulty and benefit of formulating procedures for a task
- Judging if the situation is ”under control” is important (and may be used as a criterion for crisis).
- State of the passengers (taken care of in hotels, etc.).
- State of own ATS stakeholder resources (crews, aircraft, controllers, maintenance personnel, etc.).

A number of these aspects were identified through discussion of the 2010 volcanic ash cloud crisis, as well as an ENAV technical failure, both affecting airline operations air traffic service provision to varying degrees. Although a full application of all of these aspects to these cases was beyond the

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scope of the current work (also because aspects were identified throughout the performance of the work), these two cases discussed below illustrate the relevance of a significant part of the derived endeavour space aspects to the ATS.

4.2.2. Example 1: Eyjafjallajökull, 2010

A crisis situation that occurred in Europe affecting many European ATS stakeholders, as a consequence of the eruption of the Eyjafjallajökull volcanic eruption in 2010, was discussed during one of the workshops (from the joint experience of the (academic and operational) workshop participants from EUROCONTROL, Airbus, ENAV, LSE and FOI), with the main question of which characteristics were experienced to make the situation challenging to handle.

- Number and kind of stakeholders: Initially few stakeholders in the ATS were affected, but rather soon and increasingly over time more ATS stakeholders (ANSPs, airlines, etc.) in a wider geographic area were affected, and as passengers were stranded also other branches of society were affected.
- Competing priorities: The goal of ATS stakeholders guaranteeing the safety of aircraft that were scheduled to use the potentially hazardous airspace (which was partly unknown in the beginning) through closure of airspace, but also the goal of continued revenue for the numerous ATS stakeholders and businesses with economic interests in keeping the airspace open.
- Effect time horizon: The event entailed both short term (delayed and cancelled flights due to airspace closure) and long term effects (economic effects, displaced passengers needing long times to find their way home).
- It took some time to acknowledge the event as a crisis, for some ATS stakeholders a northern European volcano was more or less outside of the usual environment to take into consideration, until the ash cloud was actually visible.
- Duration: The duration of the event for some stakeholders was a few days, others were affected for several weeks or more. The uncertainty of the duration of the event and thereby the uncertainty of the consequences and the subsequent difficulty in devising appropriate measures relative to this uncertainty of duration was a particular challenge.
- The scale of event and its consequences was the novelty, not the phenomenon of volcanic ash cloud itself.
- Knock-on effects: The initial volcanic eruption's consequences grew and cascaded across stakeholders in dimensions of for example geographical area, transportation branches, networks of business and economic dependencies.

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- Escalation mainly happened in economic terms as the airspace closure duration grew, not in terms of safety.
- Visibility and media discussion of regulator decisions, as well as media discussion of airlines urging to re-open airspace.
- The second eruption handled was handled more efficiently with lessons learnt, with more knowledge available, from the first crisis.
- A substantial degree of external knowledge was needed, as volcanic ash expertise is not in-house for most ATS stakeholders, and there was ambiguity in measurements and interpreting results of measurements and assessments.
- Procedures were available to close airspace but they had not been activated at this scale, decision to close is characterized by uncertainty in terms of the input information and consequences.

4.2.3. Example 2: Situation display failure

A crisis situation that occurred at ENAV, involving a complex situation display failure, was discussed during one of the workshops during the project (with operational experts as well as academic project partners), with the main question of which characteristics were experienced to make the situation challenging to handle.

The identified main characteristics that made the situation challenging to handle include:

- Part of the situation displays were off, the system was degraded, but traffic was incoming, thus affecting aircraft incoming and on airport as well as adjacent units.
- The immediate reaction, due to an unknown failure impacting the system, was to stop traffic on the ground and manage traffic in the air, and, at the same time, to give information, as precise as possible, to ATCOs, in order to prevent inadequate reactions.
- In the meantime the main action by technicians was to try to fix the problem, always in close contact with the head of the operations room.
- The response was coordinated by supervisors working in the operational room, in coordination with the head of the operations room.
- Even if a contingency plan was in force, it was difficult to establish an understanding of the situation, due to recent changes in ATM systems, geography, and human-machine interface. In this context, the situation needed to be handled with particular care and a proactive approach by all the “actors” involved (head of operations room, supervisors, technicians, head of Area Control Centre (ACC), etc.), to thus minimize impact on air traffic.

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- One of the main challenges, due to the unexpected system situation as described above, was to fix the extent of the technical problem and its impact on traffic, to understand how long ATCOs have to work in a degraded operational environment, to define priorities, and to accomplish an efficient coordination by many roles and actors.
- From the airborne pilots' point of view, the situation was not so clear; it was not dangerous because of lower level of air traffic in the concerned area; safety was always maintained, even if adopting higher separation minima.
- The 3-4 hour duration meant that there was an initial response to stop/clear the traffic, for the first 30 minutes of the failure. Then, after 1h-1h30, after initial assessment and subsequent technical intervention, and after joint coordination/evaluation between technicians and ACC responsible, the operative supervisors received updated and reliable information thus to manage ATS system at the right volume of traffic that could be handled. The NM Central Flow Management Unit (CFMU) was asked to set a lower traffic capacity for the ACC area (around 30% of normal ATC capacity).
- When the problem was solved, a step-by-step process followed to increase the allowed air traffic in concerned airspace.
- The sudden and unexpected event led to that adjacent ATS units were congested, NMD/CFMU adjusted traffic flow which meant that the event affected other countries.
- A particular novelty in this situation was that the ATS relevant staff (head of the operations room , supervisors, ATCOs, technicians) had not received an "update" of the specific training to take into consideration the recent changes in ATM systems (geography, HMI and roles) and, also for this reason, the initial reaction was not driven by local procedures (as for other recovery or contingency cases), but addressed by operational experience and common sense.

After this event, contingency procedures were revised, with a deep understanding that all major changes in ATM systems must be preceded by an accurate risk assessment and that training aspects must be duly considered.

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5 CONCLUSIONS AND RECOMMENDATIONS

This document reports Agile Response Capability (ARC) best practices from military and resilience theory, including 'drift-into-danger'. The work was performed using a literature review supplemented by expert input, resulting in a documentation of principles and similarities and differences between civil and military task and environment characteristics that could affect Agile Response Capability operation.

The surveyed literature and discussion of cases suggest that the notion of agility is practically relevant to handling ATS crises efficiently and effectively. The results of two workshops, two interviews, observation of a crisis exercise planning meeting, as well as partial application to two ATS case studies (Volcanic Ash and an ANSP technical failure) provide the event characteristics that define an initial endeavour space for the Air Traffic System to be applied and developed further in the remainder of the project. This in combination with the diversity in organizational solutions that has been identified implies that agility and resilience are relevant to the ATS and its components. As an example, a key issue is how a crisis cell monitors the situation and decides its mode of response in order to be in an appropriate position along the C2 agility continuum.

Although it is important to be aware of the notion of drift-into-danger and the detection of weak signals, the actual explicit development of capabilities to handle drift-into-danger is beyond the scope of the Agile Response Capability (ARC) developed in FSS P5 WP5.3. The rate of development over time and ease of detection of the phenomena that constitute the adverse event have however been taken into account as some of the factors that characterise the adverse event (i.e. they are part of the endeavour space).

In this initial phase, the ARC team have worked with the EACCC (EUROCONTROL), Airbus, KLM and ENAV. In the second year this work will continue to see how Agility and the evolving ARC concept could help improve crisis management inside these organisations. This will be achieved by not only a contrast of these organisations' processes and procedures against the agility framework, but also via participation in and analysis of actual crisis simulation(s). The guidance developed will then be tested in year 3 of the Project.

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