Agile Response Capability – scenario testing

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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 complex and inter-connected in order to be more efficient. However, this entails 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, in other words more agile. This report describes the Agile Response Capability approach, and exemplifies it via six case studies.

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Acronyms

Acronym	Definition
AFTN	Aeronautical Fixed Telecommunication Network
ANSP	Air Navigation Service Provider
AQ	Agility Quotient
ARC	Agile Response Capability
ARC TSFP	ARC Training Scenario Facilitation Process
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATS	Air Transport System
ATSU	Air Traffic Services Unit
C2	Command and Control
CFMU	Central Flow Management Unit
EACCC	European Aviation Crisis Coordination Cell
EBAT	Event Based Approach to Training
EVITA	European Crisis Visualization Interactive Tool for ATFCM
ICAO	International Civil Aviation Organization
JRCC	Joint Rescue Coordination Centre
JRP	Joint Research Programme
LVP	Low Visibility Procedure
MTO	Man Technology Organisation
MWO	Meteorological Watch Office
NOTAM	Notice to Airmen
NOTAMC	NOTAM Cancellation
SIGMET	Significant Meteorological Information
SNA	Social Network Analysis
SyRes	Systemic Resilience Model
SysOp	System Operator
TMC	Terminal Manoeuvring area Control

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TSFP	Training Scenario Facilitation Process
TWR	Tower
TWS	Technical Watch Supervisor
UAS	Unmanned Aerial system
VAAC	Volcanic Ash Advisory Centre
VAC	Volcanic Ash Centre
VIP	Very Important Person, here e.g. Head of State
WS	Watch Supervisor

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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 “man-made” events such as accidents as well as intentional coordinated events must increasingly be taken into account. How would the European aviation transport system respond to a major European nuclear accident or 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 organisation 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 NATO Science and Technology Organisation research task group SAS[1]-085, consists of six capabilities, or enablers: responsiveness, flexibility, versatility, resilience, adaptiveness, and innovativeness. NATO SAS-085 developed a conceptual framework showing 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 organisational processes in order to adjust and adapt to expected and unexpected disturbances and varying conditions. The integration of four key capabilities of anticipation, monitoring, responding, and learning is seen as essential for resilience.

The resulting approach is to provide ATS organisations with an Agile Response Capability (ARC). This report aims to present the developing ARC approach, and applies the essential questions of the approach on a number of scenarios to explore how organisations can test and improve their agile response in an effective manner through various kinds of exercises.

[1] Systems Analysis and Studies.

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Description of Work

This document briefly summarizes the main theory used in the development of Agile Response Capability (ARC), and then outlines a first version of the ARC guidance material in a brief description of the approach. Two important aspects to be explored according to agility research are here called the problem space, or the parameters that play an important role in developing and applying an appropriate response, and the solution space, or the parameters that can be varied in the organisation of the response in terms of information dissemination, allocation of decision rights and interactions within the response organisation. Guiding questions to explore these spaces are presented.

This approach is then applied to six case studies in order to test the applicability of the ARC approach and to provide further input to the development of guidance material for ARC training in the remainder of the project. The first is a literature study on published articles and reports on the first European volcanic ash crisis in 2010 and considers multiple aviation stakeholders. The second, third, and fourth scenarios explore three post-accident emergency management exercises of a European airline with partner airlines and international collaboration from document analysis, as well as interview discussions with an exercise manager. The fifth analysis explores eleven scenarios in a workshop with an ANSP exploring difficulties and challenges through the application of the preliminary guidance material for ARC. The sixth analysis explores a set of degraded modes exercise scenarios at an ANSP through the application of the preliminary guidance material for ARC during both pre-exercise and post-exercise phases. The six analyses thereby cover sixteen scenarios in total, to varying levels of detail.

Results & Conclusions

The retrospective and generative (exercise) scenario analyses indicate that the ARC approach is feasible for scenario analysis, as all ARC questions were found applicable both pan-European ATS-wide as well as airline- and ANSP-focused scenarios, and most to more than one scenario. The work reported here thus supports the feasibility of the ARC approach as a structured method for developing scenarios and analysing past experiences (actual and simulated). The ARC guiding questions are recommended to be further developed through empirical testing of their applicability and usefulness.

Applicability

The results suggest general applicability of the ARC concept to Air Transport System crisis management training, as well as specific stakeholders and functions.

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1 INTRODUCTION

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, 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

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 organisations 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

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

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.

1.3. Research objectives

The objective of this work is to outline a concept for developing training/exercise scenarios that aim to increase the ability to perform an agile response by crisis responders in the air traffic system. This is primarily achieved through exploring two important aspects of agile response, here called the *problem space*, or the parameters that play an important role in developing and applying an appropriate response, and the *solution space*, or the parameters that can be varied in the organisation of the response in terms of information dissemination, allocation of decision rights and interactions within the response organisation. The resulting approach is to provide ATS organisations with an Agile Response Capability (ARC).

This report has as its objective to present the development of the ARC approach, and applies the essential questions of the approach on a number of scenarios to explore how organisations can exercise their agile response in an effective manner through various kinds of exercises.

1.4. Approach

The proposed ARC approach outlined here utilizes a combined approach where concepts from agility, C2 agility and resilience are used to inform scenario development based on the principles of the Event Based Approach to Training (EBAT). By structuring the development of scenarios in this way, focus groups and workshops with stakeholders can outline training scenarios that challenge participants in training sessions in such a way that they have to reflect upon aspects that increase their ability to respond to crisis in an agile way.

This ARC approach is then explored further by applying it to six case study analyses in order to test its applicability and to provide further input to the development of final guidance material for ARC training (D5.8) in the remainder of the project:

- The first is a literature study on published articles and reports on the first European volcanic ash crisis in 2010 and considers multiple aviation stakeholders.

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- The second, third, and fourth scenario explore three post-accident emergency management exercises of a European airline with partner airlines and international collaboration from document analysis and interview discussions with emergency manager in charge of these exercises.
- The fifth analysis explores eleven scenarios in a workshop with an ANSP exploring difficulties and challenges through the application of the preliminary guidance material for ARC.
- The sixth analysis explores a degraded modes exercise at an ANSP through the application of the preliminary guidance material on a set of technical situation display reduced modes scenarios for ARC both before and after the exercise.

Thus, this deliverable discusses a total of sixteen scenarios, to varying degrees of detail, some single-stakeholder, some ATS-wide. Of these, five are analyses of scenarios generated outside of the project but analysed within the project with the ARC methodology, and eleven have been generated and discussed using the ARC methodology within the project.

1.5. Structure of the document

Chapter 2 outlines the ARC approach. Chapter 3 includes the six analyses applying the ARC approach. Chapter 4 concludes the work and points to research aims for the remainder of the project.

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2 AGILE RESPONSE CAPABILITY (ARC) APPROACH

Understanding and improving how organisations can work together to detect and respond to crises is the core of Agile Response Capability (ARC). The purpose of this chapter is to outline a concept for developing training/exercise scenarios that aim to increase the ability to initiate an agile response by crisis responders in the air traffic system. This is to be achieved by increasing the awareness of the dependencies between different actors in complex situations by developing exercise scenarios. Such scenarios can, by using a structured approach, also be the foundation for identifying metrics that can be used to verify that training objectives have been reached.

This chapter presents the development of an approach to developing exercise scenarios from an ARC perspective. Figure 1 below describes the main considerations taken into account during the development of the ARC training approach.

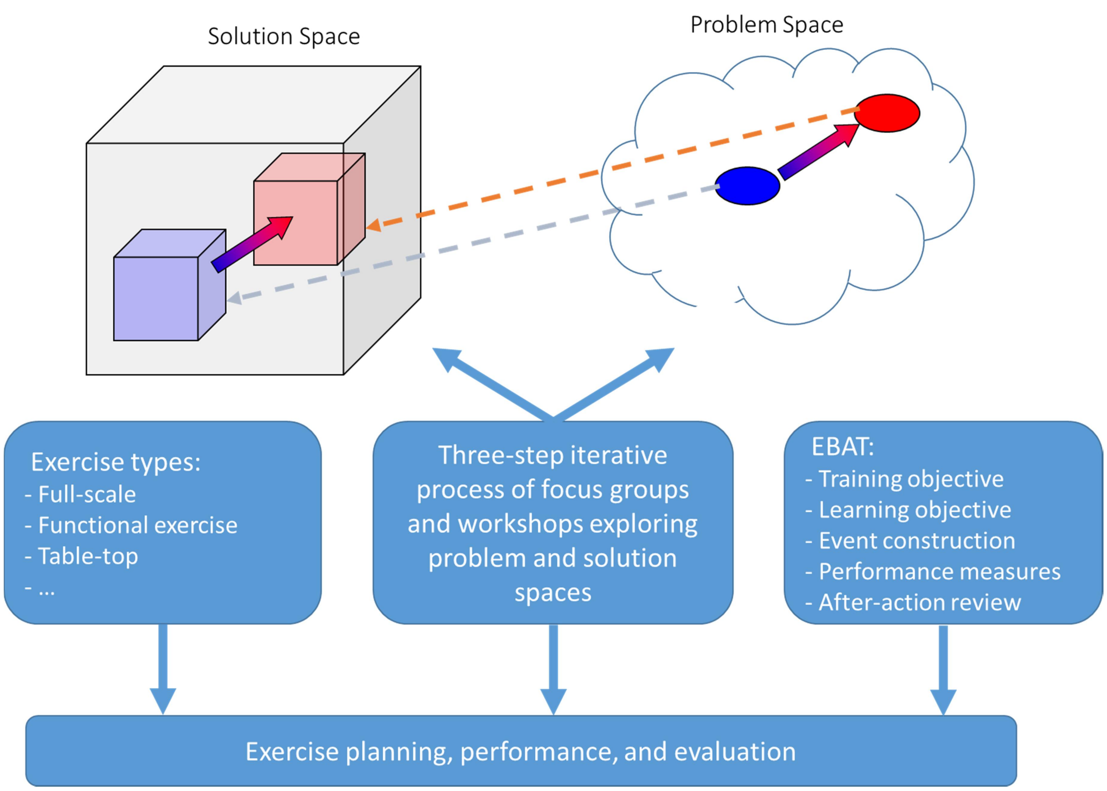

Figure 1. Conceptual framework for the approach presented in D5.7.

Theoretically, the scenario development approach has been informed by work conducted in D5.3 (Woltjer, Johansson & Kirwan, 2015) and the Event Based Approach to Training (EBAT) (see 2.1.4). While theory provides important information on abilities that need to be developed to increase ARC, workshops are needed to identify training needs of actors in the ATS. This depends on several aspects and can range from involving only key personnel such as high-level decision-makers to comprehensive approaches involving more or less all personnel that would have to be involved in a crisis response operation. In terms of training, this suggests a possible range from low-fidelity scenarios with a relatively low level of detail that generally can be used for table-top training exercises, to high-fidelity scenarios that are needed to create the necessary dynamics and realism in full scale training exercises. This conceptual framework was applied and lead to the ARC training scenario facilitation process (ARC TSFP, see 2.2), a three-step iterative process of focus groups and workshops exploring problem and solution spaces. Below follows a summary of theoretical concepts that have informed the development of the ARC TSFP.

2.1.1. Response capacity

In this context it is relevant to consider the extent to which a system is able to anticipate, monitor, respond to, and learn from (Hollnagel, 2011a) different kinds of threats. Independent of the nature of the organisation (structure) of a system that responds to a crisis, certain fundamental functions must be maintained in order to anticipate or detect cues or events that forego the crisis. Several models describing primary functions for maintaining the resilience/integrity of a system were described in D5.3 (Woltjer et al., 2015). Some of these are listed here to provide a background into which functions are critical as part of response in crisis management, as a basis for building agile response capacity.

Resilience engineering principles (Hollnagel, 2011a; Hollnagel, 2013; Woods, 2006) have recently been applied to safety assessment in 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 man technology organisation (MTO) systems. Eight principles were derived originating from resilience engineering concepts (Hollnagel, 2011a; Hollnagel, 2013; Woods, 2006) and transposed into ATM operations, which may also be applied to ATS organisations: 1) understanding work-as-done, 2) varying conditions, 3) signals and cues (for anticipation, monitoring, response), 4) goal trade-offs, 5) adaptive capacity, 6) coupling and interactions, 7) timing, pacing, and synchronization, and 8) under-specification and approximate adjustments.

Command and Control (C2), as well as crisis management, usually departs from a set of critical core functions that need to be fulfilled in order to achieve higher purposes such as coping with a crisis. Brehmer (2007) has described this as a relation between purpose, function, and form. Purpose describes *why* an organisation or system exists. Function describes *what* must be achieved to fulfil the purpose. Form describes the actual manifestation of the organisation or system, *how* it is realized in terms of people, equipment and procedures (Brehmer, 2007). When designing scenarios aiming to improve resilience and agility in an organisation, it is important to have appropriate models to inform trainers about what functions are to be the focus of training.

The Systemic Resilience Model (SyRes) (Lundberg & Johansson, 2015) was created as a way of describing resilience in the emergency response/crisis management domain. The model consists of four different

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sections: Event-based constraints, Functional Dependencies, Adjustment of capabilities and Strategy (see Figure 2). Functional dependencies will be described in detail below, and refer to a set of functions needed to create a resilient system. The event-based constraints describe how the event to be handled puts different constraints on the responding system during different phases of the event. The functional dependencies point to the core functions that must be maintained. Adjustment of capabilities refers to different approaches to shape how the functions are executed. Strategy, in turn, refers to different ways of coping with an event – in many cases these strategies are visible in terms of actions taken to keep a system out of harm's way, such as constructing barriers (immunize) or creating response systems (control) (Lundberg & Johansson, 2015).

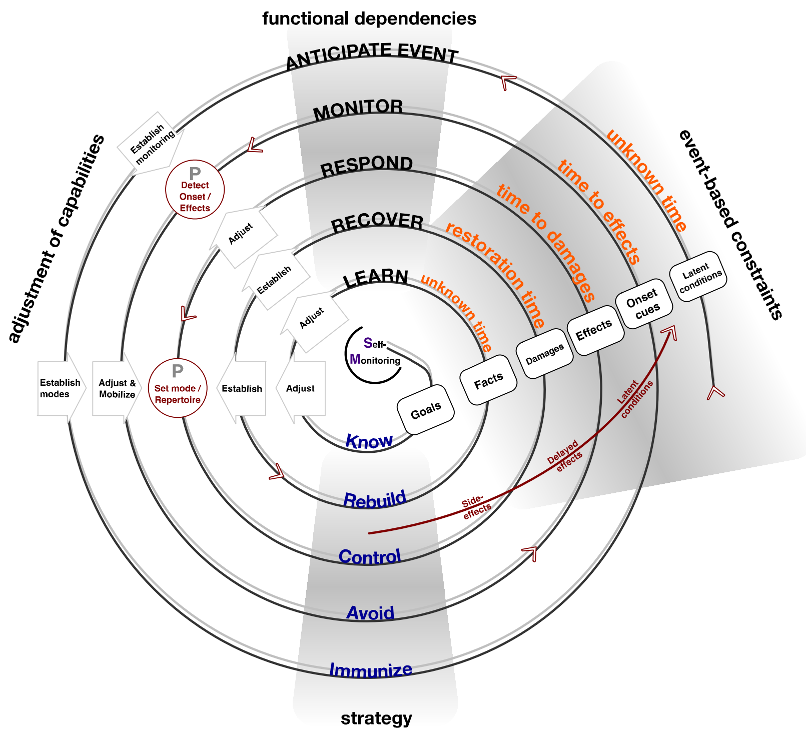

Figure 2. The systemic Resilience Model (Lundberg & Johansson, 2015).

"Functional dependencies" describes a number of such "core resilience functions": *Anticipate, Monitor, Respond, Recover, Learn, and Self Monitor*. Each function can be seen as holding the potential to cope with an undesired development – for example, if a threat is anticipated, it may be mitigated or prevented from happening at all. Likewise, if monitoring is directed in such a way that threats can be detected, harm can potentially be avoided. Response takes place as a consequence of anticipation or the detection of a threat, or even as a reaction to an event that is discovered first when it is already ongoing. Response involves an effort to control the situation and minimize or avoid harm to own, or other core system(s). If the system suffers damage in some form, recovery comes into place in order to reconstruct the system after the event. Learning steps in as an essential function needed to improve the resilience of the system by adapting ways of working or creating new means to avoid similar events in the future. Finally, self-monitoring is a continuous process needed to assess if the current way of working is appropriate to maintain an acceptable level of safety and resilience in the system (Lundberg & Johansson, 2015). In the context of the ARC concept as described in D5.3 (Woltjer et al., 2015), self-monitoring is also a function that can initiate movements in the C2 approach space (see below).

The *command and control* (C2) *approach space* (see Figure 3), is a three-axis model presenting an organisation's[3], or a system's, 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?) (SAS-065, 2010). Hierarchical, formal bureaucratic organisations with limited capability to disseminate information will position themselves on the "lower" end of the dimensions while more networked, distributed organisations with a high degree of allocation of decision rights will position themselves further out on the axes.

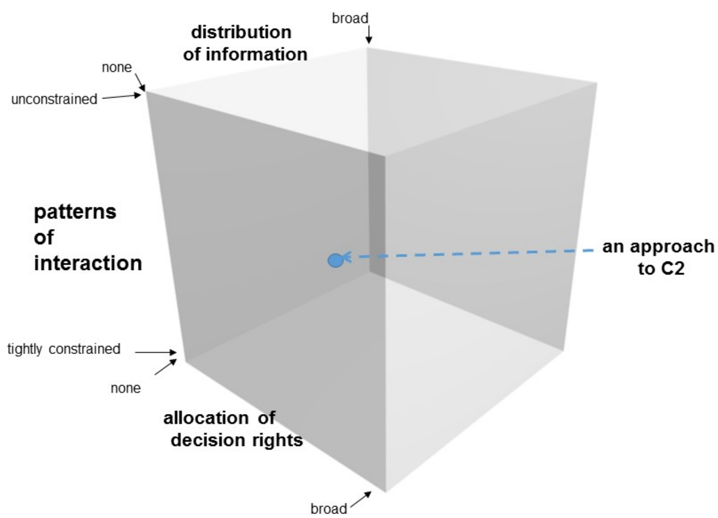

Figure 3. The C2 approach space (SAS-065, 2010).

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. This is in line with the "adjustment of capabilities" as described in the SyRes model above (see Figure 2), where core functions such as monitoring or responding can be adjusted depending on the situation at hand. Changing the allocation of decision rights within an organisation is a prime example of this, as it may

[3] Or *entity*, using the language of the SAS-085.

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"move" the ability to respond closer to the sharp end of the work system. Likewise, adjustment of the dissemination of information may be needed in a crisis (see Figure 4).

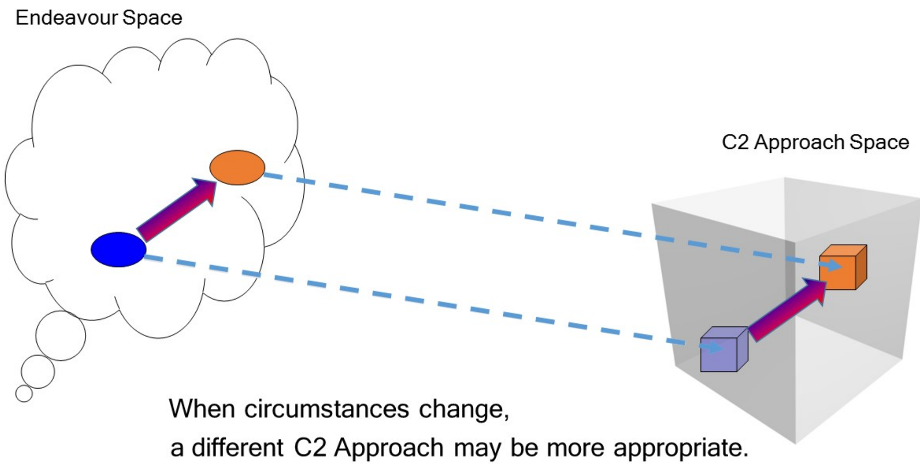

Figure 4. Adapting a different way of exercising C2 as a function of changes in the endeavour space (SAS-085, 2013).

It should also be noted that the need for being C2 agile can emerge as a consequence of the composition of a crisis response organisation (the collective, using the terminology of the SAS-groups). For example, different organisations may be called upon by the European Aviation Crisis Coordination Cell (EACCC) depending on the situation at hand. This in turn means that the various organisations 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 legal and practical, and set the boundaries for the possibility of dissemination of information.

Agile response can thus be described 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" (Woltjer et al., 2015). Research on resilience and agility in cybernetic terms may be said to investigate how a system (e.g. an individual, team, or organisation in the ATS) retains requisite variety (Ashby, 1956) in the face of (potentially) adverse events, for example by changing the organisational structure or organisational processes, in order to retain acceptable values for essential variables, similar to what in current management terms are called Key Performance Indicators. Essential variables in the ATS can be number of diversions, average or total delay time, number of flights handled in certain sectors, or loss of income. What essential variables are will differ depending on what part of the ATS that is under consideration and

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on what granularity the analysis is made. Individual flights have other essential variables than for example all flights in an air traffic sector or of an entire airline.

Critical system functions that according to the management-cybernetic Viable System Model (Beer, 1972) are required to maintain this requisite variety are (Systems 1-5 described in practical terms relevant to ARC): (1) primary activities of the processes to be controlled in the organisation's environment (e.g. crisis management functions), (2) regulation and tactical planning, including communication between primary activities, (3) operations planning and control, coordinating primary activities in system 1 with the help of system 2 communication, (4) monitor the environment to determine how the organisation needs to develop and adapt, and (5) make policy decisions within the organisation to balance and effectuate the interaction between monitoring environment and adaptation needs (system 4) and operations planning and control (system 3).

2.1.2. Agile Response Capability

The agile response capability of an entity or a collective of entities in the ATS can thus be described in terms of their ability to anticipate/detect events, control them and bounce back after they have happened. Doing so involves adapting the organisation and its resources, learning and self-monitoring, as well as the ability to coordinate its own activities with other actors. For situations lasting over longer time periods, joint planning capability may also be necessary. As the complexity of large disturbances in the ATS often require interaction between several actors, interoperability in terms of technical solutions, processes and regulations becomes increasingly important when striving for improving agile response capability. The ability of a collective of actors to jointly cope with a complex situation can be described according to different maturity levels (see Figure 5), inspired by the C2 approaches found in the NATO STO SAS literature on C2 agility (see D5.3, Woltjer et al., 2015). The most basic level is "conflicted" where the different actors have no prepared means for interacting and very limited or no means for communicating. Such a collective of organisations is likely to spend a significant amount of resources on coordinating their actions in situations that are confusing and time pressured. The next level, "De-conflicted", have resolved basic problems and have established some means for assuring communication as well as some prepared methods for collaboration. Occasional exercises may occur, suggesting that some understanding of roles and responsibilities may exist. Some technical systems may be shared or use the same standards. The third level, "collaborative" is signified by prepared channels and ways of collaborating. Joint exercises are common and well-established methods and procedures for collaboration are in place. Technical systems are largely shared or even depending on each other. The final level, "edge", represents a collective that almost lives in complete symbiosis, where collaboration occurs on an everyday basis and is an integrated part of operations. Technical systems for exchanging data and communication are in place and crisis response exercises occur on a regular basis.

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Figure 5. ARC maturity ladder.

The Agility Quotient (AQ) is a measure proposed by Alberts (2014) to assess the agility of an organisation. The AQ measure should in principle be based on the six components of agility as described in the SAS-085 (2013) work: (1) robustness, (2) resilience, (3) responsiveness, (4) flexibility, (5) innovation, and (6) adaptiveness. However, Alberts does not present any implementation of the AQ measure, meaning that little guidance exist as how to operationalize the measure. In a similar fashion, McEver, Martin, and Hayes (2008) have tried to operationalize the six agility components to make them unambiguous and measureable. In their study, they performed a literature review of works from different countries and communities. From this, they formed a definition of agility with eight attributes by extending the six components from SAS-085 with attributes of effectiveness and cognitive factors. Each attribute was given a measurement approach. Although the scale with eight attributes was not tested in the study, the paper is a starting point to link agility concepts to something observable and measurable. A further development of agility assessment has currently been outside the scope of ARC, but is subject of exploration in the workshop-based approach outlined below, which means that scenario-specific measures of (agile) performance may be generated.

2.1.3. Exercise types

A functional exercise (Perry, 2004) is a common specific type of exercise that presents considerable complexity to the participants in testing planning and training. Functional exercises select one or a few functions as a focus, may involve one or more crisis management agencies, and are usually conducted in real-time, by operational personnel with appropriate equipment, in the field and under realistic conditions (Perry, 2004). This includes a detailed preparation and implementation of a simulated course of events, as inputs and reactions to the participants' actions. Realism and validity of functional exercises are important issues in their design. Thus, functional exercises aim to represent the few functions chosen to be included in the design, the participants that would normally perform these functions, and an environment similar to the environments that participants perform these functions in. Timing and pacing and task load aspects can be investigated as the simulated scenario progresses in real-time. A table-top exercise can be seen as scaled-down walk-throughs of action intentions based on an emergency narrative,

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but does not simulate all roles or interactions and interdependencies and typically does not run in real-time as one can jump or freeze in time depending on the focus of the exercise and specific scenario characteristics. Depending on the table-top exercise details, certain parts may require very high realism whereas others can be simulated on a more abstract level. On the other extreme, a full-scale exercise implements all functions and simulates physical processes in the actual operational and management context. Realism and validity are of high importance in full-scale exercises. These exercise types may be combined for realism and validity of different functions based on the purpose of the exercise.

The issues of realism and validity are thus important exercise design factors and relate to the purpose of the exercise and the educational (learning) goals. Feinstein & Cannon (2002) discuss validity as the relationship between simulation development and educational processes. According to their model, internal validity relates representational and educational validity in that participants cannot insightfully engage in a simulation if it does not behave sufficiently like a phenomenon from the real world that they can recognize or understand. External validity relates to whether (1) the simulation represents real world phenomena (external representational validity) and (2) the simulation has the desired learning effect (external educational validity).

2.1.4. Event-based approach to training (EBAT)

The event-based approach to training (EBAT) is a methodological approach to designing, performing, and assessing simulation-based exercises. By event-based techniques events that are directly linked to training and learning objectives are implemented in training scenarios (Fowlkes, Dwyer, Oser, & Salas, 1998). This provides control that the exercise actually includes necessary elements of training on identified skills or competencies, which also facilitates relevant observation, data collection, analysis and feedback (Dwyer, Oser, Salas, & Fowlkes, 1999). The objectives of EBAT are to ensure that (Oser, Cannon-Bowers, Dwyer, & Salas 1997, in Oser et al. 1999, p. 448):

- Training opportunities are structured by use of appropriate methods, strategies, and tools.
- Learning objectives, exercise design, critical tasks, performance measurement and feedback are tightly linked.
- Training results in improved team performance.
- The exercise type is decided.
- The purpose of the training is decided.
- Scenarios are generated in cooperation with stakeholders with domain knowledge.

EBAT was originally developed for assessment of military team training in complex scenarios, but its use has been extended to supporting simulator training in other domains, as resident medical training (Rosen et al., 2010) and training of Unmanned Aerial system (UAS) operators (Dietz, Keebler, Lyons, Salas, & Ramesh, 2013).

Also, even though EBAT was created to support simulation-based exercises, it can also be used to structure more traditional training, and especially assessments of the training (Salas, Burke, Wilson-Donnely, & Fowlkes, 2004, p. 316). Thus, its methodological approach can also provide structure to more

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basic types of training exercises, as for example table-top exercises. The only requirement is that the exercise presents some type of event or scenario to the participants.

2.2. ARC training scenario facilitation process

The ARC training scenario facilitation process (ARC TSFP) aims to create scenarios that support experience based training. The purpose is to identify scenarios that include events that fundamentally challenge the involved organisation(s) ability to act in a purposeful and coordinated fashion, forcing the participants to reflect upon and work with their ability to formulate goals in the face of uncertainty, coordinate assets, and improve information exchange under pressure.

Important steps in the development of effective team training on adaptability particular to ARC are to:

- Ascertain that generated scenarios provoke adaptability and agile responses.
- Develop methods for data collection and analysis that is subtle enough to capture adaptive responses.
- Develop methods for provision of feedback, e.g. on changes, or possibilities of improvement, on adaptive behaviour.

The ARC TSFP consists of three steps (see Figure 6). The first step aims to identify potential scenarios/cases that have the potential to *challenge the agile response capability of targeted organisations*. The second step serves the purpose of identifying the *collective*, i.e. the organisations/actors that potentially could be involved in coping with the challenges identified in step one. Further, step two includes creating descriptions of *C2 linkages* between those organisations/actors. The third step concerns *assessing the potential to detect and cope with the event(s)* formulated in step one, as well as the *potential flexibility of coordinating/managing the involved organisations/actors*. The outcome of the third step should be an initial assessment plan for evaluating the exercise.

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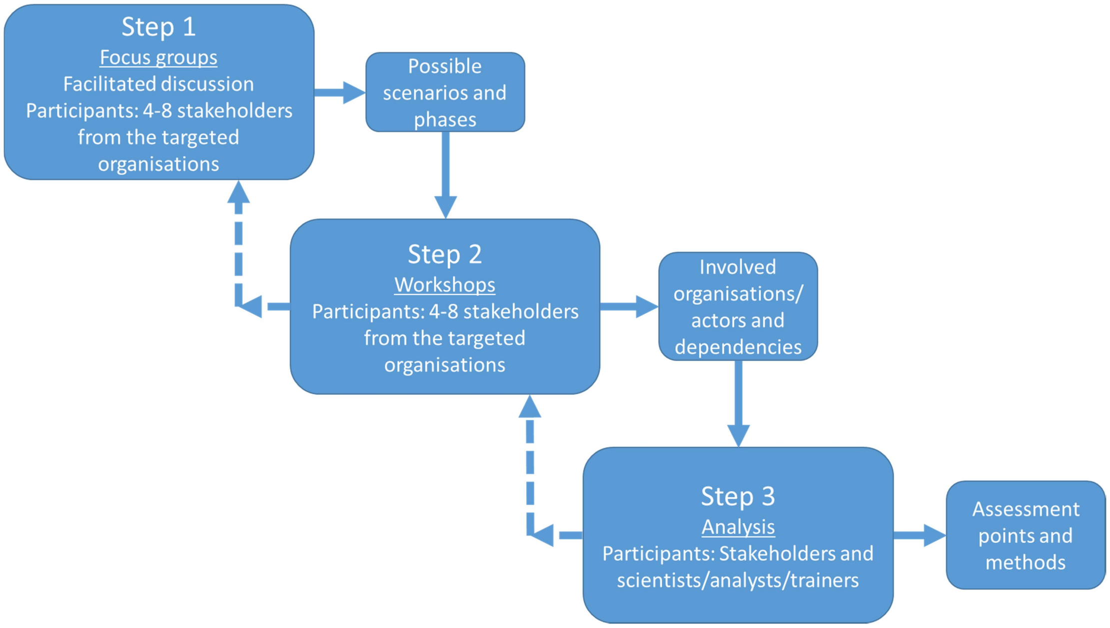

Figure 6. Conceptual overview of the ARC TSFP process.

2.2.1. Step 1 Identifying and generating possible scenarios

Step one is, in terms of methods, a facilitated process that can be conducted as a *focus group* with selected relevant stakeholders (see e.g. Bloor et al., 2001, for a detailed description of the focus group method). What 'relevant' means in this context depends on the purpose of the training which could range from a few key decision-makers in an individual organisation to larger collectives of organisations working jointly to solve a problem. Ideally, the focus group should consist of 4-8 persons, so it is generally advisable to avoid involving too many persons at this stage, or otherwise hold several parallel focus groups if a larger number of stakeholders is relevant. The primary purpose of the focus group is to identify potential scenarios at a general level, where challenging events can be introduced. In this context 'challenging' refers to challenges in terms of coordination, management, and goal formulation. In the ATS, such challenges could be extreme weather, acts of terrorism, natural phenomena such as the 2010 ash cloud, or major technical failures in ATC.

The second purpose of the focus group is to explore the potential problem and solution space, i.e. which problems could be difficult to handle with the current or newly designed constellations of crisis management organisations and roles, including functions and interactions within and between organisations. This provides information on *how and why the identified scenario(s) is/are challenging*. The elicitation of this information can be facilitated by triggering discussion by asking questions like "describe the challenge that gave rise to a need for changing the way you normally manage your organisation/organisations" or "What would have been the consequences of a failure to manage and coordinate your actions with other organisations/actors?" In the case of creating scenarios for individual organisations, this can be applied to entities within the organisation, but will also help in highlighting dependencies outside the organisation that the participants in the focus group have not thought of

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initially. To this end, the questions presented in section 2.3 of this report may be used to explore the problem and solution space.

The third purpose of the focus group is to generate trigger events in the scenario that will force organisations/actors that are exposed to the scenario to reflect upon and act on these events. Events should include properties that challenge participants' standard way of operating and interacting, and thus trigger behaviour or responses necessary to cope with these challenges. Such challenges may include changes to the organisation (which may be initiated by events outside the organisation), changes in the number of involved actors, introduction of new actors, or even changes in the operational environment, as in the case of the ash cloud.

The focus group should also *identify phases* of the scenario. As the purpose of the method is to identify critical events, the phases of the scenario typically involves at least the phases before-during-after a critical event, but more specific phases with varying time dynamics or time horizons, or development of events, for example gradual or sudden escalation or urgency of making decisions.

If the purpose of the focus group is to create scenarios with a very high level of complexity, the focus group methodology in step 1 and 2 may require iterations, i.e. that the output from an initial focus group is further elaborated in subsequent focus group(s) until scenarios and events with satisfactory quality have been generated.

2.2.2. Step 2 Identifying involved organisations and actors

Step two is a workshop with the purpose of identifying the organisations/actors that would be involved (the "collective") in the scenario and the dependencies that exist between them in terms of information exchange and power relations in terms of authority. This workshop can be manned by the same individuals that took part in step one, but other individuals with expertise or other knowledge needed to complete step two may have to be involved as well. Step 2 works out the details as envisioned in step 1, which may require iteration between the steps if new information or ideas arise. Again, the questions presented in section 2.3 of this report are intended to be used to explore the problem and solution space also in step 2, now in more detail.

In terms of method, step two is largely based on guidance from the publication *C2 by Design – A Handbook for Putting Command and Control Agility into Practice* (CCRP, 2014). Once the organisations/actors potentially involved have been identified, the task of *describing the Command and Control (C2) linkages* between the organisations/actors should be conducted. A C2 linkage consists of a description of what information that should be exchanged between different entities in a collective and what entity that is responsible for establishing the link.

When step one and two are conducted, possibly iteratively, it should be clear what the scenario looks like and what actors are potentially involved in such a scenario, as well as the basic dependencies that exist between them in terms of information exchange, and how these address the challenges in relating the solution space to the problem space.

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2.2.3. Step 3 Identifying assessment points and measures

Step 3 of the ARC TSFP should be conducted jointly by stakeholders and researchers/training personnel. The steps aims to create an assessment plan for the scenario. Primarily, this comprises elicitation of information about important skills and abilities that reflect the participants' performance in different parts the scenario. This is vital for the possibility to identify and implement relevant measures of performance.

Monitoring and responding to trigger events are by definition important skills in event/simulator- based training. Therefore to identify measures related to these skills, the questions described in section 2.3 can be used to explore in what way the collective's ability to monitor and respond to the events in the scenario would be challenged, thus informing the researchers/trainers about potential assessment points during the course of the scenario (both in terms of points in time and what functions/parts of the collective that should be assessed).

Assessment points should ideally be decision-points, related to responses to trigger events in the scenarios, i.e. situations where key information is available or situations where decisions need to be made in order to prevent unwanted outcomes of the scenario. In scenarios involving several organisations/actors, the assessment points can also be situations where information should be exchanged between organisations/actors in order to enable coordinated action. In short, the assessment points should highlight critical points in the scenario development.

In addition, step three should not only consider direct measures of performance, but also indirect measures such as understanding, effort, and actions taken that influence performance. This can, for example, be measures such as sense-making, task load, team communication, and results from social network analysis (SNA). If such measures are collected continuously during the scenario, or at least in connection to presentation of trigger events, they can provide valuable information regarding how well the participating team members understand the scenario and how difficult they find it during the different phases, and what kind of communication patterns develop during the course of the scenario. Also, in training of command and control it may sometimes be difficult to implement relevant direct measures of performance. In that case these types of indirect measures of performance may provide important indicators of performance.

An important item for Step 3 is also to collect task specific information about the work that the participants will perform to cope with the scenarios. This information is required for three reasons. (1) For identification of relevant behaviours to observe and measures of performance to record. (2) To create understanding of how collected data should be analysed. (3) To design after-action review, by presentation of relevant feedback from analysed data.

2.3. ARC problem and solution space charting

Generally the ARC approach intends to facilitate the exploration of scenarios that enable organisations to increase their crisis management capacity through exercises. Thus, events that are in some way challenging to the organisations which are in focus. The ARC approach therefore focuses on the description or imagination of an event:

- that would challenge the crisis management capacity of an organisation,
- that would demand information exchange with actors/entities that the organisation would not normally exchange information with, or
- where the allocation of decision rights within or between organisations could hamper the individual or collective ability to handle the event, so that decision rights or information flows would need to be adjusted, or responsibilities clarified (where it is unclear or ambiguous who (which actor/organisation) is responsible for coping with certain aspects).

2.3.1. Problem space - description of crisis

The purpose of this section is to describe questions that are to be used when facilitating scenario generation workshops or focus groups. By answering the questions, the problem space/endeavor space of the scenario can be described in sufficient detail to identify specific events that can be used for assessment of agile response capability.

The following questions aim to aid in the description of the crisis, for the whole scenario:

- What "data/variables" are monitored to detect if there is a crisis?
    - Motivation: This provides information concerning what the involved actors find essential to assess in order to understand when a crisis is about to happen or to detect that it has happened.
- What defines a crisis in terms of these "variables", and for whom?
    - Motivation: This information reflects the actors' models of what a crisis consists of and what threats it involves. It also provides insights in what the actors do NOT consider to be important enough to monitor.
- What aspects are difficult to capture into "data"?
    - Motivation: Monitoring is typically directed towards variables that are easily captured from sensors or statistics, such as radar, delays, and number of aircraft in a sector, etc. However, respondents are often aware of other factors that can contribute to accidents or crisis that are not continuously monitored or not assessed at all. This information contributes to the intuitive, non-formalised, model of crisis that participants may have.

The following questions can be applied to describe challenges to crisis management, during an event or when walking through a scenario:

- What are the current and expected effects on own and other resources and assets (people, functions, material, etc.)?
    - Motivation: When confronted with a scenario, the respondent(s) will reason about possible effects on their own organisation. This will also provide information on their view of the causal relations between events and consequences. Apart from physical consequences such as damage, respondents may also mention effects in terms of

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financial or reputational harm, suggesting that the questions also can give guidance on what variables the respondents find essential.

- What "category of crisis" is the organisation in? Others?
    - Motivation: This question relates to the previous question in the sense that it reflects what core values the respondent find to be challenged. Note that many events can be interpreted as a crisis from different points of view. Physical damage may be a crisis in terms of loss of lives, financial damage, and loss of reputation. One single event can thus initiate a number of different categories of crisis that occur at different points in time. Further, the same event may initiate different types of crisis for different actors, calling for different responses. Organisation A may suffer physical damage, while organisation B suffers financial damage.
- From whom is data and other input available and necessary? Are channels in place?
    - Motivation: This question reflects the degree to which the actor or collective of actors have prepared to cope with this type of crisis or their agility in terms of the capacity to create such access to data or other input. It will also reflect the involved actors model of what information is needed to cope with the situation.
- What are the uncertainties and unknowns about the situation?
    - Motivation: This question probes the uncertainty facing a decision-maker in the situation described in the scenario. It may contribute with important information about events that can be used to “inject” further events relating to the need of resilience or agility in a scenario.
- What "data/variables" are monitored? What is the frequency of updating information?
    - Motivation: This provides information concerning which information the involved actors find essential to monitor and assess in order to understand the development of the crisis as it progresses over time.
- How long are the events going on expected to last?
    - Motivation: This question probes the temporal aspects of the scenario. Will the scenario demand the initiation or establishment of a more permanent crisis response organisation or not?
- What is the potential for events to escalate in scale or severity?
    - Motivation: This question investigates the consequences of not handling an event in a timely manner. Certain events hold the potential for escalating beyond control and must thus be prioritized before more static events. Events with the potential to escalate are also candidates for being “injected” into exercises in order to see if the participants have enough foresight or anticipating capacity to understand that they need to be dealt with rapidly.
- Which stakeholders could become affected by the crisis?
    - Motivation: Many crises in the Air Traffic System entail a multitude of stakeholders due to overall system complexity, and so identifying which stakeholders would benefit from

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interactions is not a trivial task, as well as the likely changes in the set of relevant stakeholders over time as the crisis progresses.

- What does "return to normal operations" mean for this crisis?
    - Motivation: This question addresses the problem of understanding what kind of performance level can be expected or acceptable by an organisation or a collective of organisations, and when (various levels of) crisis modes can be called off.
- What are potential long-term effects that might need to be countered?
    - Motivation: This question relates to the long-term effects that may need to be countered early on, issues that can be anticipated and mitigated or monitored for in addition to the short-term “here and now” problems of crisis management that are attended. This aims to create a feed-forward or proactive aspect throughout the response.
- When is the situation considered "under control"?
    - Motivation: What are the operational criteria for being “in control”? What core values need to be protected or kept functional?

2.3.2. Solution space - description of organisation and processes

The following questions may be addressed initially for the whole scenario:

- What is the history of the current organisation?
    - Motivation: This will create an understanding of the rationale of the organisation and potentially explain why some values are considered as core values while others are not. Heritage organisational issues may also explain why certain solutions are in place and why certain interactions that have been established longer work like they do.
- What pre-defined and exercised organisational structures for exchanging information and data exist?
    - Motivation: This question reflects the preparedness of the involved organisation/organisations in terms of their maturity to cope with crisis scenarios. This relates to the ARC maturity ladder described in section 2.1.2.

The following questions can be applied to describe challenges to crisis management, during an event or when walking through a scenario:

- What information needs to be gathered before taking action?
    - Motivation: This question provides important input to what information that may, or may not, be given to participants in an exercise in order to shape the unfolding of the scenario in a desired manner.
- What information requires immediate action?
    - Motivation: This question provides important input to what information that may, or may not, be given to participants in an exercise in order to shape the unfolding of the scenario in a desired manner.
- Are goals, roles, responsibilities, and accountabilities clearly defined within and between organisations?

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  - Motivation: This question will provided information about the ARC maturity within and between organisations. This can be an important identifier of training needs.
- Which aspects of the problem are a challenge to the current organisation handling the event?
  - Motivation: This question probes for weaknesses in the current organisation in relation to the event described. Such weaknesses can be addressed in future exercises or included in plans for future improvements of the ARC.
- What is the role of media and how should they be addressed?
  - Motivation: The organized media and social media often play an important role in the spreading of useful or harmful information and possibly also the coordination or hindrance of the crisis response. Addressing media appropriately is considered important by many organisations for resolving the crisis but also to maintain positive company image in challenging times.
- What expertise is necessary to be adequately informed about the crisis? Where is it available?
  - Motivation: In the complex ATS system disturbances may originate from a large variety of sources, and subject matter experts on the sources of disturbance to inform decision making may not be available in-house and even difficult to find externally. If expert knowledge is scarce, it may hinder taking action because of lack of understanding of the essential variables of the crisis.
- What restrictions may limit information exchange (e.g. for security, legal, commercial reasons)?
  - Motivation: This question will highlight constraints that can affect the capability to cooperate during a crisis situation. It will also reflect aspects that can assist in doing an ARC maturity ladder assessment.
- Are analysis and decision support tools available and do they provide support? What are their benefits and limitations?
  - Motivation: This question will reflect both the support for decision-makers as well as the investments made by the concerned organisation/organisations in order to prepare for and support crisis management. This will directly influence the response capability of the organisation(s), given that involved personnel have adequate training in handling the tools/equipment.
- What are the main tasks that need to be performed and in what way are they interdependent (preconditions, timing, etc.)?
  - Motivation: This question aims to create an understanding for the process(es) involved in coping with the events in the scenario. It will also reflect the respondents understanding of both the situation at hand and the own and other involved organisations ability to handle the situation.
- What resources are available? Can they be re-allocated?
  - Motivation: This question reflects the flexibility and adaptability of the involved organisations and their resources. This can also be the focus of future exercises if found limited as resource allocation and re-allocation is a central theme in ARC.

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- What are the margins and redundancies in the system (e.g. unused but deployable resources) that can be used to adjust to the situation?
    - Motivation: This question relates to the one above and adds information by looking into what available resources can be used to compensate for temporary or long-term losses or additional need for resources. Performance at the boundaries of resource availability is more brittle and thus margins are essential to monitor. This also reflects the involved organisations' investment in crisis management capability.

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3 EXPLORATION OF SCENARIOS USING THE ARC APPROACH

3.1. Literature study on the 2010 and 2011 volcanic ash crises

Since training in flexible risk management is required for responding to volcanic ash cloud incidents, this chapter analyses the ash cloud crises that resulted from the Eyjafjallajökull eruptions 2010 and the Grímsvötn eruption 2011 in Iceland from the perspective of Agile Response Capability.

This was performed by a literature review of literature found until December 2016 and subsequent ARC analysis of the ash cloud crisis to aviation that followed the volcanic eruptions of Eyjafjallajökull in April 2010 and Grímsvötn in May 2011 in Iceland. The focus is on how this was handled nationally and internationally by affected stakeholders such as airlines, aviation authorities, and governments, while exploring and applying the questions developed for the Agile Response Capability (ARC) approach.

3.1.1. Method description

The literature search was performed using the Scopus scientific literature database. The literature search in Scopus was made in two steps. In the first step the search words: *ash, Iceland,* and *flight* were used. In the second step the search words *ash, Iceland*, and *air* were used. In both steps a conjunctive search condition was used, which means that all search words should be included for a publication to be identified. By this procedure 190 publications were identified. However, a large part of these publication had a purely technical focus and were not considered relevant for this work. As a consequence, only nine of the identified publications were selected as relevant and were reviewed for this work. Of these, five were included in the literature review. However, by so called "snowballing", i.e. following up on references from identified articles, more literature was identified. Of these, 18 publications were included in this literature review, which means that in all 23 publications, published until December 2016, were used.

A summary of the literature review is presented in two parts. The first part provides a scenario description, which provides a chronological description of the major events that occurred during the evolving ash crises. The second part discusses the events at a higher level, which according to the framework of the ARC methodology, serves as introduction to the scenario in the problem space perspective.

This is followed by an ARC analysis of the material from the literature review. This was performed according to the questions in the ARC approach (see Sections 2.3.1 and 2.3.2) and is, in principle, also presented according to the structure of these questions. To avoid repetition of the same information, only parts of the information of the literature review are given in the ARC analysis. Finally, building on conclusions from the ARC analysis, recommendations for ash cloud training scenarios are given.

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3.1.2. Scenario description: Ash crisis following the eruptions of Eyjafjallajökull 2010 and Grímsvötn 2011

On 20 April 2010 the volcano Eyjafjallajökull in Iceland erupted, which produced an ash cloud that caused serious disruptions on civil air traffic over northern Europe. This was a cascading crisis, with the cancellation of more than 100,000 flights in the period between April 14 and 21 2010, which in principle paralyzed the European air transport system. The countries most seriously affected were Iceland, UK, Ireland, and Finland, with a 90 percent decrease in air traffic during five days (Ellersdottir, 2014).

The main reasons for the severity of the crisis were (European Commission, 2010a):

- A severe and prolonged volcanic disruption that emitted an ash cloud.
- Weather conditions that caused the ash cloud to remain over airspace in northern Europe.
- A risk management model that was based on a strict precautionary principle.

The ash cloud caught the authorities by surprise and revealed a need to improve existing crisis preparedness and regulations for flying in ash contaminated air. At the start of the crisis, the ash concentration threshold for permitted flying was, according to ICAO guidelines, 200 $\mu g/m^3$ (Ulfarsson & Unger, 2011). The following standstill of aviation, by strict application of the ICAO guidelines, led to enormous economic consequences, which for example, led to protests among the airlines. This in turn led to demand of extended information of tolerance level from engine manufacturers and issuing of test flights that showed no adverse effects on aircraft engines in the ash concentration, where these flighst were performed (Kuipers & Boin, 2015). Due to the extensive airport shutdowns in Europe, the European Commission requested on 17 April EUROCONTROL to propose solutions to unlock the crisis. EUROCONTROL came up with three options that were discussed on 19 April at a teleconference meeting of European transport ministers. This led to the decision to impose a red zone for ash concentrations of 200 to 2,000-µg/m3, and a no-fly zone for higher densities. The red zone allowed airlines to fly provided they fulfilled maintenance and inspection requirements, had a contract with the aircraft and engine manufactures for flying in these conditions, developed procedures describing how the airline would handle the event, and had all procedures approved by the respective aviation authority (Ulfarsson & Unger, 2011; Dopagne, 2011). These zones were implemented in the morning of 20 April 2010, and by this measure air traffic was back to normal in the evening of 21 April and by 28 April 2010 the ash crisis was considered as over (Dopagne, 2011).

However, on 1 May 2010 a second eruption of Eyjafjallajökull occurred that resulted in a new ash cloud, which on 3 May 2010 led to resumed safety procedures with closures of airspace, first in the UK and Ireland and then in Portugal, Spain, Italy, and Morocco. This time the institutions involved in the volcanic ash procedures were collaborating to find better solutions to handle the crisis (Dopnage, 2011; Bolić, & Sivčev, 2011). On 4 May 2010, the Transport Council of Ministers decided on giving highest priority to the integration of the European airspace, denoted “the Single European Sky” (Kuipers & Boin, 2015, 203). The purpose was to redesign the European airspace according to traffic flows instead of national boarders (European Commission, 2010b). On 18 May 2010, the U.K. Civil Aviation Authority extended the existing flying zones by creating a grey zone with 2000- to 4,000-µg/m3 ash concentration level, where airlines

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were allowed to operate if they could present to a civil aviation authority a safety case that included the agreement of their aircraft and engine manufacturers, and by 21 May 2010 EASA officially announced the grey zone. This meant that there were now four fly zones (Ulfarsson & Unger, 2011; Dopagne, 2011):

- White – less than 200 µg/m3 ash concentration level – Normal flying operations.
- Red – 200 to 2,000 µg/m3 ash concentration level – Enhanced procedure zone where EASA considers that flying is allowed.
- Grey – 2000 to 4,000-µg/m3 ash concentration – Enhanced procedure zone where EASA considers flying operation allowed under certain conditions.
- Black – more than 4,000-µg/m3 ash concentration – No flying operations allowed.

By 24 May 2010 Eyjafjallajökull entered a paused stage and the crisis was over.

Already before the crisis ended, on the 19 May 2010, the European Aviation Crisis Coordination Cell (EACCC) was established, with the purpose to facilitate management of all types of crises affecting aviation in Europe. It is co-chaired by the European Commission and EUROCONTROL and includes members from a large number of organisations, such as aircraft operators, regulators, air navigations service providers, airports, aircraft manufacturers, the military, and ICAO (Dopagne, 2011).

After the crisis authorities and aviation organisations with responsibility for ash contingency planning continued working with procedures and measures to meet further events. In June 2010 the European Volcanic Ash Task Force was established by ICAO, with the task to revise the ash contingency plan by reviewing all guidelines regarding responses to volcanic eruptions. This should lead to the development of new guidelines for flight operation management and procedures of state aviation authorities (European Commission, 2011a). On 15-16 September 2010, the Atlantic Conference on Eyjafjallajökull and Aviation was held at Keflavik Airport, with the purpose of addressing the impact on aviation of the Eyjafjallajökull eruptions and to identify measures to reduce impact on aviation during future volcanic eruptions (Pálsson, 2010). In December 2010, ICAO finalized the revision of its 'volcanic ash contingency plan' for Europe. It includes standardized guidelines for alerting aircraft to volcanic eruption and procedures to be followed (European Commission, 2011a) and is supplemented by the elaboration of new operational guidelines for the "Management of Flight Operations when ash contaminated air is known or forecasted (European Commission, 2011c).

On 21 May 2011 the volcano Grímsvötn in Iceland erupted with the result that an ash cloud was formed, which in turn lead to the cancellation of 900 flights (EUROCONTROL, 2011). This eruption was larger than the Eyjafjallajökull eruptions 2010, but due to different weather conditions and the revision of the contingency plan and guidelines the consequences for aviation were smaller compared to the Eyjafjallajökull eruptions 2010 (Parker, 2014). On 23 May 2011, EACCC issued guidance to the member states that recommended them to adopt a revised approach in line with the new guidance material for Europe developed by ICAO. This allows airlines to decide whether or not to fly in ash contaminated air, based on safety risk assessment accepted by the relevant national authorities (European Commission, 2011b, 2011c). In April 2012 ICAO also issued regulations that provide more freedom to airline operators to decide whether or not to fly in contaminated airspace (Parker, 2014).

3.1.3. Introduction to the problem space

Volcanic eruptions occur regularly worldwide where tectonic plates meet. Such eruptions may disperse large volumes of volcanic ash into the airspace. This poses a serious threat to aircraft that fly through the ash cloud, since jet engines are particularly exposed to particles in the ash that may adhere to hot turbine blades and thus disrupt engine operation.

In 1982, an aircraft from British Airways lost engine power after entering an ash cloud that emanated from the Indonesian volcano Galunggun. Even though the pilot managed to land safely, this is one of the most well-known serious ash cloud incidents (Ellersdottir, 2014; Alexander, 2013). This event and other ash encounters due to volcanic eruptions, have received increased attention by the aviation community. For example, nine Volcanic Ash Advisory Centres (VAACs) have been established to inform and advise international aviation of occurrence, location and movements of volcanic ash clouds (Dopagne, 2011). Nevertheless, when the first Eyjafjallajökull eruption in Iceland 2010 occurred authorities and the aviation community were largely unprepared to the extent of the ash cloud and the following crisis.

Since few European nations had experience of ash clouds, when Eyjafjallajökull erupted, several governments did not have prepared plans for how to handle this type of event (e.g. Parker, 2014). Similarly, the EUROCONTROL risk management had prior to the crisis primarily focused on general accident prevention and had not considered the possibility of disruptive ash clouds caused by volcanic disruptions (EUROCONTROL, 2006, in Parker, 2014).

Further, since characteristics and consequences may differ between volcanic ash crises, it is not possible to create guidelines with exact instructions that are applicable to all crises (European Commission, 2011a). Instead a more flexible risk management is preferred, where aviation authorities, air navigation service providers, and aircraft manufacturers assess potential risks based on particle concentration levels and known effects of particles on aircraft engines.

Due to the Eyjafjallajökull ash cloud incident, authorities realized that new contingency plans are needed for these types of events. Before this event, the assumption was that ash clouds could simply be avoided by flying alternative routes, or handled by closure of affected airspace. However, the incident clearly demonstrated that simply closing all affected airspace for extended periods of time entails immeasurable consequences. Thus, this revealed a need for new guidelines to determine safe thresholds for air operation in contaminated air space, and the need to regularly update and revise such guidelines (Parker, 2014). The no-fly threshold was directly after the acute phase of the crisis increased to 4,000 $\mu g/m^3$. Aircraft were then allowed to fly in concentration levels of 2,000-4,000 $\mu g/m^3$ provided that airlines present a safety case that include the agreement of their aircraft and engine manufacturers (Ulfarsson & Unger, 2011). Although the weather conditions were more benign during at the Grímsvötn eruption 2011,

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the revised the contingency plan and guidelines contributed to smaller consequences for aviation compared to the Eyjafjallajökull eruptions 2010 (Parker, 2014).

Regulations that provide more freedom for airline operators to decide whether or not to fly in contaminated airspace is in line with the principle of resilient incident management, which for example emphasizes decentralization and deference to operational leaders (Parker, 2014). However, although regulations guide the interaction among participants, they also need to understand each other’s roles, responsibilities, and information requirements. To improve communication and coordination among participants, Ulfarsson and Ungar (2011) suggest international exercises in volcanic ash event response and management. Lack of coordination between nations may otherwise be a barrier to efficient communication and cooperation. Such training is also advocated by aviation stakeholders to improve work procedures and practices for operations in low-contamination airspace (Scaini, Bolić, Folch, & Castelli, 2015).

A major result of these crises was that the European aviation authorities developed adaptable and resilient methodologies for safe and efficient crises management for these type of incidents. One example of this development is the Ash Contingency Plan that provides graduated responses to ash contaminated air, for example new procedures which give airline operators more freedom to decide whether or not to fly in contaminated airspace (European Commission, 2011b).

3.1.4. ARC analysis of literature review

This section contains the ARC analysis of the literature review of the ash crises following the Eyjafjallajökull and Grímsvötn eruptions in Iceland. This was performed by exploring and applying the questions developed for the ARC approach (see Sections 2.3.1 and 2.3.2).

Questions for general challenges

- What is the challenge for the organisation’s C2 capacity?

The regulations when the Eyjafjallajökull incident occurred was based on the assumption that ash clouds could be avoided by simply flying around them. Participating organisations were therefore unprepared to assess and evaluate any gradual risks.

- What are the demands on information exchange between actors/entities that would not normally exchange information?

Although established procedures were used for informing relevant parties about the volcanic eruption and ash cloud dispersion, new means had to be found for information exchange in flexible risk management.

- Does the chain of command (allocation of decision rights) hamper the organisation’s ability to handle the event?

The regulations when the Eyjafjallajökull incident occurred did not provide any freedom for air service providers to decide when to fly in ash contaminated airspace.

- Is it unclear who is responsible for coping with the event?

Among national authorities, there was uncertainty as to who was in charge and could be held accountable for economic consequences of the standstill (Kuipers & Boin, 2015).

General questions for problem space challenges

- What "data/variables" are monitored to detect if there is a crisis?

The VAACs monitor geological activity to detect eruptions and whether an ash cloud has formed. The meteorological situation is then used to forecast ash cloud dispersion.

- What defines a crisis in terms of these "variables", and for whom?

The effects of the volcanic ash cloud can be divided up in both direct and indirect effects. Direct effects were physical damage to aircraft and aircraft engines, while indirect effects were the closure of the airspace and restrictions for flying (Ulfarsson & Unger, 2011).

- What aspects are difficult to capture into "data"?

Although research is performed on techniques for both detection and modelling, spatial, and temporal uncertainties of forecasts are still significant (Bonadonna et al., 2011, 2013, in Scaini et al., 2015).

Recurring questions for problem challenges

- What are the current and expected effects on own and other resources and assets (people, functions, material, etc.)?
- What "category of crisis" is the own organisation in? Others?
- From whom is data and other input available and necessary? Are channels in place?
- What are the uncertainties and unknowns about the situation?

The main reason that the authorities found it difficult to agree on a common approach to the crisis was their absence of shared understanding of the situation and how it could be solved. The three main factors of uncertainty were (Kuipers & Boin, 2015):

1. Uncertainty concerning the ash cloud. Experts were unsure about its exact location and content. No one knew which sectors might be closed, when, or for how long. The lack of relevant guidelines created a deadlock among the stakeholders.
2. Uncertainty concerning the consequences on jet engines.
3. Uncertainty of responsibility, e.g. concerning who was in charge, who could be held accountable for the economic consequences of the standstill.

The most important factors to reduce the uncertainties about how to act was the redefinition of the acceptable risk level, information from engine manufacturers, and data from test flight in ash contaminated air (Kuipers & Boin, 2015). Although new procedures were introduced both during and after the ash crisis 2010 to improve the possibilities to handle ash cloud crises for aviation, there was still disagreement concerning approaches to handle this type of crises in Europe. (Dopagne 2011). In the study

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by Scaini et al. (2015) no group of stakeholders supported the zero ash tolerance criterion. Because of the small risk of damage to the aircraft they also considered it as having low applicability. However, although aviation stakeholders found the “visible ash” tolerance criterion (2000 µg/m^3) set by ICAO as applicable, scientists and other stakeholders found the criterion less applicable.

- What "data/variables" are monitored? What is the frequency of updating information?

The primary type of information that is monitored is ash dispersal forecasts (Scaini, et al., 2015). The present update rate of such forecasts is approximately six to twelve hours. However, all stakeholders would like to have forecasts every one to six hours and some even at time intervals less than one hour.

- How long are the events going on expected to last?

Even though the effects of the Evjafjallajökull ash cloud was devastating for aviation, the volcanic eruption was small in comparison to the worst possible scenario. For example, Katla is considered as the most dangerous volcano in Iceland and an outbreak is estimated to have the potential to ground European air traffic to a much larger extent (Ellersdottir, 2014; Alexander, 2013).

- What is the potential for events to escalate in scale or severity?
- Which stakeholders could become affected by the crisis?

Directly affected are stakeholders from aviation, the scientific community, security organisations, authorities, media, and passengers. Indirectly affected are insurance companies and all types of organisations that are affected by disturbances in air traffic.

Other problem space questions not explicitly addressed in the literature that was reviewed:

- What are potential long-term effects that might need to be countered?
- What does "return to normal operations" mean for this crisis?
- When is the situation considered "under control"?

However, regarding return to normal and being “under control”, network management generally considers factors such as sector capacity (including non-closure of airspace), flight cancellations and delay minutes as indicators of the “normality” of ongoing operations in the network not being in a “crisis” state.

General questions for solution space challenges

- What is the history of the current organisation?
- What pre-defined and exercised organisational structures exist?

When the first volcanic eruption of Eyjafjallajökull occurred in April 2010, airlines and aviation authorities followed the latest version of the contingency plan issued by ICAO 2009. It provided, for example, actions and guidelines for air traffic controllers in case of volcanic eruption. In principle it comprised three phases (Ulfarsson & Unger, 2011):

1. The alerting phase is the initial emergency response stage when the eruption occurs. A temporary danger zone of 120 miles around the volcano is declared. The meteorological watch office (MWO)

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and volcanic ash centre (VAC) inform EUROCONTROL in Brussels of the volcanic eruption. The Central Flow Management Unit (CFMU) then issues a message to air controllers in its area of responsibility with information on air traffic flow and capacity management. The air traffic controller then sends a message to aircraft operators, denoted Notice to Airmen (NOTAM) with precise information including coordinates of importance for aviation safety.

2. The reactive phase is the intermediate stage and is characterized by organisation and rerouting of in-flight aircraft. It is initiated when MWO has issued a message with significant meteorological information (SIGMET) about the volcanic eruption to air traffic control (ATC). ATC then issues a NOTAM message to aircraft operators. MWO should then every sixth hour issue a SIGMET message with information of distribution of the ash cloud and its forecasted movements. This information is used in the affected areas to produce NOTAM messages with coordinates, which allow flight operators to plan routes.
3. The proactive phase is the final phase of the crisis. Standing procedures are adapted every sixth hour to route traffic clear of the affected area. SIGMET and NOTAM messages with volcanic ash information and advice are sent every sixth hour. When an area is no longer contaminated a NOTAM cancellation (NOTAMC) message that cancels previous notices is sent to aircraft operators.

Recurring questions for solutions to challenges

- What information requires immediate action?
- What information needs to be gathered before taking action?
- Are goals, roles, responsibilities and accountabilities clearly defined, within organisations and between organisations?

ICAO had before the crisis 2010 developed a series of guidelines in the form of advisory manuals for aviation in ash contaminated airspace. Although there was no established ash concentration threshold for jet engines, the guidelines provided, irrespective of ash concentration level, clear recommendations of procedures for pilots. The recommendation given was just to avoid, which is exactly the same recommendation as for low-level wind shear (ICAO, 2007 in Parker, 2014). The decision to open or close airspace is national, which means only a member state could make the decision to open or close its national airspace. If a member state took the decision to close its airspace, the decision was implemented by EUROCONTROL who then approved flight plans for all involved airlines (European Commission, 2010a).

- Which aspects of the problem are a challenge to the current organisation of handling the event?

Several organisations were involved in the crisis, as for example VAACs, MWOs, volcano observatories, ATM, airlines, and airports. Under normal circumstances these organisations do not work together on a daily basis. Even after a few weeks of cooperation during the crisis, they were still seeking means for efficient communication (Bolić & Sivčev, 2011). For example, the communication and information flow between aviation and scientific communities were identified as a major concern (Bonadonna et al. 2011, 2013, in Scaini et al., 2015). Additionally, many of the involved states had no volcano on their territory,

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and thus no experience of responses to volcanic eruptions. In this respect several involved organisations had not faced this type of emergency before, which meant that it was the first time that they used guidelines and recommendations for aviation in ash contaminated air and made decisions based on VAAC forecasts (Bolić & Sivčev, 2011).

- What is the role of the media and how should they be addressed?
- What expertise is necessary to be adequately informed about the crisis? Where is it available?
- What restrictions may limit information exchange (e.g. for security, legal, commercial reasons)?
- Are analysis and decision support tools available and do they provide support? What are their benefits and limitations?

Several visualization tools have been proposed after the Eyjafjallajökull and Grímsvötn ash cloud incidents. EUROCONTROL has developed the EVITA tool (European Crisis Visualisation Interactive Tool for ATFCM), which is an interactive web based visualisation tool for ash dispersal forecasts and air traffic operating in the European airspace (Sivčev, 2011, in Scaini et al., 2015; Gait & Sivčev, in Scaini et al., 2015). Further, Scaini, Folch, Bolić, and Castelli (2014) have developed a more generic GIS-based tool for assessing impacts of volcanic ash dispersal on civil aviation.

- What are the main tasks that need to be performed and in what way are they interdependent (preconditions, timing, etc.)?

When the effects of zero-tolerance for flying in ash contaminated air became clear during the Eyjafjallajökull crisis, there was increased pressure to find ways to easing the threshold without compromising safety. Due to lack of information regarding effects of volcanic ash on aircraft engines, several airlines and air forces from member states performed test flights through the ash cloud. Pressure was also put on engine manufacturers to present available data on tolerance levels for ash contamination (Kuipers & Boin, 2015). Additionally, the agreement to new operating thresholds that distinguished between different degrees of ash concentration levels offered member states greater flexibility in deciding how to manage their airspace, allowing for less flight disruption while still ensuring the highest level of safety (EUROCONTROL, 2010). Thus, the implementation of these procedures eased the crisis. In this respect, in spite of lacking preparedness among air service providers and authorities, the aviation community had the capacity to be both innovative and flexible when facing a novel situation (Parker, 2014). The initiative of the European Commission to bring together all stakeholders, which meant that they could work together to develop a strategy for management of aviation safety in ash contaminated air, was crucial to solve the crisis (Kuipers & Boin, 2015).

Other solution space questions not explicitly addressed in the literature that was reviewed:

- What resources are available? Can they be re-allocated? Are there enough margins?
- What are redundancies in the system (e.g. overlaps in competence/resources) that can be used to adjust to the situation?

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3.1.5. Recommendations for ash cloud training scenario

The Eyjafjallajökull ash cloud incident showed the need for flexible responses when air service providers and aviation providers have a shared responsibility for risk assessment of ongoing incidents. Regulations should whenever possible accommodate this need for flexible response, considering decision processes and authority structures, to find the appropriate context-dependent balance between production needs and safety of operations. Further, such flexible incident management also increases training needs for communication and coordination among involved participants. Training scenarios for flexible incident management of volcanic emergencies should therefore reduce uncertainties among participants and increase confidence in projections of possible alternative consequences (Alexander, 2013). The training scenario may even be a worst case scenario that includes other transportation problems, interruptions of business activities, and possible interruption of essential activities, such as medical services, in order to highlight interdependencies between the Air Transport System and other transportation and societal systems. Indeed, exercises such as the regular VOLCEX exercises (not reviewed here) have been introduced since the actual volcanic ash crisis, and discussions and exercise observations during the WP5.4 work indicate that many organisational interdependencies have since been addressed. To give more specific guidance, most of the ARC questions discussed throughout this section were found applicable to the volcanic ash crisis, and the ARC questions (Section 2.3) are thus suggested to be used for exercise scenario design and after-action review and analysis of volcanic ash exercises. The final ARC guidance will address how to do this in more detail.

3.2. Exploration of airline exercise scenarios

Many airlines regularly perform emergency management exercises to educate and train on procedures, information exchange, and roles and responsibilities among partners and other stakeholders. Although scenarios that directly affect one airline or flight have a more focused scope than scenarios that affect the whole European aviation community, they can still require an adaptive response capability. Three such scenarios of past exercises were therefore analysed in terms of challenges from the ARC-approach.

The purpose of all three exercise scenarios was to enable individual and group learning and investigate changes or improvements in procedures and processes, both intra-organisationally and inter-organisationally. The scenarios were discussed during two telephone interviews with an airline emergency manager that set up the exercises. The descriptions and analyses presented here are not complete in details and actors, but aim to illustrate the relevance of the factors in the ARC-approach that were discussed during the interviews. Only factors that are relevant for the ARC-approach are discussed. Although the interviews do not provide the same amount of information as a full workshop, the analyses of the three scenarios provide further support to the relevance of the ARC-approach questions.

As outlined in the theoretical background of this report, the ARC approach aims to help organisations assess that their solution space (or current organisational setup of crisis management) matches the problem space (or crisis at hand). The following sections outline the exploration of challenges in matching problem and solution space for the three scenarios. Each is in principle structured according to the ARC

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approach questions (see Section 2.3), combining problem and solution space pairs of questions where appropriate.

3.2.1. Scenario 1: Water landing after engine flame-out during final approach

A flight experiences electrical smoke from an unknown source on the flight deck. The flight crew declare an emergency and divert the flight towards an airport that is not a usual destination of the airline or their partners. Shortly before landing, both engines flame out unexpectedly. Without engine thrust, the aircraft quickly descends below the approach path and the crew is forced to perform a water landing. After landing the aircraft, the evacuation signal is activated and crew and passengers evacuate through all doors and over wing exits. All emergency slide rafts are deployed; many but not all passengers and crew were able to put on their life vests. Not all survivors managed to get into the life rafts, several ended up in the cold water. It is believed that the aircraft may have hit a small fishing vessel during its water landing, but this is not confirmed.

The national Emergency Response Plan was activated which resulted in the activation of the Joint Rescue Coordination Center (JRCC). As the waters are popular for fishing, many fishing boats of various sizes were present in the area of the downed aircraft. Coincidentally, the Coast Guard patrol aircraft had just begun a coastal patrol flight and is relatively close by. The aircraft is quickly designated as on scene coordinator and will be able to remain circling the accident site for several hours, if required. Immediately upon activation of the JRCC, two helicopters were dispatched to the accident site to initiate sea rescue and casualty evacuation operations. They arrived on scene some 20 minutes after the water landing. One helicopter accommodates 22 passengers and the other only two.

Many of the fishing boats offer assistance in the search and rescue operations. Rescued survivors and floating human bodies are being transferred onto a large fishing trawler that was transiting the area and has stopped to offer assistance. Seriously injured survivors are airlifted from this fishing trawler to hospitals ashore.

General questions for the whole scenario

- Problem Space: What "data/variables" are monitored to detect if there is a crisis?

In the initial stage, a MAYDAY distress signal is communicated which is an indication of high risk for a crisis developing. The MAYDAY signal indicates imminent and grave danger and that immediate assistance is requested. The airline immediately retrieves the number of passengers and crew on board.

- Problem Space: What defines a crisis in terms of these "variables", and for whom?

The procedures for MAYDAY calls, as well as classification of incident/accident events may be considered well-established for airlines. From a rescue perspective, the criteria for JRCC action in a European perspective may be seen as relatively well-defined. The difficulty will be rated high in this case due to the high number of injured people relative to the rescue helicopters availability and capacity. However, rescue operations may suffer from ambiguity in classification of the event (see for example Herrera et al.

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(2016) where ambiguity in the classification of an event had an effect on sea rescue operation's coordination).

Recurring challenges to crisis management

- Problem space: What "category of crisis" is the own organisation in? What are the current and expected effects on own and other resources and assets (people, functions, material, etc.)?
- Solution space: What information needs to be gathered before taking action?

The incident activates concerned airlines' (operating carrier and code-sharing partners) emergency local (destination airport, accident airport, departure airport, and AOC) command centres, and likely a board level unit for strategic corporate decision making. An airline response team is typically dispatched, which includes personnel for crisis management and accident investigation. Each of these have their own information needs. The accident airport command centre will be mostly concerned with gathering information about the local situation in order to coordinate the response, and the destination and departure airport will likely be concerned with information needs of family and friends, and to provide information about the flight that is beneficial for the other command centres to coordinate the response. The AOC and its board room will be most occupied with gathering information both flight-specific and corporate level information, on tactical and strategic levels.

- Problem space: Which stakeholders could become affected by the crisis? From whom is data and other input available and necessary? Are channels in place?
- Solution space: Are goals, roles, responsibilities and accountabilities clearly defined, within organisations and between organisations? Which aspects of the problem are a challenge to the current organisation of handling the event? What expertise is necessary to be adequately informed about the crisis? Where is it available? What restrictions may limit information exchange (e.g. for security, legal, commercial reasons)? What are the main tasks that need to be performed and in what way are they interdependent (preconditions, timing, etc.)?

Involved affected organisations include at least the airline operations centre (for carrier and code-sharing airlines), local emergency response units, and airline and airport staff at the departure station, accident station and arrival station. Local affected parties include rescue ships, JRCC, local hospitals.

Interactions between departure and arrival station, code-sharing and partner airlines and their AOCs may generally be expected to be well-established. Generally aviation and other authorities at departure, accident, and arrival locations at national or where appropriate European level will be notified through established channels. Similarly, local interactions at the accident site in European countries may generally be expected to be well-established.

However, challenges may occur at the interactions between accident site and the AOC when the accident site is not close to a base or a regular destination airport of the airline or their partners. In this scenario, communication channels need to be established to obtain information from local aviation and rescue actors. Further, the availability of experts may be a challenge depending on the local circumstances and

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type of third party effects, for example to determine the impacts on affected fishing vessels other sea-based activities.

- Problem space: What is the role of the media and what demands do they put on the crisis management organisation?
- Solution space: What is the role of the media and how could they be addressed to be an instrumental part of the solution, or at least not hinder the solution?

The media is likely to be rapidly engaged and dedicated to cover the accident in great detail. The affected organisations, particularly involved airlines and local rescue operations actors, are likely to be approached as soon as eye-witness reports and response communications reach the public and media. Media officers of affected organisations are likely to be in place and/or appointed to offload the emergency response coordination personnel and board rooms from the workload for media communication. Stakeholders in the response may also benefit from appropriate communication of known information to the media and thereby the public in case such interaction is sought, e.g. to provide resources or refrain from using resources critical to the response.

- Problem space: What are the uncertainties and unknowns about the situation? What "data/variables" are monitored? What is the frequency of updating information?
- Solution space: What information needs to be gathered before taking action?

When the water landing is a fact, establishing the location, the level and numbers of injuries sustained by the passengers, crew and third parties is the main priority and the initial parameters for rescue coordination. Main parameters for the rescue operation in this specific scenario are the availability of rescue and other ships, rescue and other helicopters that can be used, and the number of places for appropriate care (considering the injuries) at hospitals. Resources (transport means, fuel ranges, etc.) are critical for the rescue. Once the rescue operations are ongoing continuous follow-up of number of people and level of injury is necessary, as well as to which hospitals they can be or have been transported. As time progresses survival chances are monitored, since weather and specific accident factors together with injury levels determine how the rescue operation is best coordinated and prioritized.

- Problem space: How long are the events going on expected to last? What is the potential for events to escalate in scale or severity?
- Solution space: What are redundancies in the system (e.g. overlaps in competence/resources) that can be used to adjust to the situation? What resources are available? Can they be re-allocated? Are there enough margins?

Factors that affect the expected duration of the rescue operation and possibly escalation of events may include: weather aspects affecting survivability of injured passengers/crew/third persons, the degree to which third persons and third parties are affected on the accident site, accessibility factors of rescue operations personnel and transport means to the accident site, and resources available for the rescue operation and transport.

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- Problem space: When is the situation considered "under control"?

The primary control variable is the evacuation from the injured persons from the accident site to appropriate health care units. Regular procedures for cancelled flights and displaced crew and passengers may be employed to care for uninjured and recovered crew and passengers in the aftermath of the rescue operation.

3.2.2. Scenario 2: Accident upon landing involving three airlines

The scenario includes an accident upon landing at the scheduled arrival airport with confirmed serious injuries, possible deaths, but no fire. The scenario tests the emergency management interaction between the three participating (partner or code-sharing) airlines whereby the operating carrier remains in charge.

General questions for the whole scenario

- Problem Space: What "data/variables" are monitored to detect if there is a crisis?
- Problem Space: What defines a crisis in terms of these "variables", and for whom?

The detection process was not simulated in this exercise but a landing accident would be a well-defined case of declaring an accident at the accident airport and for the airlines involved. If this aspect would be trained, difficulties in ascertaining the status of the flight could be built in, due to unavailability of technical data transmission, observational reports, or other ambiguity in indicators.

Recurring challenges to crisis management

- Problem space: What "category of crisis" is the own organisation in? What are the current and expected effects on own and other resources and assets (people, functions, material, etc.)?
- Solution space: What information needs to be gathered before taking action?

The accident activates concerned airlines' (operating carrier and code-sharing partners) emergency local (destination airport, accident airport, departure airport, and AOC) command centres and likely a board level unit for strategic corporate decision making. An airline response team including a number of crisis management and accident investigation according to regulations is typically dispatched. See Airline Scenario 1.

- Problem space: Which stakeholders could become affected by the crisis? From whom is data and other input available and necessary? Are channels in place?
- Solution space: Are goals, roles, responsibilities and accountabilities clearly defined, within organisations and between organisations? Which aspects of the problem are a challenge to the current organisation of handling the event? What expertise is necessary to be adequately informed about the crisis? Where is it available? What restrictions may limit information exchange (e.g. for security, legal, commercial reasons)? What are the main tasks that need to be performed and in what way are they interdependent (preconditions, timing, etc.)?

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When report on the accident comes in, AOCs of all airlines activate a number of functions at their respective emergency response centres, including at the board level for strategic corporate decision making. A local liaison at the place of the accident is typically established to provide observations on the state of the aircraft and passengers/crew. Once rescue operations commence, seriously injured persons are air lifted, and local response plans are activated. Hotel reservations and accommodation for passengers and crew are another coordination concern. On scene, a centre for the survivors of a crash needs to be established.

Additionally, decision on VIP treatment may be a complicating factor when considering national and international laws of VIPs regarding government functions and security requirements. In this scenario, a VIP request to accompany an injured member of their delegation further extended this challenge.

- Problem space: What is the role of the media and what demands do they put on the crisis management organisation?
- Solution space: What is the role of the media and how could they be addressed to be an instrumental part of the solution, or at least not hinder the solution?

The scenario contains the occurrence of a Tweet spreading a rumour of injured cabin attendants, which subsequently needs verification and may be unknown from official channels. This highlights the speed of social media compared to traditional media and the potential for spread of misinformation. Further, one of the three partner airlines calls for a press conference, which forces the other airlines to decide whether or not to participate and what message should be communicated.

- Problem space: What are the uncertainties and unknowns about the situation? What "data/variables" are monitored? What is the frequency of updating information?
- Solution space: What information needs to be gathered before taking action?

Initially, information is retrieved about flight details, number of passengers and crew members, and hazardous goods. Passenger list and crew list are priorities in an early response phase. Once on-site information becomes available, casualty and injury reports are the main factor as part of the triage coordination process, i.e. injury levels and corresponding number of persons. Several people remain on board.

In the case of this scenario VIPs on board was another challenging issue, as initially the identity of the VIPs were unknown and needed further investigation. Once identity of VIPs was established security measures could be coordinated, as well as status of the other members of the accompanying delegations.

In terms of accident aircraft status, the damage assessment of the aircraft is critical to ascertain the fire risk, e.g. the detection of fuel leaks etc. The degree to which emergency equipment has worked, e.g. slides deployed, is another important piece of information when assessing risk in the initial situation.

- Problem space: How long are the events going on expected to last? What is the potential for events to escalate in scale or severity?

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A number of physical factors at the accident site could affect and escalate the fire development. Also, the situation of the passengers and crew and the prospect of successful treatment of their injuries could result in a wide range of different outcomes, resulting from the physical development of the fire and evacuation.

- Problem space: When is the situation considered "under control"?

Depending on the risk for escalation or spreading of the crisis, and the degree to which the situation is considered "under control", further questions could be asked about the scenario, to address whether the organisations are able to respond to the escalation/spreading and retain control. For a number of what-if following events, the following questions could be addressed (not simulated nor discussed for this scenario):

- Solution space: What are redundancies in the system (e.g. overlaps in competence/resources) that can be used to adjust to the situation? What resources are available? Can they be re-allocated? Are there enough margins?

3.2.3. Scenario 3: Runway excursion after drone collision at diversion destination

An escalating situation with unruly passengers on board a flight of a subsidiary airline leads to a diversion to a destination of the main carrier airline. On the approach to the diversion destination, the aircraft collides with a remotely-piloted aerial system (commonly called drone) at low altitude which damages the nose gear. This damage contributes to a runway excursion after landing where after one engine catches fire.

General questions for the whole scenario

- Problem Space: What "data/variables" are monitored to detect if there is a crisis?
- Problem Space: What defines a crisis in terms of these "variables", and for whom?

Crew is trained to recognize and handle unruly passengers so that identification and communication about the diversion and passengers are relatively well-defined. However one can imagine situational aspects making this judgment difficult in combination with VIPs on board, weather, and technical aspects (crew decision making was not assessed in this exercise). If this aspect would be trained, difficulties in ascertaining the appropriate action (landing or not, where to divert, etc.) could be built in.

The damage by the drone collision could be made obvious to a varying degree, and training aspects could be included in how to ascertain the damage during the flight using collaboration between a number of actors. The runway excursion as such is, of course depending on weather and ground radar, expected to be an accident that is readily detected and well-defined, but the consequences may not immediately be obvious, which an exercise could also put emphasis on ascertaining.

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Recurring challenges to crisis management

- Problem space: What "category of crisis" is the own organisation in? What are the current and expected effects on own and other resources and assets (people, functions, material, etc.)?
- Solution space: What information needs to be gathered before taking action?

For airlines this type of event would activate the concerned airlines' (operating carrier and code-sharing partners) emergency local (destination airport, accident airport, departure airport, and AOC) command centres and likely a board level unit for strategic corporate decision making. An airline response team including a number of crisis management and accident investigation according to regulations is typically dispatched. At this level of abstraction it is similar to Airline Scenario 1 and 2.

- Problem space: Which stakeholders could become affected by the crisis? From whom is data and other input available and necessary? Are channels in place?
- Solution space: Are goals, roles, responsibilities and accountabilities clearly defined, within organisations and between organisations? Which aspects of the problem are a challenge to the current organisation of handling the event? What expertise is necessary to be adequately informed about the crisis? Where is it available? What restrictions may limit information exchange (e.g. for security, legal, commercial reasons)? What are the main tasks that need to be performed and in what way are they interdependent (preconditions, timing, etc.)?

Local response plans are activated various local and AOC emergency command centres. Similarly to Airline Scenarios 1 and 2, health care response needs to be organized for injured passengers after triage, and hotel accommodation and appropriate security arrangements need to be made for survivors, family members, crew, staff, and dispatched airline response team.

Further, the airport closure due to the accident creates a need for coordination with AOCs of planned flights to this airport. Other stakeholders are family and friends that need coordination at local sites, as well as via telephone, pilot and cabin crew unions, the local police that locate and detain the unruly passengers, and national authorities in other countries.

The main challenge in the scenario is information exchange routines within and between airlines and between airlines and local stakeholders. It is of vital importance that the appropriate actors in the local control centres receive correct information. The scenario provides opportunities for actors to raise the urgency of information requests to be communicated to them by exercise participants. This emphasises the information exchange network of various stakeholders and their respective roles and functions.

- Problem space: What is the role of the media and what demands do they put on the crisis management organisation?
- Solution space: What is the role of the media and how could they be addressed to be an instrumental part of the solution, or at least not hinder the solution?

In the scenario, an aircraft spotter's movie goes viral on social media showing a drone hitting the aircraft, which raises the question if this was done intentionally or not and what the implications this may have for outward communication. The pressure and challenge regarding media is therefore when and what to

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issue in terms of press/social media statements. Press statements also lead to demands on coordination processes internal to the organisation since the information needs to shared, checked, and approved by a number of organisational functions and levels. Coverage of the accident is all over the internet with speculations on the accident cause and the number of survivors due to the big fire. This quickly grows to an overwhelming request for information that makes it difficult to reach support telephone numbers. Further, a media centre is set-up at a hotel to facilitate media interaction. After some time television interviews are requested, where the cause and blame of the accident are likely subjects of discussion.

- Problem space: What are the uncertainties and unknowns about the situation? What "data/variables" are monitored? What is the frequency of updating information?
- Solution space: What information needs to be gathered before taking action?

Initially, information is envisioned to be retrieved about flight details, number of passengers and crew members, and hazardous goods. Passenger list and crew list are priorities in an early response phase. Dangerous goods assessment is vital for making a health risk assessment for those that are or will be working in/around the aircraft. Once on-site information becomes available, casualty and injury reports are the main factor as part of the triage coordination process, i.e. injury levels and corresponding number of persons. Information on presence of VIPs and special groups is another uncertainty for which clarification is requested.

- Problem space: How long are the events going on expected to last? What is the potential for events to escalate in scale or severity?
- Solution space: What are redundancies in the system (e.g. overlaps in competence/resources) that can be used to adjust to the situation? What resources are available? Can they be re-allocated? Are there enough margins?

In the scenario, the airport authorities are not in control of the situation in the sense that the terminal situation is escalating. The fire extinction is hindered by strong winds, which means that the aircraft is on fire longer than expected. Further, the evacuation is less than optimal due to obstruction of evacuation doors. Another resource issue is the hotel accommodation around the accident airport. Due to a big conference, hotels have low availability, which creates problems of separating passengers, crew, staff, media interaction, and family support to different hotels.

- Problem space: When is the situation considered "under control"?

Some parameters that from an airline perspective are important for getting the situation under control are the spread of the fire, health care for injured, whether all persons are accounted for, the local airport terminal situation, and handling of media and associated family and friends.

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3.2.4. Lesson from exploring the three airline scenarios

Although the interviews and analysis of past exercise scenarios do not provide the same amount of information as a full workshop, and the interviews and analysis were highly time-constrained for practical reasons, the analyses of the three scenarios provide further exemplification of the relevance of the ARC-approach questions. All ARC questions were found applicable to at least one of the scenarios, and the discussion of the scenarios in relation to agile response provides a positive feasibility assessment that airline scenario workshops based on the ARC approach could provide a structured brainstorming method to developing scenarios.

3.3. ANSP1 testing ARC TSFP methodology

The fifth analysis explores a number of scenarios in a workshop with an ANSP exploring difficulties and challenges through the application of the preliminary guidance material for ARC.

3.3.1. Method and process

3 ACC and 1 TWR ATCOs & Watch Supervisors (all highly experienced and with additional roles in training and/or safety management) participated in a 2-day workshop that consisted of several focus group sessions based on the ARC TSFP (as described in Section 2.2):

The setup for the workshop was the following:

- Day 1
    - Introduction to FSS and Agile Response Capability (ARC)
    - Introduction to ARC Training Scenario Facilitation Process (ARC TSFP)
    - Focus group of the TSFP, Step 1 and 2
- Day 2
    - Scenario workshop: Application of the TSFP, Step 1-3 (ctd.)
    - Discussion and evaluation of focus group/workshop

In step 1, the following facilitated process of conducting the focus group was performed:

- An example is given – questions are posted
- Individual answers/suggestions are written down
- Each participants describes his/her thoughts
- Group discussion of each question and reactions to the others’ answers
- Wrap-up discussion

As part of step 1, the following questions were used to reflect and start the focus group discussion:

- Can you describe/imagine an event that would challenge the crisis management capacity of your organisation?
- Can you describe/imagine an event where it is unclear who (what actor/organisation) is responsible for coping with it?

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- Can you describe/imagine an event that would demand information exchange with actors/entities that you would not normally exchange information with?
- Can you describe/imagine an event where the allocation of decision rights within you organisation could hamper your ability handle the event, so that decision rights or information flows would need to be adjusted?
- Can you describe/imagine an event where it is unclear who (what actor/organisation) is responsible for coping with it?

The expected outcome of the focus group (TSFP step 1) was a list of factors that make crises difficult to handle in the participants' experience with examples of operational situations exemplifying these factors, with some explanation of why the factors constitute difficulty. These factors and situations have in TSFP step 2 been taken as workshop discussion points for exercise scenarios.

In step 2, the purpose of the workshop was to elaborate a few of the scenarios suggested in the focus group for potential inclusion in future exercises.

Desired potential outcomes of the workshop were, where possible, to:

- identify actors affected by and involved in the scenarios;
- identify dependencies between those actors;
- describe the ”problem space” of the scenario(s);
- describe phases of the scenario(s);
- describe when the “problem space” can be considered as “under control”.

In step 3, ways to evaluate performance and organisational agility were addressed.

After applying all steps, a concluding discussion evaluating the method was performed.

The results of this analysis are included in Appendix A to this report.

3.3.2. Lessons from ANSP1 analysis

Overall, eight “major challenge” or “crisis” situations were explored in detail, two of which were developed into crisis exercise scenarios. The brainstorming on challenging factors in various scenarios including various types and kinds of crises in step 1 shows that the ARC TSFP method contributes to eliciting what makes scenarios difficult and to an understanding of the need for agile response in these scenarios. The factors found resonate well with the factors determined in the TSFP questions. The factors found in this workshop will be elaborated in the final guidance (D5.8) to cover the difficulty factors that were found throughout the project. Application of ARC TSFP step 2 shows that exercise scenario design can benefit from the ARC method and the results of ARC step 1 in order to build in agility-challenging scenario elements into the scenario. Application of ARC TSFP step 3 shows potential to conclude scenario discussions with performance indicators based on the discussions of challenges/difficulty generally and challenging elements in the specific scenarios in steps 1 and 2. The ARC final guidance should thus take these steps and experiences on board in its challenging situations analysis and exercise scenario generation process.

3.4. ANSP2 testing ARC TSFP methodology

The sixth analysis explores a currently performed reduced modes exercise at an ANSP through the application of the preliminary guidance material for ARC.

The training discussed is a reduced modes training where different kinds of failures of the situation display system (for example, various kinds of radar and data processing failures) and related technical systems are simulated. The training is given to ATC Watch Supervisors (WS) and Technical Watch Supervisors (TWS) and organized by a WS (focusing on operational aspects) and a SysOp (focusing on technical aspects). The organizing WS and SysOp together with another WS were presented with the ARC questions and asked how they apply to their reduced modes training during a 2.5 hour workshop.

The purposes of the training are (a) refresher training on reduced modes and system failures and the associated checklists, and (b) a walkthrough of the checklists of new systems or system changes since the last training. The training also relates to actual events that participants discuss based on experience, related to the scenarios played. The training also serves as a recap of the vocabulary used by WS and TWS for the different systems and failures as well as checklist items. Moreover, known upcoming changes to the systems are discussed. Some of the resulting experiences that the trainers want to achieve, besides the purposes of the exercise, is that participants get a feeling for what the difficulties are, so that they gain important experience and extend their understanding of the technical systems and their interdependencies. It is an exercise that recurs at regular intervals although there are progression and changes over time as to the specific content of the exercises and the detailed technical scenarios.

During the training a group of WSs and TWSs take turns so that one WS and one TWS are responsible for working through a scenario using available checklists, the others play ATCOs and technicians simulating their tasks and performing their checklists. Checklists are applied and checked for fitness for purpose. A debriefing is done after every scenario. Then, the next WS and TWS take responsibility while the others watch and/or simulate ATCOs/technicians. Roughly half a dozen runs with different scenarios are performed during the training, which last roughly a full day including some other systems setup and contingency plan walkthroughs. Several days of training are run so that all relevant active personnel can participate.

3.4.1. Method and process

The TSFP ARC questions on difficulty factors were applied first during the planning phase of the exercise, in a workshop with the operational and technical exercise managers, and then directly after the exercise in a questionnaire to exercise participants. The pre-exercise workshop results are presented first, the post-exercise questionnaire results are presented thereafter, both in Appendix B to this report.

3.4.2. Lessons from ANSP2 analysis

The results of applying the ARC TSFP show first of all that many of the factors can be tied to the reasoning about the exercise scenario design, pre-exercise, and second that these then can be used to guide a

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discussion on the difficulty factors in the exercise, using a questionnaire to trigger reflection, in debriefing post-exercise. Both pre- and post-exercise, the difficulty factors seem to support discussion from both an exercise management (design and evaluation) and an exercise participant perspective, although tailoring of the questions to the specifics of the exercise appears necessary recommendation as part of the final ARC guidance.

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4 CONCLUSIONS AND RECOMMENDATIONS

This report has summarized the main theory used in the development and outlined a preliminary version of ARC guidance in a brief description of the approach. Two important ARC aspects that have been explored here are the problem space, or the parameters that play an important role in developing and applying an appropriate response, and the solution space, or the parameters that can be varied in the organisation of the response in terms of information dissemination, allocation of decision rights and interactions within the response organisation. Guiding questions have been presented and are explored in six analyses covering sixteen scenarios, in order to test the applicability of the ARC approach and to provide further input to the development of guidance material for ARC training in the remainder of the project. One of the analyses addresses European-wide Air Traffic System scenario, the other three involved one or more airlines, one or more ANSPs or ATC units with interactions with other ANSPs, and local actors.

4.1. Conclusions

The Agile Response Capability Training Scenario Facilitation Process (ARC TSFP) approach was further developed into a set of methods with associated questions that enable the exploration of the problem and solution spaces of Air Transport System stakeholders' crises and other types of challenging situations. The questions exploring problem and solution space addressing difficulty factors and challenges were applied to six analyses using different data sources and methods of exploration and analysis. The ARC approach is demonstrated to be useful and relevant in each of the various studies presented in this report in the sense that a) the scenarios provide further exemplification and illustrations of the relevance of the ARC-approach questions, b) the questions could be applied in a relevant way to the scenario details to either describe aspects of the scenario related to ARC that were present in the scenarios, or ask further questions or point to future exercise possibilities where certain aspects were not found in the scenario data, c) the ARC-questions can be used to generate general scenarios and guide a discussion on the difficulty factors in hypothetical actual events and future exercise scenarios, and/or d) used as a set of discussion points after the fact, to analyse actual past events or as a post-exercise debriefing discussion and reflection guide. Moreover, the ARC method seems to support discussion from both an exercise management (design and evaluation) and an exercise participant perspective, although tailoring of the questions to the specifics of the exercise is a recommendation to be taken on board for the final ARC guidance for post-exercise discussion facilitation. The ARC questions were found applicable to both pan-European ATS-wide, as well as scenarios focusing on single or few stakeholders (airline and ANSP).

The discussion of the scenarios in relation to the developed ARC approach thereby indicates a positive feasibility assessment that Air Transport System crisis scenario discussions based on the ARC approach could provide a structured brainstorming method to developing scenarios for exercises and understanding actual and simulated/hypothetical events.

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4.2. Recommendations

The ARC approach is recommended to be pursued further in the remainder of the project. The ARC guiding questions are recommended to be further developed through empirical testing of their applicability and usefulness, and formulated into the final ARC guidance (D5.8) using the suggested approach further developed in this report, of combined and iterative focus groups and workshops, combined with scenario generation and observation and evaluation of exercises, where practically possible.

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