The SCALES Framework for Identifying and Extracting Resilience Related Indicators: Preliminary Findings of a Go-around Case Study

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Abstract — **Resilience Engineering scope includes a better understanding of the functioning of organizations to improve their ability to anticipate adverse and beneficial conditions and to act effectively. Indicators related to resilience provide important information showing how the ATM system adapts and works to decide where and how act. The SCALES project addresses the research question: *What added value can the combination of Enterprise Architecture with Resilience Engineering bring to measure the resilience potential of the ATM system?* This paper outlines the SCALES framework, its application to a concrete case and discusses preliminary findings regarding indicators and patterns. The discussion reflects on added value to solve the research question, including theoretical and practical implications. From the current work we can conclude that the complementary strengths of Enterprise Architect and Resilience Engineering enable improved capability to identify resilience indicators and patterns for ATM complex socio-technical system. Further validation in the project´s case studies will be performed to further develop the framework and strengthen this conclusion.**

Keywords-component; Resilience Engineering, resilience indicators; Go-around procedure; Enterprise Architecture modelling; ACC perfomances

I. INTRODUCTION

Resilience Engineering (RE) aims to improve the ability of complex socio-technical systems to continue operations under expected and unexpected conditions. It expands the focus of analysis of proactive Safety Management Systems including data about what goes wrong (Safety I) as well as what goes right (Safety II) [1] [2]. One important activity within safety management is the monitoring of the system performance. For monitoring, it is essential to look for the “vital signs” in a flexible way identifying areas where an action is needed. This is the role of indicators: to provide actionable information. In relation to indicators, Resilience Engineering aims to provide a better understanding of the functioning of organizations to improve their ability to anticipate adverse and beneficial conditions and to act effectively. Many conceptual papers on models and indicators have been published. Still, developments in this area are immature and there is a need of practical tools including evidence of their benefits supported with empirical studies. This situation inspired SCALES project to address the following research question:

> What added value can the combination of Enterprise Architecture (EA) with Resilience Engineering (RE) bring to measure the resilience potential of the ATM system?

Enterprise Architecture typically prescribes a holistic approach where the technology is not isolated from the human aspects and proposes an integration of technical system components and human stakeholders (often specified as roles with instantiations of human actors) and application of separation of concern through the use of perspectives and viewpoints. The feature of possibilities to monitor the system from different viewpoints seems very attractive and in line with resilience engineering regarding monitoring systems in a flexible way. Therefore, the SCALES framework combines knowledge from Resilience Engineering and Enterprise Architecture into a model that integrates human, organizational and technical aspects, dependencies within and across organizations. Different perspectives are explored by different viewpoints. The SCALES Framework includes a functional viewpoint, a process viewpoint and an information viewpoint. In addition we are proposing a new viewpoint, the Resilience viewpoint which aims to explore and identify a set of indicators from the former views as patterns. Indicators are not isolated but affect each other influenced by the context of operations. So we propose a set of indicators as patterns of resilience.

From the RE literature, terms and definitions are not static and evolve reflecting new knowledge, views of researchers and new areas to explore. Hollnagel [3] proposes four capabilities as essential for a resilient socio-technical system: 1) Learning from experience requires actual events, not only data in databases; 2) Responding to regular and irregular threats in a robust and flexible manner; 3) Monitoring in a flexible way means that the system’s own performance and external conditions focus on what is essential to the operation and 4) Anticipate threats and opportunities. It is not only about identifying single events, but how parts may interact and affect each other. Woods [4] identify that contributions to resilience include: 1) Buffering capacity - size or kind of disruption that can be absorbed without a fundamental breakdown; 2) Flexibility - system's ability to restructure as response to changes and 3) Cross-scale interactions - how local adjustment can influence strategic interactions. Further work has been performed in the context of SESAR, which builds on knowledge presented in the RE literature proposing resilience principles as relevant aspects when designing resilient systems [5]. These concepts are still young and further work is needed to bring them closer to practical tools. For the SCALES project the main purposes of indicators are: 1) to monitor the status of the system its performance, 2) to decide, where and how to take action, and 3) to motivate those in a position to take necessary action to actually do so. Early warnings and leading indicators address the need to predict and act before a desired or undesired event occurs (adapted from [6]). For the project indicators should be related to aspects that are important for resilient systems. These indicators are not seen as related to single components or factors. They are rather seen as patterns as a composition of indicators related to the ability of the system to adapt to disturbances showing interdependencies and relations. In the SCALES project one objective is to bring these concepts closer to practical applications.

This paper outlines the SCALES framework, its application to a concrete case and discusses preliminary findings regarding indicators and patterns. It starts with a short description of SCALES framework. Then, it introduces a concrete case on a go-around procedure where air traffic controllers contributed in a positive way to a successful operation. After, the SCALES framework is applied to this case. Finally results from this application are presented and discussed. The discussion reflects on added knowledge to solve the research question, theoretical and practical implications. Recommendations for further refinements of SCALES are also summarized.

II. THE SCALES FRAMEWORK

Based on a body of knowledge that collects information on RE and EA documented in [11], the SCALES Framework includes a methodological approach to apply Enterprise Architecture in combination with a theoretical framework from Resilience Engineering. This approach encompasses the steps illustrated in Figure 1 below.

From a focused literature review, a set of four initial cases has been selected. These cases are applied both to validate the approach and to establish a baseline architecture that will be further applied in consecutive case studies. The baseline architecture includes constructs primarily for the Roles (e.g. Aircraft, ATC, and technical systems involved) and the functional view (i.e. the functions performed by the roles). The rationale for selecting exactly these four cases was that they represent both successful and unsuccessful operations, both from the aircraft and from the ACC.

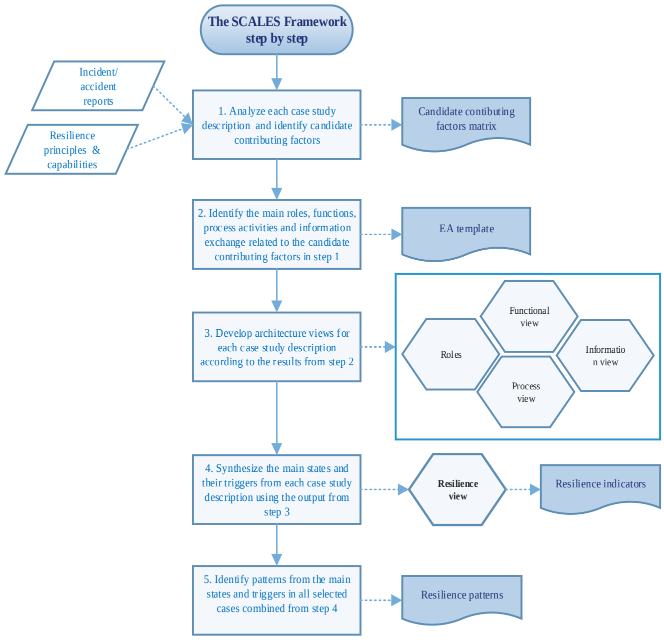

Figure 1: Preliminary approach to apply the SCALES framework

A. *Step 1: Analyze each case study description and identify candidate contributing factors.*

In this step each incident report for the selected case studies was screened "manually" by analyzing the descriptions made by the incident investigators. Although many of the contributing factors associated with the incident were explicitly stated in the report, some additional possible contributing factors were identified through the analysis. As an input into this activity the resilience capabilities and principles (see Table 1) were used as cues in order to characterize and organize the candidate contributing factors identified.

B. *Step 2: Identify the main roles, functions, process activities and information exchange related to the candidate contributing factors in step 1*

This step organizes aspects relating to the contributing factors identified in the previous step into roles, functions (responsibilities), activities and information exchange. The output of this step is a template (see Table 2) describing relevant roles (both humans and systems), the functions these roles perform, which process activities they engage in (interaction among roles) and information being exchanged in these activities.

C. *Step 3: Develop architecture views for each case study description according to the results from step 2*

In this step the template developed in the previous step is transformed into architectural notation for a given case study. Here, the roles, functions, information exchanges and process activities identified in Step 2 are described in appropriate architectural views. These views are *functional view*, which essentially describes the responsibilities associated with the roles; *information view*, which defines the information

Identify applicable sponsor/s here. *(sponsors)*

elements exchanged; and *process view*, which defines the processes undertaken and interaction between roles (including information elements being exchanged).

D. Step 4: Synthesize the main states and their triggers from each case study description using the output from step 3

Once the process view for a particular case is complete, the main states and their triggers are extracted from the process view. The triggers are treated as candidate resilience indicators. For example, the case study in the next section describes a potential severe incident prevented by a second air traffic controller who noticed the communication between a controller and the aircraft. This second controller redirected the aircraft under his responsibility. This action prevented two aircraft from a collision course. The fact that the second controller overheard the communication between the controller and the aircraft is regarded as a candidate resilience indicator (trigger) and the state in this case was that the aircraft he was responsible of was redirected.

E. Step 5: Identify patterns from the main states and triggers in all selected cases combined from step 4

While the previous step extract candidate resilience indicators from the individual cases, this step aims to identify resilience patterns from a consolidated view. The patterns are constructed on the basis of current Resilience Engineering concepts as well as findings from the case studies in the project [7] [8]. A resilience pattern is a collection of candidate resilience indicators and the basis from which more concrete hypothesis can be made. For example, are the pattern compositions from a given set of indicators representative in other cases? These hypotheses will be evaluated in the case studies that will be performed in the SCALES project.

III. Summary of Arlanda go-around incident

A. Go-around procedure

A G/A is an aborted landing of an aircraft that is on final approach. It can be adopted when everything is not quite right for landing. Initiation of a G/A procedure may be either ordered by the controller or decided by the pilot in command for several reasons. A G/A does not in itself constitute any sort of emergency. Indeed, a properly executed G/A is a safe, and well-practiced manoeuvre; however it requires proper execution by pilot and adequate support by the controller. It occurs with an average rate of 1-3 per 1000 approaches and one in ten go-around lead to a potentially hazardous outcome [9].

Several elements play a role during a G/A such as, pilots, aircraft elements used for landing and taking off, runway and weather conditions, ATCOs supervise the landing part of the flight, landing systems used by both pilots and ATCOs, safety nets as the Ground Proximity Warning System, communication devices between pilots and ATCOs, procedures for landing, runway layout, managing G/A and re-routing of an aircraft.

In a resilience perspective, a G/A can be considered as an event which generates a disturbance into the system under analysis (e.g. an ACC) which has to deal with it. How the ACC copes with this disturbance allow us to identify some contributing factors, positive and/or negative, which can be correlated to resilience aspects.

As explained in section II, the presented approach aims to identify these contributing factors, to extract the related resilience indicators, and to model them through a dedicated view, the Resilience View. The indicators will in this view be consolidated into patterns, named Resilience Patterns, which can be investigated in future SCALES case studies.

B. The Arlanda incident: a brief description

On January 21, 2011, an aircraft aborted at a late stage the landing on runway 26 at Arlanda airport at the same time as another aircraft took off from runway 19R. At missed approach to runway 26 right turn should be carried out as soon as possible in order to avoid conflict with departing traffic from another runway. The aircraft that aborted the landing followed the prescribed procedures for missed approach only after three calls from the ATCO.

Although the conflict was observed by the ATCO and the departing aircraft had been instructed to change its course a separation infringement occurred.

During the G/A, the Commander took over the control of the aircraft. The Commander’s taking over the controls at a late stage probably resulted in a lack of sufficient remaining capacity to immediately follow the published missed approach procedure [10].

IV. Application of SCALES to Arlanda G/A incident

This section provides an illustrative example of how the SCALES framework is applied to a specific case study.

A. Step 1: Analyze the Arlanda case study description and identify candidate contributing factors

The first step is performed without any architectural support and includes the identification of possible contributing factors from the incident report. Examples of contributing factors identified were:

- The landing aircraft was too high and too fast to make a proper landing
- The PF of the landing flight had too low experience to land (considering the context)
- The Commander (taking over PF role) experienced information overflow when receiving information from traffic control and aircraft instruments in an already stressful situation
- Communication between one of the controllers and the landing aircraft was picked up by a second controller in the tower

Related to the resilience principles [5] the following matrix is developed for this case study:

TABLE 1: RESILIENCE PRINCIPLES [5], CAPABILITIES [3] AND POTENTIAL INDICATORS, (+) POSITIVE AND (–) NEGATIVE, FROM ARLANDA CASE STUDY

RESILIENCE PRINCIPLES [5]	CAPABILITY TO ANTICIPATE	CAPABILITY TO MONITOR	CAPABILITY TO RESPOND	CAPABILITY TO LEARN
1. **Work-as-done** addressing understanding of everyday operations		(+) ATCOs monitor each other	(+) Additional action performed by one of the ATCOs in order to correct the situation	
2. **Varying conditions** means variations internal or external affecting the operation of the system	(-) Unexpected condition (not the G/A itself, but the fact that the aircraft did not follow the instructions from the controller)			(+) Training and competence when situations fall outside the procedure
3. **Signal and cues** that alerts operating and/or management personnel	(-) STCA does not work when the aircraft is close to landing and there is no other system helping if this is not the case.	(-) Flight instruments for landing (aircraft position)		
4. **Goal trade-offs** multiple shifting goals affecting operations				
5. **Margins, redundancy and adaptive capacity** aims to keep sufficient resources not the work alone but also accounting for potential changes			(+) G/A potential conflict managed by two ATCOs	
6. **Coupling, interactions cascades** deals with cooperation, coordination and knowledge sharing.		(+)ATCO monitor each other	(+) Avoidance on potential collision	
7. **Timing, synchronization, and time scales**		(-) The ATCO had to send 3 instructions to the arriving aircraft before action was performed.		
8. **Under-specification and approximate adjustments**			(-) Not all details on G/A are specified in the procedures. Buffering capacities to cope with under-specifications	

B. *Step 2: Identify the main roles, functions, process activities and information exchange related to the candidate contributing factors in step 1*

In this step, the roles, functions, activities and information exchanges related to each of the identified contributing factors are described in a matrix form. For example, the contributing factor "The Commander experienced information overflow when receiving information from traffic control and aircraft instruments in an already stressful situation" can be described as reported in Table 2. The table exemplifies that for each identified contributing factor the architectural constructs are mapped. In the "Involved Role(s) and actors" column the role includes the actor (i.e. the instantiation of the role in this particular case) in parenthesis. In this case the activities mentioned are equivalent with the functions, but this is not necessarily so. An activity can also be a sub-part of a more complete function (i.e. the relevant responsibility of the role). In this particular example there were 3 ATC instruction messages sent from the tower controller to the aircraft but only the third was acknowledged by the pilot. The table also presents ATC roles and prompt ATCOs interaction.

TABLE 2: MATRIX INCLUDING ROLES, FUNCTIONS, PROCESS ACTIVITIES AND INFORMATION EXCHANGE

CANDIDATE CONTRIBUTING FACTOR	ACTIVITY	INVOLVED ROLE(S) AND ACTORS	FUNCTION	INFORMATION EXCHANGE
The Commander experienced information overflow when receiving information from traffic control and aircraft instruments in an already stressful situation.	Receive ATC instructions	Airspace User (Aircraft CRJ-200)	Receive ATC instructions	* ATC instruction # 1 * ATC instruction # 2 * ATC instruction # 3
	Provide ATC instructions	ATC (Tower Controller 2 (Arlanda))	Provide ATC instructions	
The ATCOs support each other in monitoring and coordinating the inbound traffic	Monitor separation	ATC (Tower Controller 1 (Arlanda))	ProvideATC instructions	* A/C 1 change heading to avoid A/C2 collision
	Monitor separation	ATC (Tower Controller 2 (Arlanda))	Provide ATC instructions	* ATC instruction # 1…#3

C. Step 3: Develop architecture views for the Arlanda case study description according to the results from step 2

In this step the roles, the functional, the information and the process views for the specific case study are developed [11]. Using existing constructs from the baseline architecture in the SCALES Framework, the process view for this particular case is developed according to the sequence of events.

From the baseline architecture we can say that the roles, functional view and information view constitute a knowledge base or a catalogue from which inherent constructs can be collected from when constructing the process view (as illustrated by the black arrows in Figure 2). That is, the roles, the functional view and the information view are more static representations across the cases. If a case introduces new roles (or actors), new functions or new transactions these views are updated in the framework. However, for each case study there is developed an individual process view (due to space constraints, an excerpt of the Arlanda case study process view is provided in Figure 3).

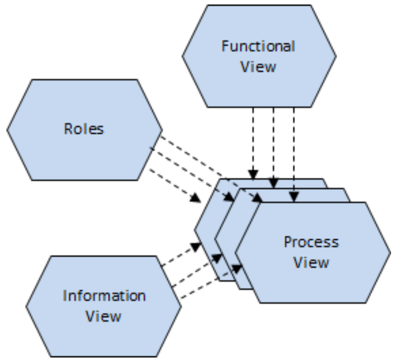

Figure 2: Process view collects constructs from other views

The reason for this is that although the roles, functions and transactions are important, the relevant constructs from these are also included in the process view and as such this is the view that provides the most detail. A complete architectural representation of the different views is provided in the web report [12].

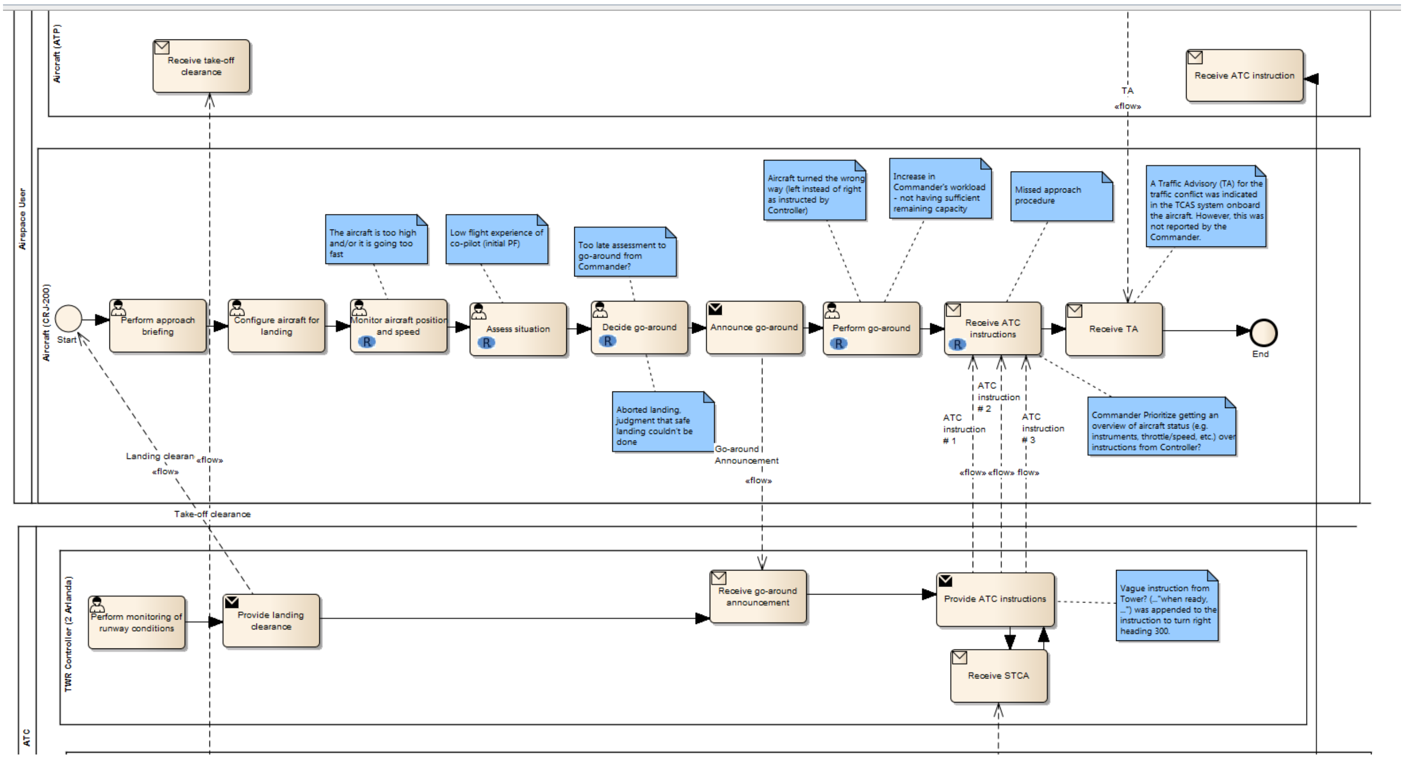

Figure 3: An excerpt of the Arlanda case study process view

D. Step 4: Synthesize the main states and their triggers from the Arlanda case study description using the output from step 3

Once having developed the process view, another analysis takes place. Step four aims to extract candidate resilience indicators from the consolidated view provided by the process view (including sequences of activities as well as interaction and information exchange between roles and actors).

For this we are applying UML state diagrams. The intention of a state diagram is to represent states and their triggers. Considering the nature of resilience, we are interested in a system state (either positive or negative) and the triggering factors that bring the system into such a state.

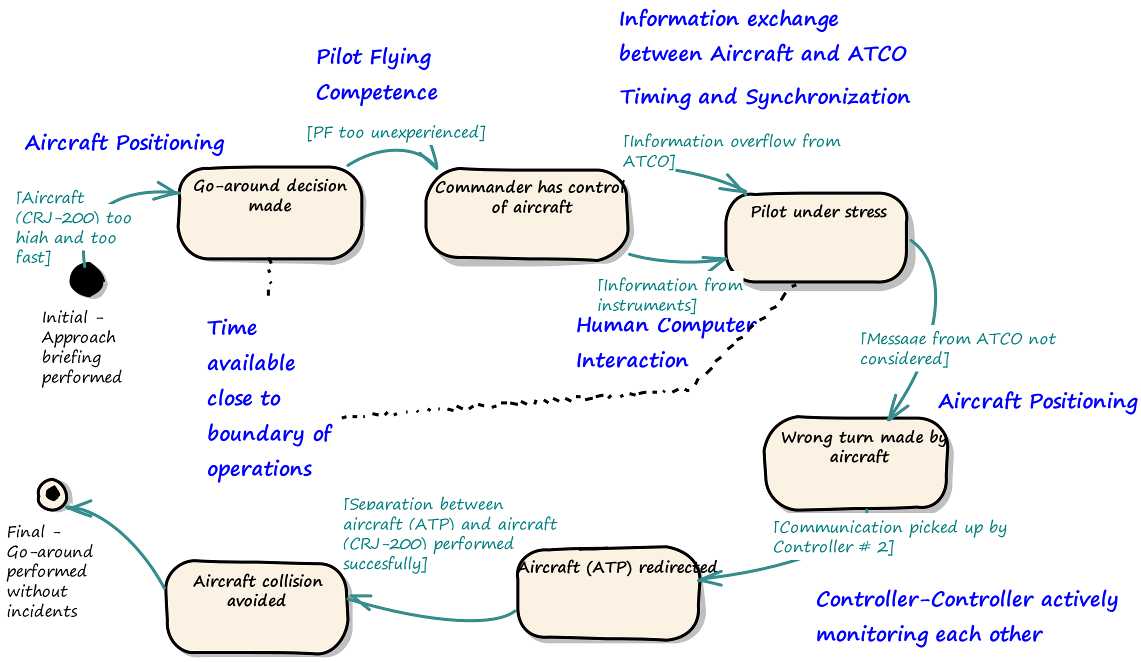

Figure 4: State diagram representing main stages of the Arlanda case and their triggers

From this, state diagrams enable us to “zoom in” on the details regarded as most relevant and abstract away details that are less relevant and that potentially can blur the overall picture. Figure 4 is an example of a state diagram for the Arlanda case study.

What the above illustration shows are the main states following from the analysis of the process view of the Arlanda case. The rounded rectangles indicate the main states while the arrows between them are their triggers. Extracted from the triggers are candidate resilience indicators that will be brought on to the next step – the identification of resilience patterns.

E. Step 5: Identify patterns from the main states and triggers in the Arlanda case study and in the other selected cases combined from step 4

This step consolidates the results from the analysis of the Arlanda case study in order to identify resilience patterns. The result from this consolidation is a composition of resilience patterns and associated candidate resilience indicators forming such patterns. As illustrated in Figure 5, the «Resilience Pattern» is the “Organization of Traffic management TWR” which is constituted by 2 «Resilience indicators» that are “Information exchange between aircraft and ATC – Timing and Synchronization” and “Controller-Controller actively monitoring each other”.

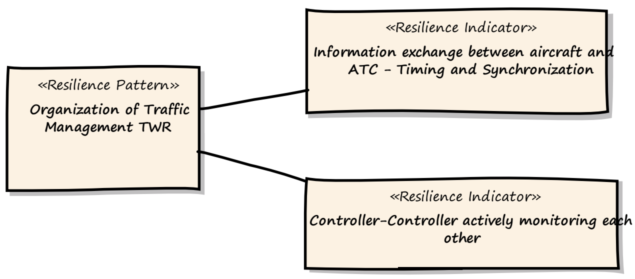

Figure 5: Composition of Resilience Patterns from candidate Resilience Indicators

V. Discussion

Resilience Engineering (RE) sees safety as the ability to succeed under varying conditions. In line with this view safety performance should be related to those factors that enable the system to continue operations. Operations of complex socio-technical systems such as ATM are produced by dynamic interactions of many actors human, technical and organization within and across different organizations such as air navigation service providers and air space users. In addition, an essential capability of a resilient system is “*knowing what to look for*” in a flexible manner, analyzing the current status of the system and its context of operations. The monitoring should look into what happens in the environment of operations and the system itself [3]. We argue that Enterprise Architecture facilitates monitoring in a flexible manner and change of perspectives to achieve better understanding about how the system really works and what aspects affects its operation. It allows changing focus from roles, to information, to process viewpoint. In addition, we have developed a resilience viewpoint collecting resilience related information from analyzing the other viewpoints.

The previous sections present our first combination of resilience engineering and enterprise architecture. The basis to structure resilience related indicators is a review of relevant literature and developments in ATM, nuclear, oil and gas and health care domains (for detail information of this review the reader is referred to our deliverable D1.1 [11]). We started with Resilience Analysis Grid [8] that has been applied to measure performance of organizations in the oil & gas [13]. RAG has also inspired development of resilience principles proposed in SESAR P16.01.02. These resilience principles result from combination of characteristics of resilience systems [14], RAG, resilience capabilities, ETTO [1] and experiences from applying the principles to a SESAR ATM case study. There is no one to one relation between principles, abilities and characteristics. Combination of these concepts reflects how resilience engineering evolves. It also reflects how different concepts inspire and affect each other. The aspect of evolutions within Resilience Engineering gives a premise to SCALES; our framework should be able to evolve as new validated knowledge in Resilience Engineering is produced. Therefore, we consider the construction of SCALES as iterative. It is relatively easy to update the current version to new conceptual developments and we do not see the final product as a static framework, but rather as a tool that can evolve.

Current version of the SCALES framework shows how resilience concepts can be related to successful and unsuccessful ATM operations. The indicators and patterns identified are derived from a checklist that combines resilience abilities and resilience principles. These are not independent indicators. For example cues and signals provided to the ATCOs from the controller working position will have an impact on the ability to monitor, to anticipate and to respond. It is not possible to have indicators directly derived from the checklists; these indicators should be related to the specific operation. EA facilitates to see possible impact of the indicators within and across organization. For example: the way that ATCO´s monitor each other informally and provide guidance to the aircraft. We also could map how organizational functions affect everyday operations e.g. the way air traffic controller responsibilities and their collaboration are defined. Our findings start to show that resilience related indicators address proactive work, flexibility and how distributions are managed.

The SCALES framework and its associated tool are still under development and the finding can be argued as preliminary and not conclusive. More systematic approach to a resilience view, identification of indicators and patterns is needed including guidance to the analyst. More case studies and empirical data are required to provide validated results. All these aspects should be considered for further work.

VI. CONCLUSIONS AND FUTURE WORK

This paper has presented the SCALES framework for identifying and extracting resilience related indicators. This process has been thoroughly applied on the go-around procedure, in particular on the Arlanda case study.

The analysis presented in the paper represents a first step and the results are preliminary. These concern Resilience Engineering, Enterprise Architecture and, in detail, the project research question in which we address the added value in combining them.

With regard to Resilience Engineering, the SCALES framework supports in the identification and extraction of resilience indicators and in mapping into patterns. Moreover, the project aims at unifying the current terminology related to the Resilience Engineering domain in order to create a common vocabulary and to avoid misunderstandings and confusion when these terms are used.

With regard to Enterprise Architecture, it is applied in a new application domain and the SCALES framework develops a combination of Resilience Engineering and Enterprise Architecture in ATM. In addition, the framework provides an absolutely new Resilience view which can be implemented in the Enterprise Architecture. These improvements are aligned to EATMA [7] making possible to analyse current ATM functionalities and SESAR changes.

Both presented preliminary findings deal with the still vivid interest of the scientific and SESAR community in Resilience Engineering and Enterprise Architecture domains. Together they direct attention towards important aspects related to flexibility and adaptations of the ATM system.

Finally, preliminary findings addressing the project research question suggest a framework supported by empirical data and new representation with different viewpoints supporting flexible monitoring and anticipation of cross level interactions, interdependencies and potential cascades. The developed framework is an iterative methodology to combine Enterprise Architecture and Resilience Engineering and it provides system of systems approach modelling of interactions within and across organizations. The integration of the Resilience Engineering analysis supports the illustration of adaptations necessary for the ATM system to continue operations.

The application of the framework on a set of case studies exhibits directions for future work and raises some issues. At the moment, we have some preliminary indicators which need to be validated and qualitatively and quantitatively evaluated with the support of Subject Matter Experts such as ATCOs, pilots and ATM stakeholders. Future work needs to include sufficient guidance indicating how to develop the resilience viewpoint in a systematic manner. Another important challenge is to deal with dynamic operations while adopting these types of notations which can offer just static views. These issues offer us the opportunity to further explore the Resilience Engineering, improve the Enterprise

Architecture and create a common framework for their integration.

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