RESILIENCE ENGINEERING (RE) IN DESIGN: INITIAL APPLICATION OF A NEW RE ASSESSMENT METHOD TO THE MULTIPLE REMOTE TOWER CONCEPT

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Abstract

The paper presents initial application and further development of a resilience engineering (RE) assessment method to the multiple remote towers (MRTWR) concept. The RE method is operationalised through a set of eight principles identified from existing RE literature. These principles are 1) Work-as-Done; 2) Varying conditions; 3) Signals and Cues; 4) Goal trade-offs; 5) Margins and adaptive capacity; 6) Coupling, interactions and cascades; 7) Timing, synchronisation and time scales; and 8) Under-specification and approximate adjustments. The application of the RE method to the concept of MRTWR has helped to understand the significance of the change and associate design requirements at a larger scale, focusing not only on the function of specific components, but on the ATM system as a whole. Results from this application show how understanding everyday operations (work-as-done) helps to evaluate the gaps between current and envisaged design of a new operational concept (MRTWR). Based on work-as-done the principles are used to develop design requirements how to enhance resilient performance of systems. Sharing this experience may offer practitioners and researchers from aviation and other domains the opportunity to build on lessons learnt from this application to investigate how resilience can be enhanced in their systems.

1 INTRODUCTION

Resilience Engineering (RE) is 'the scientific discipline that focuses on developing the principles and practices that are necessary to enable systems to function in a resilient manner' (Hollnagel, 2014). According to Hollnagel (2011) resilience is defined as the ability of a system to adjust to changing conditions (expected or unexpected) in order to sustain required operations. As such RE requires a mind set change moving from classic safety assessment approaches towards approaches addressing the dynamics of complex socio-technical systems in context. The body of RE knowledge and practices is under continuous development and evolution. Methods and approaches to describe, assess and measure resilient system performance have evolved over the past decade, but still need further development and practical validation.

2 RESEARCH GOALS, METHOD AND DESIGN

2.1 Research goal

The research goals of this activity were firstly, to demonstrate added value of the RE assessment method to the MRTWR concept in the design phase with respect to classical safety approaches (complementing work-as-imagined with work-as-done). Secondly, to refine and further develop the RE assessment method in terms of improving its guidance for application to a wider community of practitioners based on practical lessons learnt.

About the new MRTWRS concept: Provision of Air Traffic Services (ATS) is costly and there is a need to increase cost-efficiency, particularly at low to medium density airports. A possible way to reduce costs without reducing the level of safety is the Remote Tower concept in which the provision of ATS is no longer located at the aerodrome and will be re-located to Remote Tower facility. In Multiple Remote Tower operations, ATS may be provided simultaneously to more than one aerodrome by a single controller from a remote location.

Air Traffic Management is undergoing a significant shift in its evolution as a part of the European Commission Single European Sky strategy. Single European Sky Air Traffic Management Research (SESAR) is the research and development foundation for the eventual implementation. The RE method was developed to augment the current Safety Reference Material for safety assessments of new operational concepts in SESAR. In addition possibilities and capabilities of RE beyond SRM will be explored. Thus application of the RE Method is for the assessment of resilience in new concepts/designs for implementation in ATM.

The SESAR programme includes safety within its compass. The SESAR work includes the development of Safety Reference Material (SRM) that can be applied to safety assessment of SESAR projects. The SRM includes a section addressing deployment and the development of guidelines for the safety assessment of resilience in new ATM designs (called hereafter RE Guidelines). Subsequent SESAR projects have been instigated that further develop RE Guidelines and associated methodology exploring resilience engineering in new design of systems in the design phase of an operational concept.

The RE Guidelines are a structured approach to the application of the RE method. This is an iterative exercise that requires a multidisciplinary team composed of designers, practitioners and researchers. The nature of the changes within the social-technical system – which the ATM system is representative of – are varied. These changes typically involve changes to procedures, the introduction of new technology and changes in tasks – the work undertaken – by the human. The extent of these changes, increasingly involves the interaction between organizations, increase use of new technologies, airport actors, pilots and controllers at the operational interface.

Experience of earlier implementations of the RE guidelines has found that new system behaviours emerge from new interactions and dependencies that were not previously identified in safety assurance activities. Emergent properties are defined by Woods as a system property, arising in the interactions across components, subsystems, software, organizations, and human behaviour (Woods, 2006). Safety is in and of itself an emergent system property.

Safety in ATM is currently assessed and measured using classic safety assessment techniques that are well defined in ESARR 4 & 5 [Eurocontrol, 2001; Eurocontrol, 2002]. It has been recognised that these classical approaches have limitations [Sheridan, 2007, Hollnagel, 2013], particularly the gap between safety assessment of systems in the design and pre-implementation phase and the subsequent operational implementation. This is particularly pertinent with regard to the nature of the functional work of the system – the control and management of air traffic. Frequently this is investigated in terms of work-as-imagined (WAI), and not as work-as-done (WAD) (Hollnagel, 2014).

The issue is further exacerbated, in that the work to be undertaken – the future work-as-done itself - is changing, just as work-as-done currently it naturally changes too. The limitations of the capability of simulation facilities (i.e. an ATC simulator can never replicate the real environment including all relevant interfaces, features, processes and procedures) and the approach to system development means that safety assessment of new designs is perforce limited and the real nature of work-as-done is therefore underspecified. The nature of simulation facilities in ATM is such that it is rare to replicate the varying conditions that are experienced in the operational environment. Additionally, the multiplicity of interaction with other actors and agencies is wide and is impracticable to simulate fully. The concept of operations itself is often underspecified. These varying conditions significantly influence system behaviour, and thus leave work-as-done underspecified as well. The application of the RE assessment method MRTWRS explores resilience engineering to address these issues.

2.2 Resilience Engineering Guidance

This iteration of the application of the SESAR resilience engineering guidelines built on those delivered in 2014 A first application of the guidelines was developed to the concept Initial Four Dimension Trajectory/ Controlled Time of Arrival (i4D/CTA) representing a technological and operational change to improve operations in 2012. This application identified additional safety and design requirements that traditional safety assurance processes did not identify (Woltjer et al. 2013, Woltjer et al, 2015).

The experience of the initial application of the RE method to the i4D concept provided the impetus to explore the concept further and apply the RE guidelines elsewhere within the SESAR ATM activities. One major need that emerged related to the practical application and operationalisation of RE to improve the RE assessment. The expected benefits were to make the guidance more practical and easily applicable for safety practitioners. Applying the guidelines should not require acquisition of in-depth scientific knowledge or expertise. Additionally, the need for a methodology *per se* was identified.

The intent was to further develop the RE guidelines and refine a methodology in a way that it can be applied to a range of different Air Traffic Management system changes and to extend the existing SESAR SRM method. An additional goal was to develop an accompanying RE familiarisation and training package for practitioners based on easy-to-understand and practical real-life examples (how to cook an egg, how to enter a roundabout when driving) but also ATM examples. The training package delivers the new RE language, terms and definition as well as system thinking.

Resilience Engineering Principles in SESAR

RE is operationalised in the guidelines through eight principles. The eight principles are shown in figure 1, with an exemplar of each principle added. Each principle represents a *lens* by which to explore the system characteristics, properties and the nature of work-as-done in the current operation and in the new design in terms of specific RE attributes. With the knowledge thus gained it is possible to explore the hypothesised work, as will-be-done using the same lens to explore the resilience of the new design.

The focus of the exploration is day-to-day work (Work as Done) what external (non-operational) observers see as adaptations needed to get the work done. Variations (internal or external), trade-offs and goal conflicts, are seen and perceived by those performing the work as normal. The eight RE principles therefore provide the means by which to carry out the operational exploration of work-as-done and principles were drawn from RE theory. This is the basis for exploring resilient performance, the analytical frame with which to explore resilience and, is entirely consistent with the projects working definition of resilience engineering (Hollnagel, 2014).

The RE guidelines include guidance with which to explore each principle. These form one dimension of an analytical framework with which to frame the exploration of each one of the eight principles. The other dimension is an operational dimension in terms of the services that the work-as-done is serving to fulfil and enact.

Figure 1. Example of principles related to the following operational story: Spacing between two aircrafts at the same level and crossing each other with estimated 3 miles. The example describes Work-as-done and the other seven principles seen through an operators (in this case an Air Traffic Controller) lens. Different scenarios have been used to stimulate the thoughts of the operator to achieve the description.

SESAR Resilience Engineering Assessment Process Phases

An overarching principle of the guidance and methodology is the need for a method that can be generalised to different concepts. The initial process for the application of Resilience Guidance consisted of eight steps. These steps comprised exploring, sequentially, each RE principle with each of the ATM services identified as salient or germane. The guidance material provides exemplars of RE characteristics and operational ATM functions with which to guide the application of the guidance. The RE guidance proposes a number of ways to capture the data, a workshop composed of operational personnel with knowledge and experience of both the current and new designs as well a project team members is the preferred method

Defining each step of the guidance was a key part of assessing the RE Guidelines. A need to improve guidance to personnel involved in the RE principles assessment was addressed through consolidation and simplification of the initial process as described below. The process is in three easy to follow phases a preparation phase, a data collection phase (workshop) and a data analysis and results phase as illustrated in figure below. Thus, a structured approach to the application of the RE guidance and methodology was developed and tested.

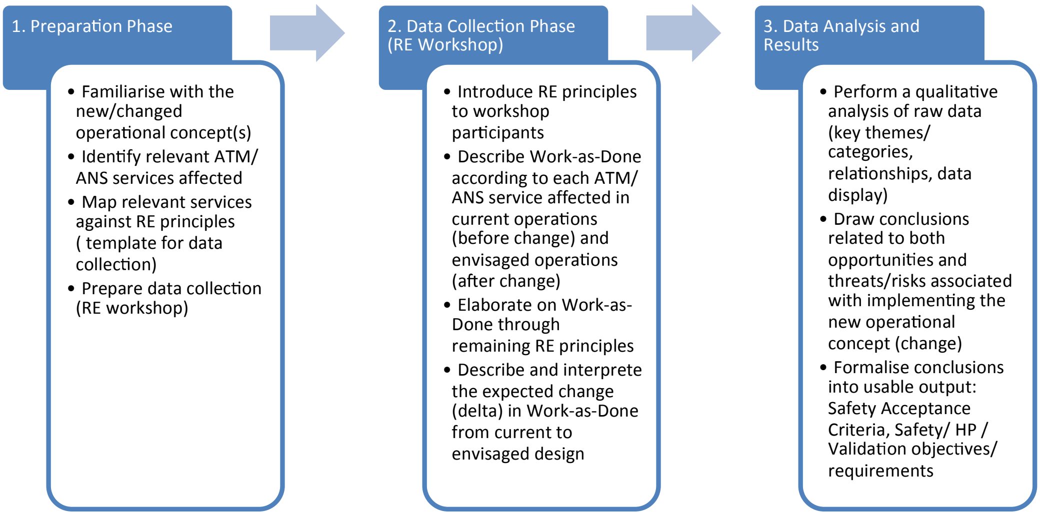

Figure 2. The SESAR RE process phases

1. Preparation Phase

The preparation phase entails developing an understanding of the new operational concept. The objective of this is preparation for attaining the entry criteria for phase two.

The preparation phase involves familiarization with the new concept (new design). Typically this will involve a review of the operational concept and design documents and method of operations and procedures. Informal interviews and observation of operations during simulation of live trial activity are also useful for gaining an appreciation operations currently and as envisaged.

The phase also involves identifying the ATM services in the current and new designs and assessing the salience for inclusion in the workshop. A service represents elements of the purposeful; activity of the system e.g. Sequence aircraft inbound from fix *v* for arrival at runway *n* at airfield *y*; traffic planning and sequencing at airfield z; managing the manoeuvring area at airfield *z*.

The creation of the ATM Service/RE Principle matrix that will be used to structure the RE Phase 2 workshops and fulfils the entry criteria into phase 2. Along with the organisation and planning of the phase 2 workshop.

2. *Data collection Phase (RE workshop)*

The data collection phase is performed through two days workshop with participation of technical and operational experts together with RE assessment team. During the workshop current and envisioned work is systematically mapped to the most relevant services and principles.

This phase then is the primary means of data capture in the application of the method. The workshop commences with an introduction to the concept of RE and preparation for the exploration of the ATM services, work as done and the other RE principles.

Data is captured in a spread sheet and documents the discussion as each principle is discussed in the context of each salient ATM service of the ATM Service/RE Principle matrix. For each principle a description of current operations (Work as Done), description of change in operation (work as envisioned) and delta of the change are captured.

3. Data analysis and results

The analysis task is essentially one of qualitative analysis of the data obtained from the workshop. Coding of the data can be conducted by identifying pertinent themes and narratives formed by correlating and interpreting participant comments in the context of the themes. From this arguments can be made to support and reason specific conclusions related to design.

A multidisciplinary team (ATCOs, pilots, safety analysts etc.) performs a qualitative analysis. An initial list of questions related to each principle is provided in the initial guidelines and provides an analytical framework. Results can be used to provide new validation objectives, HMI design, structural and procedural changes of new system designs. The RE Method can also provide insight into the other SESAR Key Performance Areas (KPAs) other than safety e.g. capacity, flexibility, predictability, efficiency, cost effectiveness, and environment. The conclusions derived provide the basis for recommendations that constitute the results. The use of the workshop narrative can provide a rich picture with which to amplify and emphasise the conclusions.

This process assumes that the analyst team involved in the exercise are familiar with Resilience Engineering and Complex Socio-Technical Systems.

With a light on improving the existing RE method as described above two RE principles were investigated. The first exercise focused on P2 (varying conditions) and a second exercise focused on P4 (goal trade-offs) related to Safety Acceptance Criteria (SAC). SAC are explicit and verifiable criteria that set the acceptable safety level of the implemented change. SAC include not just specific risk targets but also safety (and other), regulatory requirements, operational and equipment standards and practices.

- The first exercise intends to explore conditions affecting performance variability as a way to understand how and why adjustments are performed. It explores which conditions need to be managed and which adjustments are required. Innovation games create a space where conditions can be identified. The idea is to identify conditions relevant to everyday operations of the Air Traffic Controllers projected to the Multiple Remote Towers concept. An innovation game the Blind Side is selected as game for brainstorming. This game is adapted from Game-storming (Gray, D. et al., 2010), already proven guidelines and templates were used. At the end of the exercise a list of conditions affecting variability for multiple remote towers were gathered. Additionally, way this variability is management and any possible adjustments were identified.
- The second exercise addresses a key question how can findings from everyday work support updating a risk picture. It aims to understand which Key Performance Areas (KPAs)s are traded-off in specific situations, understand if and how safety may be impacted and understand the contributing factors and multiple effects affecting safety acceptance criteria. After a short introduction on Safety Acceptance Criteria and the process, participants were introduced to the purpose and the logic of the exercise discussing the above questions through specific scenarios related to the new concept. The impact of trade-off in everyday operations within tested scenario was reflected on how it could affect the performance levels such as effectiveness, capacity or cost benefits.

3 RESULTS

The RE guidelines supported assessment of the MRTWR concept by looking into the relevant air traffic services and the eight RE principles using the structure outlined in table 1. Services such as Traffic planning and sequencing, the Navigation function of controller, Meteorological services, Communication (Information / Decision Services), Potential conflict / collision detection and Start-up are the services for which RE provides additional insights.

Aggregated results were summarized through the RE principles in current and envisioned operations and an assessment of the change. Results from the application of the RE guidelines are integrated into the SESAR Safety Assessment Report consequently the assessment output gathered the recommendations in terms of

Key Performance Areas such as Human Performance and Safety issues, as well as validation needs.

Table1: Example first two columns show information collected during workshop, last two columns show results from the RE analysis

Service 1: Traffic planning and sequencing	
Current Work-as-done (P1)	In a small airport the traffic patterns and variations are well known. Planning and sequencing of aircraft is seldom an issue. Controllers perform a number of tasks beyond those strictly associated with being a tower controller
Envisioned Work-as-done (P1)	It is uncertain if the MRTWR controller is allowed to operate simultaneous arrivals/departures at different aerodromes. Scanning patterns are extended to incorporate all of the airfields that the MRTWR ATCO is responsible for. PTZ augments and supports scanning patterns.
Assessment of Change Work-as-done (P1)	*D14 Work-as-Done Guide: Which techniques are envisioned to be used with the change to meet changing demands and cope with complexity of everyday situations?* MRTWR controller has a new interfaces human and technical for multiple locations. Nature of MRTWR controller is different because of managing concurrent airfield operations. The service should be the same but will at times require prioritization between airfield operations. Local knowledge and multiple remote operations: It is uncertain how local and tacit knowledge is available for other sources
Assessment output (design RE recommendations)	Validation needs: Define interfaces and validate the relationship of the MRTWR controllerand other local actors. How do actors support each other to deliver effective and timely services. Modified scanning patterns pose the risk of selective information search and the controller only activating selected information in the other airfield (e.g. only check one rwy) without actually activating the latest contextual information of the environment. Work is redistributed and the MTTWR controller needs to have sufficient local knowledge to provide effective ATS to aircraft operators and other users of the airfield. Controllers need to be trained and prepare in managing their workload including prioritization of tasks and tasks scheduling for concurrent airfield operations.

Key Findings (Application)

The application of the RE principles to the concept of MRTWRS has helped to understand the significance of systems change at a larger scale, focusing not only on the function of specific components. Hence, as a result, to identify design improvements for the proposed MRTWRS design.

<u>SESAR KPA Safety: evidence of new interfaces and interdependencies</u>

The MRTWRS concept changes the role of the ATCO from being solely dedicated to TWR functions that embraces aerodrome and approach control as well as supervisory tasks in a single person operation to a aerodrome controller providing ATS at two or more aerodromes. The RE workshop tested a number of assumptions and dependencies. Additionally, dependencies between the MRTWR controller, the supervisor (SUP) and remote tower centre (RTC) approach (APP) were explore and the method provided added value in our understanding on how these roles interact. The nature of work for a MRTWR ATCO is different because of managing of concurrent airfield operations. This will manifest in practical terms for traffic planning and sequencing as well as trade-offs when prioritizations have to be made that allow the ATCO to concentrate on specific tasks at a particular airfield. In cases where the MRTWR ATCO has to give priority to one aerodrome (i.e. due to an emergency), it was assumed by workshop participants that a supervisory function was available to coordinate emergency response units and organises management of traffic at the other aerodrome (close airspace or find a second ATCO to take care of aerodrome 2). Another assumption was made regarding the 24/7 availability of an RTC APP unit that will assist the MRTWR ATCO in traffic sequencing. As a consequence, a recommendation was made from the application of the RE method reading: "MRTWR controller, SUP and RTC

APP by design provide a cohesive and consistent ATS". This recommendation goes along with a validation need related to the definition of the interface between MRTWR controller, SUP and RTC approach function as well as their relationship.

SESAR KPA Human Performance : different Scanning Patterns and Workload Prioritisation

The MRTWR controller has a new interface that is currently performed by single TWR controller. RTWR controller prioritization is different for multiple airports e.g. simultaneous take-off operation, two or more aircraft issue take off clearance at same time or two aircraft given landing clearance at same time. In order to accommodate the changing nature of work training need to be provided to support development scanning patterns with the new tools (e.g. runway sweep function, pan-tilt-zoom camera), techniques and new roles. Modified scanning patterns pose the risk of selective information search and the ATCO only activating selected information in the other airfield (e.g. only check the runway) without actually activating the latest contextual information of the environment (e.g. weather). ATCOs need to be trained and prepare in managing their workload including prioritization of tasks and tasks scheduling for concurrent airfield operations.

Key Findings (Development of Methodology)

For the methodology, a more structured documentation (easy-to-use templates), new innovative and creative knowledge elicitation approaches including innovation games and a way to perform analysis (e.g. system thinking, mapping of interdependencies) based on resilience engineering have been proposed. Using a workshop as the principal means of exploring the resilience of the new design can be an effective tool but shouldn't be the only one. A toolbox should be provided that gives an overview of suitable RE tools and when they should be used and shouldn't be used. Additionally the important issue of how the design and operational communities – air traffic controllers, engineers, project managers etc. are able to operationalize the RE output has been identified as an important issue to address. As is the nature and substance of the RE output – especially the added value provide to the design and project teams.

Key areas of improvement for the methodology included the fact that RE language (e.g. adaptive capacity, cascading, emergent factors, under-specification, tight coupling etc.) is not easy for practitioners to comprehend, because these terms are not part of their natural language. Project managers and teams need to be prepared and trained to enable an effective interpretation of the results. As a consequence different levels of training are required for different actors (e.g. safety and operational experts, workshop facilitators, data analysts). In this application not all of the system of interest was represented (i.e. the supervisor). It is necessary to represent in the scaled world of the method the key interaction components and entities to create al picture of the ATM system in context as rich as possible. Finally more work needs to be done on the data analysis and objectivity of results. So far it is essentially deductive reasoning, which requires rigour to deliver consistency – but in turn does not produce easily generalizable or repeatable results. Project teams are seeking a high level comparative resilience performance between designs.

In this application the game-storming exercise showed to be an effective approach to capture conditions affecting everyday operations related to a new operational concept (i.e. MRTWR). The SAC exercise identified elements that could potentially influence the SAC and other KPAs via trade-offs. However, the granularity of results showed that collected outputs are arguments for evidence of safety, or about the need to demonstrate with evidence the need for safety, rather than driving the SAC setting process itself. This exercise was focused on investigating goal trade-offs further have potential to provide deeper insights in the affected KPAs and in this application helped to identify which elements are required for possible safety improvements.

4 CONCLUSIONS AND FURTHER WORK

Our argument is that the resilience principles proposed, and deployed in the methodology enhances the understanding of everyday operations. The focus in the guidelines is on understanding everyday operations and exploring the principles (work as done, coupling and cascades, etc.) in anticipation of the future ATM system and to explicit the subtle changes actually brought by the envisioned ATM system. The key is to relate future concept design to work-as-done and to learn from the way in which ATM system (organizations, technical systems and humans) adjust all the time to varying conditions. Learning from work as done, the strategies operators apply to solve complex situations, organization of work, use of new tools deserves to be considered from a systems perspective already in the design phase of an ATM system with the purpose to improve resilient performance. Sharing this experience may offer practitioners and researchers from aviation and other domains the opportunity to build on lessons learnt from this application to investigate how resilience can be enhanced in their systems.

For the methodology, areas of improvement concern a more structured documentation providing practical hands-on guidance when and how to explore resilience in action suitable for practitioners with different backgrounds. The importance of work as done and adaptation within ATM actors as a web of interdependent actors, leads the method to consider further developments addressing sustained adaptive capacity as proposed by Woods (2015).

The methodology should suggest a toolbox of techniques such as innovation games and a way to perform analysis based on resilience engineering have been proposed. Additionally the important issue of how the design and operational communities – air traffic controllers, engineers, project managers etc. are able to make use of the RE output in project activities has been identified as an important issue to address. As is the nature and substance of the RE output – especially the added value provide to the design and project teams. The analysis of the various feedback on the RE methodology and the RE workshop itself leads the project to derive the lessons learned from this application case. Specific areas of improvement have been identified such further developments on operationalization of sustained adaptive capacity. This will be explored further to improve the methodology in general and to provide more detail guidance in its application.

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6 SELECTED REFERENCES

Eurocontrol, (2001). ESAAR 4: Risk assessment and mitigation in ATM. Brussels Safety Regulation Commission, Eurocontrol

Eurocontrol. (2001). ESAAR 5: ATS Service Personnel. Brussels, Safety Regulation Commission, Eurocontrol

Gray, D. et al. (2010). Gamestorming: A playbook for innovators, rulebreakers, and changemakers. Sebastopol, CA: O'Reilly Media.

Hollnagel. (2014). *From Safety I to Safety II*. Farnham, U.K. Ashgate

Hollnagel, E. (2013). A tale of two safeties. *International Journal of nuclear safety and simulation. Vol 4*; (1)

Hollnagel E., Woods D. D, Leveson, N. 2006. *Resilience engineering: concepts and precepts*. Ashgate.

Hollnagel, E. (2011). Epilogue: RAG – The resilience analysis grid. In E. Hollnagel, J. Pariès, D. D. Woods & J. Wreathall (Eds.) *Resilience engineering in practice: A guidebook*. Farnham, UK: Ashgate.

Hollnagel, E. (2009). The ETTO Principle: Efficiency-Thoroughness Trade-off, Why Things That Go Right Sometimes Go Wrong,. UK: Ashgate.

Sheridan, T.B. (2007). Risk, Human Error, and System Resilience: Fundamental Ideas. Human Factors; Vol. 50, (93) p. 418-426.

Woltjer, R., Pinska-Chauvin, E., Laursen, T., & Josefsson, B. (2013). Resilience Engineering in Air Traffic Management: Increasing Resilience through Safety Assessment in SESAR. *Proceedings of the Third SESAR Innovation Days*. EUROCONTROL. http://www.sesarinnovationdays.eu/files/SIDs/2013/SID-2013-14.pdf

Woltjer, R., Pinska-Chauvin, E., Laursen, T., Joseffson, B. (2015). Towards understanding work-as-done in air traffic management safety assessment and design. *Reliability engineering and system safety*, In press

Woods, D. D. (2006). Essential characteristics of resilience. In E. Hollnagel, D. D. Woods & N. Leveson (Eds.), Resilience Engineering: Concepts And Precepts (pp. 19–30). Aldershot, UK: Ashgate.

Woods, D. (2015). Four Concepts for resilience and the Implications for the Future of Resilience Engineering. *Reliability Engineering and System Safety*, http://dx.doi.org/10.1016/j.ress.2015.03.018