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Analysis of the roles of pilots and controllers in the resilience of air traffic management

Sybert H. Stroeve *, Bas A. van Doorn, Mariken H.C. Everdij

National Aerospace Laboratory NLR, Anthony Fokkerweg 2, 1059 CM Amsterdam, The Netherlands

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ABSTRACT

The objective of this paper is to show how qualitative resilience analysis approaches can be effectively structured for large sets of disturbances and strategies for work-as-done at the sharp end of a complex sociotechnical system. This is pursued by studying the roles of air traffic controllers and airline pilots in dealing with a wide set of disturbances in current air traffic operations. Disturbances are events or conditions that may affect one or more components or processes of the ATM system and thereby perturb air traffic operations. A set of 459 disturbances are clustered at three abstraction levels and characterised with respect to frequency of occurrence. Strategies of pilots and controllers for dealing with these disturbances are identified, and these strategies are also clustered at three hierarchical levels. The strategies are analysed with respect to key characteristics, such as detection and interpretation of the disturbances, coordination about the strategy, and strategy acquirement. The effects of the strategies on the key performance areas (KPAs) safety, capacity, environment and cost-efficiency are characterised and ranked. The results show that the strategies for dealing with disturbances have positive safety implications for the majority of disturbances and negligible safety effects for the remaining cases. The effects on the other KPAs are negligible in the majority of cases, but they are negative for a variety of disturbances. The results emphasize the important roles of pilots and controllers for dealing resiliently with disturbances in ATM.

1. Introduction

The concept of resilience has gained considerable interest for the design and analysis of sociotechnical systems. As outlined in reviews of (Folke, 2006; Francis, 2013), the origins of the resilience perspective stem from ecological studies on the dynamics and interactions of prey and predator populations, including a core paper of Holling (1973). In the early 1990s the resilience perspective for the analysis of ecosystems revived and was also extended to socio-ecological systems. In (Folke, 2006; Walker et al., 2004), resilience is defined as the capacity of a system to absorb disturbance and to re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedback. In general, a disturbance is an event that is (potentially) detrimental to one or more components or processes within a system (Francis, 2013). What constitutes a disturbance depends on the system context, e.g. in ecological systems a disturbance typically refers to something that leads to loss of biomass, such as a forest fire, hurricane, or a new predator. The analysis of resilience of sociotechnical systems has been stimulated considerably by safety-related research of Hollnagel and co-workers and their introduction of the resilience engineering research field (Hollnagel et al., 2006; Nemeth et al., 2009). This has led to the identification of Safety-II, i.e. a way of understanding safety beyond the traditional way (Safety-I). Hollnagel et al. (2013) make clear that the focus of Safety-II is on everyday actions and outcomes, rather than the restricted view on (rare) accidents and incidents in Safety-I. As such, Safety-II can be understood as studying safety via a work-as-done viewpoint in resilience engineering.

Various views exist on key aspects of resilient systems and ways to assess resilience. According to Hollnagel (2009) the four essential cornerstones for a resilient system are the abilities to respond to the actual, to monitor the critical, to anticipate the potential, and to learn from the factual. Following an extensive review of resilience in a variety of fields, Francis and Bekera (2014) conclude that absorptive, adaptive and restorative capacities are at the core of a resilient system, indicating capacities to absorb system perturbations, to adjust to undesirable situations by undergoing change, and to return to an acceptable level of operations, respectively. For the assessment of resilience in air traffic management (ATM), Woltjer et al. (2013) use the following principles: work-as-done (understanding the way work is done,

* Corresponding author. Tel.: +31 885113104.
E-mail addresses: Sybert.Stroeve@nlr.nl (S.H. Stroeve), Bas.van.Doorn@nlr.nl (B. A. van Doorn), Mariken.Everdij@nlr.nl (M.H.C. Everdij).

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including operator performance variability, rather than the work-as-imagined); varying conditions (considering expected and unexpected conditions that may be encountered); signals and cues (considering the information for anticipation, monitoring, and response by operators to varying conditions); goals trade-offs (understanding the trade-off operators make between various goals); adaptive capacity (considering the capacity to adjust to foreseen and unforeseen varying conditions); coupling and interactions (considering the complexity and distributed nature of the ATM sociotechnical system); timing, pacing, and synchronization (understanding the dynamics of the ATM sociotechnical system); under-specification and approximate adjustments (considering the incompleteness of procedures and the adjustments operators have to make in their work-as-done). These principles were applied in a workshop format for analysis of resilience of a future ATM operation. Furniss et al. (2011) developed a resilience markers framework for reasoning about resilience in small teams, which studies behaviour in a hierarchy of three levels of abstraction (from high to low): a markers level describing the high-level principle, a strategy level expanding on details of the marker level, and an observation level describing the detailed work-as-done in a particular context. The strategy level is structured by four elements: a resilient repertoire, encompassing the skills and competencies to respond to threats and vulnerabilities outside the design-base; a mode of operation, describing the style, structure or organisational mode in an operational context; resources and enabling conditions, describing the hard and soft constraints that influence whether a strategy can be enacted; and vulnerabilities and opportunities, describing events and conditions that, respectively, may reduce or improve system performance. The resilience markers framework was applied in a case study for analysis of control room crews of a nuclear power plant using a re-analysis of previously recorded simulator experiments. Rankin et al. (2014) developed a strategy framework for analysis of resilience in everyday operations. It uses the following categories for structuring work situations: strategies, describing mechanisms used to cope with variations; objectives of strategies; forces and situational conditions, describing the context in which strategies are carried out; resources and enabling conditions, describing necessary conditions for successful strategies; resilience abilities, referring to the four cornerstones of (Hollnagel, 2009); sharp-end and blunt-end interactions, describing how a strategy has impact on different parts of a distributed system. In addition to these strategy categories, Rankin et al. (2014) developed a variety space diagram, which relates the frequency of a disturbance, the availability of responses to cope with a disturbance, and the level of sharp- and blunt-end interactions in a strategy. The approach has been applied using results of group discussions between safety practitioners on safety–critical situations in various domains (e.g. health care, nuclear power, air traffic control). In summary, these resilience analysis approaches all describe work-as-done using various viewpoints along strategy categories and principles. The results are mostly textual descriptions of work-as-done along these viewpoints. In the applications such results were derived for selected operations by workshops or analysis of simulator experiments.

The objective of this paper is to present an effective and structured qualitative approach for the resilience analysis of large sets of disturbances and strategies for work-as-done at the sharp end of a complex sociotechnical system. This will be pursued by studying the roles of air traffic controllers and airline pilots in achieving resilience in current-day air traffic operations. Air traffic controllers and airline pilots are key operators working at the sharp end of air traffic operations. In their work they have to deal with a large variety of potential disturbances and in their strategies they need to balance the effects on a range of key performance areas (KPAs), e.g. safety, capacity, environment and costs. We consider quite generically that a disturbance in ATM somehow perturbs air traffic operations and thereby may affect the performance in one or several of its KPAs. Examples of disturbances in ATM are bad weather, system malfunctioning, airspace closure, and misunderstandings. In the context of ATM, resilience has been defined similarly to (Folke, 2006; Walker et al., 2004) as the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions (Eurocontrol, 2009). The resilience engineering perspective stresses the flexibility and system oversight of pilots and air traffic controllers as being essential for efficient and safe operations in normal and uncommon conditions (Eurocontrol, 2009; Eurocontrol/FAA AP15 Safety, 2010). As a way towards the main objective, we have the following sub-objectives:

- To identify and hierarchically structure disturbances in air traffic operations and assess their frequency of occurrence;
- To identify strategies (work-as-done) by pilots and controllers for dealing with disturbances;
- To hierarchically structure strategies of pilots and controllers;
- To analyse the strategies w.r.t. detection, coordination and strategy acquirement in the organisation;
- To evaluate the effects of disturbances on the ATM KPAs safety, capacity, environment, and cost-efficiency;
- To derive statistics for the analysis results.

It is expected that the approaches developed in this paper for ATM can also be used to study resilience in other complex sociotechnical systems with large numbers of potential disturbances.

This paper is structured as follows. Section 2 introduces the main sources used as input for the analysis. Section 3 presents the identification of disturbances in ATM, the clustering of these disturbances and an assessment of their frequency. Section 4 presents the identification, clustering and characterization of strategies for dealing with the disturbances. Section 5 presents an assessment of the effects of the strategies on KPAs in ATM. Section 6 presents a discussion of this research.

Parts of this research were presented in a conference paper (Stroeve et al., 2013a).

2. Main sources for the analysis

As input for the analysis we have used three main sources: a list of disturbances (Section 2.1), interviews with pilots and controllers (Section 2.2), and a workshop with pilots and controllers (Section 2.3).

2.1. List of disturbances

There exist a broad variety of events, conditions and circumstances that may disturb air traffic operations. As a starting point for the analysis in this paper we use a list of disturbances that was presented in (Stroeve et al., 2011). The basis for this list are disturbances that were identified during hazard brainstorm sessions with pilots, controllers and other experts, as part of a large number of ATM safety assessment studies. Key objectives of these brainstorm sessions were to identify as many as possible events, conditions and circumstances that may potentially have a negative effect on safety, and to refrain from any criticism and/or analysis during the brainstorm (De Jong, 2004). As result of these 'pure brainstorming' sessions, a wide variety of events, conditions and circumstances that may occur during ATM operations were identified, which were not analysed or restricted to situations that affect safety only. Therefore, such brainstorming sessions resulted in a wide variety of disturbances that may perturb ATM operations