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Assessing a requirements evolution approach: Empirical studies in the air traffic management domain

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ABSTRACT

Requirements evolution is still a challenging problem in engineering practices. In this paper, we report the results of the empirical evaluation of a novel approach for modeling and reasoning on evolving requirements. We evaluated the *effectiveness* of the approach in modeling requirements evolution by means of a series of empirical studies in the air traffic management (ATM) domain. As we also wanted to assess whether the knowledge of the method and/or the application domain influences the effectiveness of the approach, the studies involved researchers, master students and domain experts with different level of knowledge of the approach and of the ATM domain. The participants have applied the approach to a real evolutionary scenario which focuses on the introduction of a new queue management tool, the Arrival MANager (AMAN) and a new network for information sharing (SWIM) connecting the main ATM actors. The results from the studies show that the modeling approach is effective in capturing requirements evolution. In addition, domain knowledge and method knowledge do not have an observable effect on the effectiveness of the approach. Furthermore, the evaluation provided us useful insights on how to improve the modeling approach.

1. Introduction

The evolution of mission-critical requirements at enterprise level is known to be possible, but it is unknown whether it would happen: the *known unknowns* (Tran and Massacci, 2011). Unfortunately, large organizations cannot wait until the unknowns become known. The process of tendering and organizational restructuring requires a significant amount of time and planning. Decision makers at high-level must essentially bet on the final organizational solution and possibly minimize the risks that the solution turns out to be wrong. There is, thus, the need of approaches for evolving requirements that should help decision makers to select an optimal system design alternative that is resilient to requirements evolution.

In this paper we present the results of an empirical evaluation conducted on a requirements engineering approach to model and reason on requirements evolution (previously proposed in Tran and Massacci (2011)). The evaluation aimed to assess the *effectiveness* of the approach in modeling requirements evolution and whether the effectiveness depends on the analyst's level of knowledge of the approach and of the application domain. To this end, we conducted three empirical studies with participants having different level of knowledge of the modeling approach and of the application domain. Fig. 1 summarizes how our empirical studies developed along a two-year horizon. First, we have conducted a study within the research team who have proposed the approach to model evolving requirements. Then, we have pushed the envelope further by carrying out a series of workshops with domain experts and industry practitioners as in Ncube et al. (2007). Last, we conducted a study with MSc students.

As context for our evaluation, we have chosen the air traffic management (ATM) domain for three main reasons. First, ATM systems are complex and critical systems that are going through significant architectural, organizational, and operational changes as planned by the EU Single European Sky ATM Research (SESAR) Initiative (EUROCONTROL, 2003). Second, change management is a critical issue in the ATM domain. The need of system engineering techniques to support change management is well recognized (Graham et al., 2009). Last but not least there is a significant body of research about empirical evaluations of requirements engineering approaches in the ATM domain (Maiden and Robertson, 2005; Maiden et al., 2004; Ncube et al., 2007). For example, in Maiden et al. (2004), DMAN (Departure MANager), a system for managing

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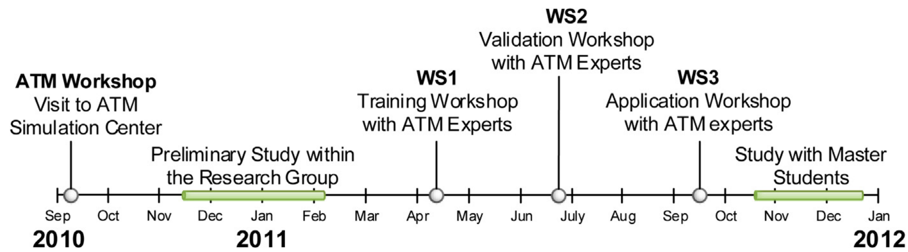

Fig. 1. Chronology of the family of empirical studies.

departure of aircrafts, is used as context of evaluation. This makes it easier to benchmark our studies.

In our empirical evaluation, we have focused on changes associated with the introduction of a new decision supporting tool (the AMAN – Arrival MANager) and SWIM (System Wide Information Management) in the ATM domain.

The results from the studies show that the modeling approach is effective in capturing requirements evolution. In fact, the studies showed that it is possible for people different than the method's own inventor (such as students or domain experts) to build significantly large models, and identify possible ways for these models to evolve. Moreover, the studies have shown that domain knowledge and method knowledge have no observable effect on the effectiveness of the approach.

The paper is structured as follows. Section 2 introduces the context of our studies. Section 3 gives an overview of the approach to model requirements evolution being validated. We describe the research methodology in Section 4. Section 5 presents the analysis of the data collected during the studies. Section 6 summarizes the main findings. Section 7 discusses the threats to validity. Section 8 gives an overview of related works while Section 9 concludes the paper with the lessons learned.

2. Application scenarios

The context of our study is the evolution in air traffic management procedures planned by the SESAR (Single European Sky ATM Research) programme which is building the future European air traffic management system. The application scenarios (Table 1 provides a list of technical documents) were provided by Deep Blue Srl, an Italian consultancy company specialized in human factors, safety and validation of ATM concepts and systems, which actively participates to the SESAR Initiative. The scenarios focus on the introduction of a new queue management tool, AMAN, and the introduction of a new data transport infrastructure, SWIM, that will replace the current phone-communication lines.

Before the introduction of the AMAN, the flight arrival management operations are performed by the Sector Team composed by two controllers, the Tactical and Planning Controllers. This is done with the support of the CWP (Controller Working Position). The controllers have to compute the arrival sequence for the flights and give clearances for landing to the pilots flying in their sector on the basis of the information displayed by the CWP such as air traffic, radar data, and weather condition provided by different ATM actors. The communication among these actors takes place over a dedicated and secure communication line.

After the introduction of AMAN, the AMAN provides support to controllers by automatically generating the arrival sequence. The AMAN may also provide other functionalities, such as generation of advisories for aircrafts, or metering capabilities for a runway, or support runway allocation (at airports with multiple runway configurations). At the organizational level, the introduction of the AMAN requires the introduction of a new type of controller, namely, the Sequence Manager who will monitor and modify sequences generated by AMAN, and will provide information and updates to Sector Team. At the operational level, all ATM actors (including AMAN) communicate via SWIM, a new network for the management and sharing of information. This communication would provide authenticity, integrity and availability that should be comparable with the one provided by the dedicated communication lines (e.g., phone) currently used by controllers.

3. The validated approach

This section gives an overview of an approach (Tran and Massacci, 2011) to deal with requirements evolution at design time. The ultimate objective of the approach is to help decision makers to select an optimal design solution so that the deployed system could be operational without (or with less) modification, while still

Table 1
Technical documents of the scenario.

Name	Document title	Description
SC-D1.1[a]	Description of the scenarios and their requirements	Describes in detail the requirements for the ATM scenario. Changes concerning to the introduction of AMAN are also elaborated.
SWIM-D1.2.1[b]	Information Content and Service Requirements	Provides an overview of SWIM, ATM information content requirements and services requirements.
SWIM-D1.6.1[b]	SWIM Prototype Requirements for Iteration	Describes the system context that the SWIM will face and support, including a set of usecases, scenarios where SWIM integrates with other systems. Requirements for the prototype iteration are also elaborated.
SWIM-D2.3.1[b]	SWIM-SUIT information models and services	Describes existing ATM information systems, and future SESAR ATM system, as well as the role of SWIM network in the SESAR ATM architecture. Evolution of the SWIM services is also elaborated.
SWIM-TECH[c]	Segment 2 Technical Overview	Describes in detail the functional architecture of SWIM, including architecture options, design solutions, and technologies.

[a] http://www.securechange.eu/content/deliverables.
[b] http://www.swim-suit.aero/swimsuit/projdoc.php.
[c] http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/atc_comms_services/swim/documentation/media/Segment%202/SegmentTechnicalOverview_10709.pdf.