The impact of COTS software on the public procurement of mission-critical systems: the case of the Spanish ATC system

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Abstract

This research proposal addresses the influence of COTSS on the procurement model of safety-critical information and communication systems in public organizations or state-owned companies and falls into the field of Information Technologies, Services and Systems (ITSS). COTSS can be defined as a commercially available or open source piece of software that other software projects can reuse and integrate into their own products. The theoretical benefits of COTSS are basically the capability to speed up the product development process and reduce overhead costs.

This piece of research uses an innovative approach whereby the use of COTSS for Safety-Critical Applications (SCA) and the public procurement of ITSS are brought together through the case study of a major state-owned Air Navigation Services Provider (ANSP) and its ATS system. ATS systems play an important role on the economic development of a country. Hence the relevance of the procurement processes and strategies that should ensure that only the most suitable providers and systems are selected. On the other hand, state-owned or governmental ANSPs raise special interest insofar as public money is directly or indirectly at stake.

A comprehensive review of the state of the art confirmed that no piece of research tackles the impact of COTSS on the public provision of ATS systems to date.

In order to fill this research gap, a case study is proposed. The case study focuses on Spanish Automated Air Traffic Control System (SACTA) as a safety-critical system owned and managed by a state-owned ANSP and exposed to the emergence of COTSS in the sector. The Spanish company Indra has been continuously implementing and upgrading SACTA for the Spanish Air Navigation Services Provider (AENA) since 1984. This system is in operation at every single Spanish ATS facility. Nevertheless, the liberalization of ATS and Communications, Navigation and Surveillance (CNS) services in Spain has already paved the way for future scenarios in which new certified ANSPs might decide to replace SACTA with different ATS systems following a Commercial Off-The-Shelf (COTS) strategy in order to reduce costs.

The research is conceived as an descriptive-exploratory study where interviews are used to collect data that will subsequently be analyzed by using quantitative methods. Further details on the methodology as well as a schedule of the research activities are included in this proposal.

Keywords— safety-critical, mission-critical, information systems, COTS, public procurement, Air Navigation Services Provider, SACTA, AENA

List of acronyms

ACC Area Control Center

AENA Spanish Air Navigation Services Provider

ANSP Air Navigation Services Provider

ATC Air Traffic Control

ATCO Air Traffic Controller

ATM Air Traffic Management

ATS Air Traffic Services

CANSO Civil Air Navigation Services Organisation

CAQDAS Computer-Assisted Qualitative Data Analysis Software

CNS Communications, Navigation and Surveillance

COTS Commercial Off-The-Shelf

COTSS Commercial Off-The-Shelf Software

CWP Controller Working Position

DGAC Spanish Civil Aviation Administration

ESARR EUROCONTROL Safety Regulatory Requirement

EUROCONTROL European Organization for the Safety of Air Navigation

GSN Goal Structuring Notation

ICAO International Civil Aviation Organization

ICSS Information and Communication Systems and Services

ICT Information and Communication Technology

IEC International Electrotechnical Commission

ISO International Organization for Standardization

ITSS Information Technologies, Services and Systems

NASA National Aeronautics and Space Administration

NATS National Air Traffic Services

RSS Radar Site Services

SACTA Spanish Automated Air Traffic Control System

SES Single European Sky

SCA Safety-Critical Applications

TWR Control Tower

1

Introduction and justification

The present research proposal comes up from the author's interest in analyzing the issues that arise in the public procurement of safety-critical software, particularly in the ATS domain, a very specific field in which no extensive research has yet been carried out to date. Introducing a procurement-driven approach in the research of advanced safety-critical systems for ATS applications may help public ANSPs improve decision-making processes to select the provider and the system that best fits its requirements.

COTSS has proved to be one of the principal factors influencing decision making when it comes to procuring new Information and Communication Technology (ICT) systems or new features to upgrade existing ones as concluded in a number of studies found in the literature. ATS systems are special mission-critical ICT systems which are designed to support the provision of ATS operating in highly demanding safety-critical environments. The economic development of a country depends to a great extent on the performance of its Air Traffic Management (ATM) system nowadays (19). ATS systems constitute an essential support element of the ATM system, along with the CNS systems, and hence the importance of acquiring proper ATS systems and optimizing its performance throughout its life cycle so as to establish a solid basis for the services they support: ATS in a direct way and ATM indirectly. Figure 1.1 places ATS systems among a hierarchy of global concepts and terms defined by the ICAO.

Over the last few years, new regulatory scenarios and a recession economy have been putting state-owned ANSPs under pressure to reduce costs in order to confront new

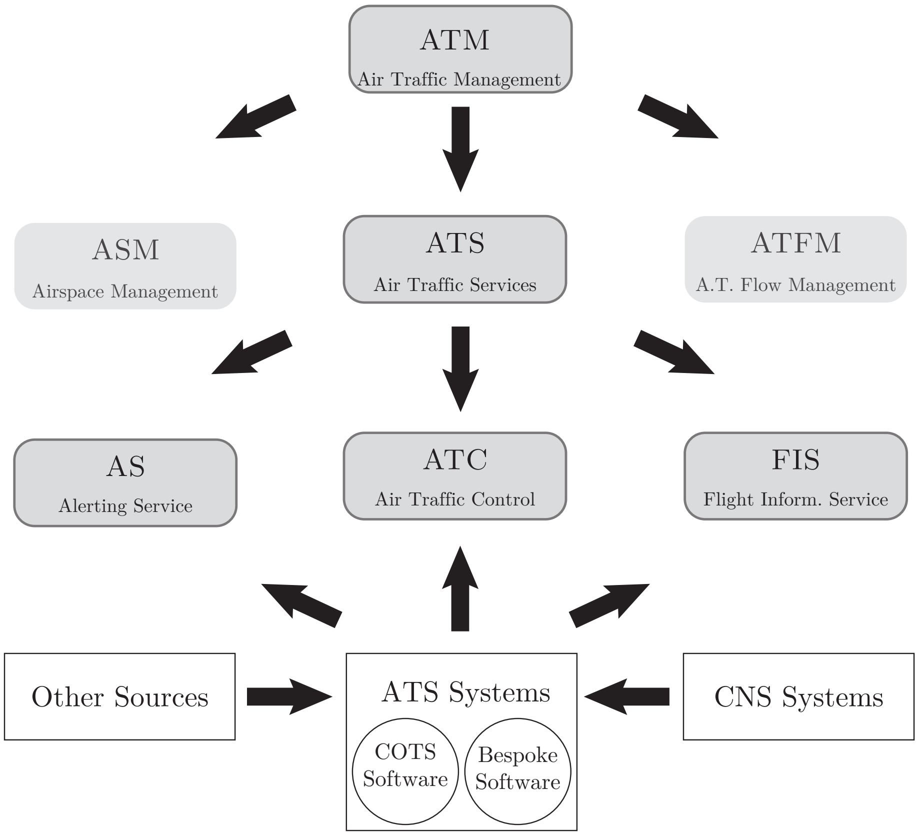

Figure 1.1: Relation between ATS systems and the hierarchical structure of services defined by ICAO

models of competition while maintaining or even improving safety levels at the same time. In Europe, one of the main aims of the Single European Sky (SES) initiative, promoted by the European Commission, is to prevent exiting public ATS monopolies by facilitating the setting-up of new free market models. The SES initiative has led to the liberalization of ATS in Spain, and so to the apparition of new privately-owned ATS and/or CNS providers which represent tough competition to AENA, the Spanish state-owned ANSP or ATS provider (17).

Nevertheless, no piece of research among those reviewed by the author of this research proposal seems to focus straight on the impact of COTSS on the provision of ATS systems. ATS comprises Air Traffic Control (ATC), flight information and alerting services. The prime goal of ATS is to prevent collisions between aircraft through ATC, whether taxiing on ground, taking off, cruising or landing (18). ATS systems are in place to enable a safer, sustainable and more efficient operation of air transit by integrating relevant information from a variety of sources such as flight plans, CNS systems, meteorological offices or aeronautical information providers. In addition, modern cutting-edge ATS systems automate routine functions, thus contributing to a reduction of the operator workload. The automation of routine functions allows the operator to dedicate more cognitive resources on the resolution of complex and unexpected situations when required.

It would not be absurd to think that state-owned ANSPs are looking at COTSS today as a means to reduce costs and gain leverage within a scenario of free competition. However, how COTSS is being affecting the procurement of ATS systems by state-owned ANSPs has not been studied in depth yet. The present research proposal aims to contribute filling this research gap and explore prospective research lines that could help setting a conceptual framework on the procurement of ATS systems by state-owned ANSPs in the future. More specifically, the objective of the research here proposed is to comprehensively analyze in a real setting how and to which extent COTSS influences the selection of suitable ATS systems and providers in one of the mayor ANSPs in Europe.

After a first review of the relevant literature to the topic, the concrete objectives of the research as well as the methodology to be followed are described in this document. Lastly, a preliminary schedule of the proposed research is included.

2

Proposal

2.1 State of the art

2.1.1 Brief history on ATS systems in Spain

ATS systems have historically been based on air surveillance radars capable of determining the position of the aircraft under control. The ICT systems that were in place to support ATC were cumbersome and large computers a few decades ago. Such devices received and processed data from radar before providing Air Traffic Controllers (ATCOs) with the position of the aircraft on a radar display.

Nowadays, the global objectives of the ATM system are much more challenging and demanding mainly due to a sustained growth in the air transport industry over time. ATC technology had to evolved in order to being able to safely and efficiently manage more and more congested airspaces. The processing, integration and distribution of flight plan data was one of the key enablers of the ATM development. Flight plans contain detailed information on the future flight intentions as well as further relevant data. The flight plan information for all the traffics planned to flight within a delimited volume of airspace during certain time frame constitute an essential element to fulfill the requirements of modern ATM.

The Spanish ATC centers were initially equipped with different autonomous ATS systems until the early 1980s. It was then when the Spanish Civil Aviation Administration (DGAC) awarded the contract to develop SACTA to the Spanish companies

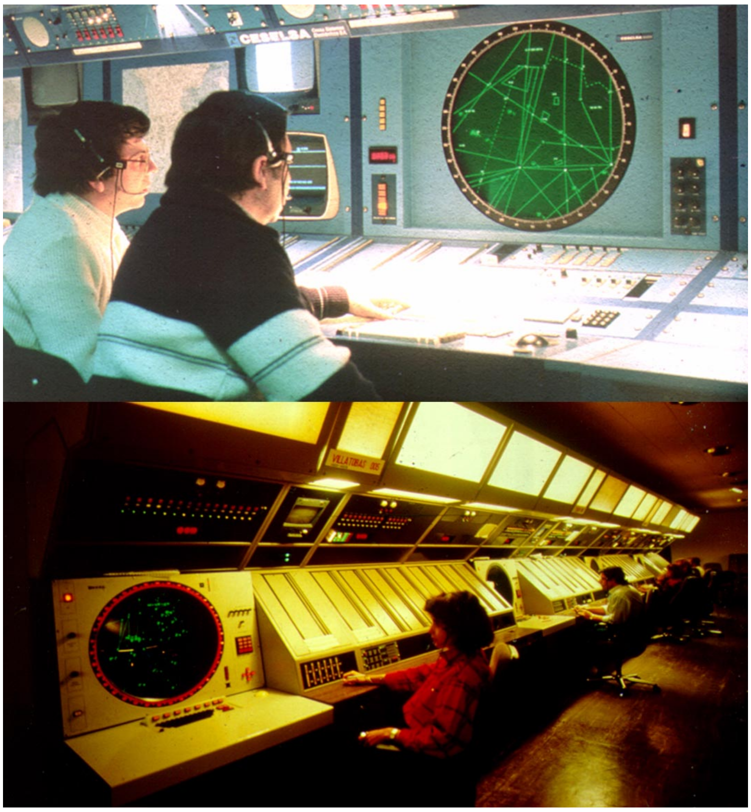

Figure 2.1: Pre-SACTA radar consoles in Spain (AENA)

Ceselsa and Inisel, which previously gathered important know-how developing cutting-edge air defense systems together with the North American Hughes Corporation and developed some of the autonomous ATS systems that were in operation at several Spanish ATC centers at the time. Cecelsa and Inisel were the main companies from which the current Indra stemmed later on in 1992. The SACTA project was conceived after tough negotiations in a time in which the Spanish industry had high technological potential and remarkable public investments were available to increase the safety and efficiency of the national ATM system. Another spanish company that was involved in the development of SACTA is Isdefe, a engineering consulting firm created by the Spanish government through the Ministry of Defence with the initial mission of controlling and validating the development of the contracts on a continuous basis. The development of the pioneering version of SACTA comes to an end in the late 1980s and eventually came into operation at the Palma de Mallorca ACC in 1990. The com-

Figure 2.2: ACC Madrid with the current CWPs (AENA)

missioning of SACTA in Madrid, Sevilla, Barcelona and Canarias followed in 1991, 1992, 1993 and 1994 respectively. The result was a fully integrated network of ATC automation systems for all ACCs and Control Towers (TWRs) in Spanish airspace enabling seamless interoperability among them. This event is considered one of the most important and successful milestones in the history of the spanish high-tech industry, and a clear example of how large public procurement projects can be used to boost the national industry without any dependency on third parties.

AENA was created in 1991 due to the need to separate the ANSP and the national civil aviation regulatory body. Indra has been continuously implementing and upgrading SACTA for AENA (previously for the DGAC) since 1984. This system has undergone extensive evolution and enhancement of its features in the last few years. In 1999, SACTA version III was commissioned and remains today in operation. The SACTA model has been considered as one of the most advanced in the world to date when it comes to the provision of ATS in high-density areas by means of highly-automated ATS systems. A key factor contributing to the success of this bespoke system developed from-scratch by Spanish engineers is certainly the fact that SACTA is in operation at every single Spanish ATS facility, thereby avoiding the complex technical and managerial problems that arise when dealing with different ATS systems from different providers. Nevertheless, the liberalization of ATS in Spain has already paved the way for future scenarios in which new approved ANSPs decide to replace SACTA with another ATS system - perhaps with a COTS-based system in order to minimize costs - (17).

2.1.2 Procurement of COTS software for general-domain applications

The definition of a COTS product is something on which most authors researching the topic seldom fully agree (6, 43). Nevertheless, Torchiano and Morisio (43) provide an empirical-based definition obtained out of a number of structured interviews with systems integrators from small and medium-sized enterprises:

"A COTS product is a commercially available or open source piece of software that other software projects can reuse and integrate into their own products."

According to (43), the main characteristics for a COTS product to be considered as such are:

- It is not exclusively produced for the project.
- It can be closed source or open source[1].
- It is not a commodity[2].
- It is integrated into the final delivered system but it is not a development tool.
- It is not controllable, in terms of provided features and their evolution.

A complementary definition of COTS products can be found in (6), where products which do not stick to the following requirements are not considered pure COTS products:

[1]In this case open source is usually treated as if it were closed

[2]COTS products are not provided with the development environment or the operative system

- Sold, leased, or licensed to the general public.
- Offered by a vendor trying to profit from it.
- Supported and evolved by the vendor, who retains the intellectual property rights.
- Available in multiple, identical copies.
- Used without modification of the internals.

The COTS products, as much hardware as software, have been widely studied from different points of view given the supposed benefits they offer to speed up the product development process and reduce overhead costs. Some studies focus on proving or refuting the advantages of COTS or COTS-based solutions over bespoke ones (also known as custom or tailor made) within particular environments or application (4, 11, 31). According to those studies, COTS-based solutions do not always reduce the investment of time and effort required to successfully complete the project, rather, they radically change the way the project has to be handled, putting more focus on the integration and suitability of every component. COTS-based projects introduce new key activities or processes such as product evaluations, product familiarization, and vendor interaction into the development cycle.

Others have developed new methods and frameworks to enable an earlier detection of interoperability conflicts between COTS products (2, 3), whereas many aim to explain the issues that arise with the integration of COTS products with other legacy systems and propose possible solutions or good practices (8, 12, 25, 26, 46, 49). Such issues are summarized and listed below:

- Architectural mismatches.
- Dependency on the COTS vendor.
- Product line stability.
- Black-box approach hinders the resolution of mismatches.
- Cost and time overrun due to inappropriate integration strategies.

Different methodologies and techniques to streamline the assessment and selection of optimal COTSS and providers have been devised in (6, 10, 20, 30, 34, 35, 44). Topics such as quality (5) and cost (29) models, contracting and procurement (28) or the maintenance phase (37) have also been exclusively tackled in the COTSS literature to a lesser extent.

Important to note is the fact that not many publications in the field have drawn on empirical data so far (2, 3, 20, 25, 28, 30, 31, 34, 35, 37, 42, 43).

Table 2.1 summarizes all the references found that somehow deal with COTSS in the general domain. Moreover, an attempt has been done to classify the references according to the main topics addressed in the text.

References	**Topics addressed**										**Based on empirical data?**
	Definition	Perspective of small enterprises	COTS vs Bespoke	Interoperability conflict detection	Integration issues	Assessment and selection	Quality models	Cost models	Procurement and Contracting	Maintenance	
Bhuta and Boehm (2)				X							X
Bhuta and Boehm (3)				X							X
Blanchette (4)			X								
Carvallo et al. (5)							X				
Comella-Dorda et al. (6)	X					X					
Couts and Gerdes (8)					X						
Dean (10)						X					
Doblar et al. (11)			X								
Egyed et al. (12)					X						
Keil and Tiwana (20)						X					X
Land and Crnkovic (25)					X						X
Lauesen (26)					X						
Mansoor et al. (28)										X	X
Minkiewicz (29)								X			
Mohamed et al. (30)						X					X
Morisio et al. (31)			X								X
Morris (32)											
Ochs et al. (34)						X					X
Patricia et al. (35)						X					X
Reifer et al. (37)									X		X
Rosa et al. (38)											
Talbert (41)											
Tarawneh et al. (42)											X
Torchiano and Morisio (43)	X	X									X
Wanyama and Far (44)						X					
Wile et al. (46)					X						
Yang et al. (49)					X						
Overall	2	1	3	2	6	7	1	1	1	1	12

Table 2.1: Topics addressed in the general-domain COTSS literature reviewed

2.1.3 Procurement of COTS software for safety-critical applications

Safety-critical systems are those systems whose failure could result in loss of life, significant property damage, or damage to the environment (23). Such systems pose a special challenge for the organizations taking responsibility for its definition, maintenance and upgrading due to the need to deal with strict safety requirements which include the development of a safety case, the safety assurance of the final system and its certification by a competent authority.

Regardless of the difficulties inherent to safety-critical systems, COTSS is also becoming commonplace in this particular sector in order to reduce costs and development time. Nevertheless, the main problem when putting together complex safety-critical systems and COTSS is still the lack of systematic approach in supporting the selection and evaluation, integration and maintenance of COTSS or COTSS-based products (51). The need to establish specific guidelines to ensure the suitability of COTS components for SCA was already identified in (24) along with the shortage of empirical research in the field carried out to date.

Two main problems with the integration of COTS components into large safety-critical system developments were identified in (9): potential of systematic errors arising from 'badly fitted' COTS components and meeting the obligations of the safety case. In order to reduce the impact of such problems, Dawkins and Kelly (9) advocated for the use of the Goal Structuring Notation (GSN) (48) as a means of improving the definition of safety arguments concerning the components involved.

A number of strategies and methodologies have been proposed to minimize the risk of component mismatching in safety-critical environments. Safety case contracts are proposed in (50) to capture the safety aspects of the functional relationship between a safety application and a potential COTS component, which in turns facilitates COTS component evaluation and selection through investigating the matching between application requirements and COTS component features (51).

Special predictive techniques used for financial credit scoring have been proposed by Morris (32) to be utilized in the COTS domain. By developing functional and environmental software measures as well as trade-off analyses, this technique addresses the acceptability of the final product. Nevertheless, the main drawback of this strategy is its reliance on a solid initial data set.

The use of COTSS within safety-critical domains is, though, clearly supported by Wetherholt (45), who states, out of her research at National Aeronautics and Space Administration (NASA), that not considering COTS for SCA would be a mistake. On the other hand, in (45) it is also concluded that some modifications in the software assurance and safety approaches need to be done in order to ensure the successful assurance of COTSS products.

A summary of the references analyzed in this section can be found in Table 2.2.

References	**Topics addressed**				**Based on empirical data?**
	Suitability of COTS for SCA	Production of safety cases	Evaluation and acceptance of COTS in SCA	Recommendations for COTS in SCA	
Dawkins and Kelly (9)				X	
Knight (23)	X				
Kohl (24)				X	
Morris (32)			X		
Wetherholt (45)				X	
Wilson et al. (48)		X			X
Ye and Kelly (50)			X		
Ye and Kelly (51)			X		
Overall	2	1	3	3	1

Table 2.2: Topics covered in the literature reviewed on COTS products for SCA

Procurement of COTS software in aviation

Air transport is one of the most important pillars of the social and economic progress. An efficient and safe ATM system would be nowadays inconceivable without the contribution of modern ICT systems on the ground as well as in the air. However, the amount of research tackling the life cycle of ICT systems within such a demanding safety-critical domain seems to be still very limited, specially when it comes to COTS.

Alford (1) advocates that COTS is a possible way for aviation components, even though it requires careful planning and forethought. The benefits that COTS components bring might be overshadowed by the modifications and re-certifications requirements inherent to this safety-critical environment.

The results of the investigations made by United Kingdom's National Air Traffic Services (NATS) on the impact of using COTS components on the operation and support costs for Radar Site Services (RSS) is presented in (47). This study concludes that NATS was able to find a suitable RSS upgrade strategy based on COTS components which was proved to be more economical than those based on bespoke systems while maintaining required safety, reliability and availability levels.

In regard to COTSS, most of the research focuses on the certification process, which is indeed the distinguishing phase in comparison with general-domain COTSS. For instance, Ferrell and Ferrell (16) proposed the use of service history as certification credit for airborne COTSS and identified a lack of guidance material associated with this issue as well as a shortage of techniques to guarantee the consistency of such data.

The use of operating systems in ATS applications was addressed in (36), where the relevance of those systems for the safety case of the whole component is recognized and it is shown how to obtain requirements supporting the selection of the operative system for ATS applications through a convincing safety case.

Kesseler (21) made a series of recommendations to promote the inclusion of certification evidences from other safety-critical fields in the current aviation software safety standards, thereby increasing the flexibility of the certification schemes and enhancing the certificability of integrated systems containing COTSS. A few years later, Kesseler also conducted a case study in the civil aviation domain (22). The expected benefits of COTSS components that constituted one of the initial hypothesis could not be corroborated. Such benefits are:

- Reduced time-to-market.
- Increased responsiveness to evolving requirements.
- Improved affordability.

Kesseler (22) also evidenced the importance of the management style, which may dramatically influence the overcome of the project even to a greater extent than the software development and integration process themselves. Hence, further research in this line is advised.

The reviewed references concerning COTS-based products in aviation are listed in Table 2.3.

References	Topics addressed					Based on empirical data?
	Suitability of COTS in civil aviation	Certification of aviation COTSS	Reduction of maintenance costs in ATS through COTS	Procurement of COTS in aviation	COTS Operative Systems in ATS	
Alford (1)				X		
Ferrell et al. (16)		X				X
Kesseler (21)		X				X
Kesseler (22)	X					X
Pierce et al. (36)					X	X
Willard (47)			X			X
Overall	1	2	1	1	1	5

Table 2.3: Topics covered in the literature reviewed on COTS products in the aviation domain

The industry standards and certification documents behind the integration of COTSS in aviation deserve a special mention. Every single system in aircraft as well as on-ground ATM systems has to be certified, and thus, evidences need to be provided to demonstrate that such systems will maintain the safety levels according to the applicable standards or regulations.

A relevant sample of standards in the aviation field were analyzed by Kesseler (21) with regard to how their requirements tackle COTSS. The outcome proved that there is room for COTSS in aviation SCA. However, the strictness of the certification process varies between standards. For example, DO-178C/ED-12C (40) only takes into account COTS-based systems whose development strictly meets all the requirements of the standard. Unlike DO-178C/ED-12C (40), DO-278A/ED-109A (39) allows for the certification of COTS-based systems that integrate pre-existing COTSS. In any case it must be demonstrated that unused features of pre-existing COTSS will not affect the system in any way. Service experience is also introduced by DO-278A/ED-109A (39) so that the need to meticulously stick to a given development process, such as that in DO-178C/ED-12C (40), can be waived.

It is important to note that in ATS there are other prescriptive standards, such as those from International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC), which ATM-system providers or ANSPs could decide to follow. In that case, the standard ED-153 (13) aims to provide links between its low-level requirements and those within the different standards available, thereby bringing some unity to this complex compliance scheme. ED-153 (13) was developed in 2009 with the objective to provide acceptable means of compliance with the European Commission Regulation (EC) No 482/2008 establishing a software safety assurance system to be implemented by ANSPs. This regulation constitutes the transposition into European law of one of the EUROCONTROL Safety Regulatory Requirements (ESARRs) approved by the European Organization for the Safety of Air Navigation (EUROCONTROL) Permanent Commission, namely the ESARR-6 entitled “Software in ATM Systems” (14).

The document “Recommendations for ANS Software” (15) provides support on how to meet the requirements of the ESARR-6 for developmental and non-developmental ATM software (e.g. COTSS). As far as COTSS is concerned, (15) recognizes the trouble of producing assurances for COTSS in comparison with developmental or bespoke software and promotes the adoption of additional considerations in the planning, acquisition and verification phases to augment the assurance data. Furthermore, (15) also recommends the use of risk mitigation techniques to reduce the reliance of the final ATM system on the COTSS. In chapter 7 of (15) “Additional ANS Software Lifecycle Objectives”, particular guidelines for software life cycle processes involving COTSS are given and the usefulness of services experience data for assurance credit is predicated based upon two main factors: sufficiency and relevance.

2.1.4 Conclusions

Possible benefits of COTSS

- Faster development process
- Lower overall costs
- Better responsiveness to evolving requirements

Potential downsides of COTSS

- Architectural mismatches among components
- High dependency on the provider and product line
- Lack of flexibility to match user requirements
- Inappropriate selection and integration strategies
- Difficulties to meet strict safety criteria for certification

Specific to safety-critical applications

Figure 2.3: Main benefits and downsides of COTSS for general-domain and safety-critical applications

In light of the literature review carried out it can be stated that the research on aviation COTSS is still very limited in comparison with that done in some other SCA or general domains. Most of the research addressing aviation COTSS makes no distinction between the different fields of the aviation (e.g. ATS, airborne systems, airport systems, etc) or basically focuses on airborne systems (1, 16, 21, 22). The rest of the reviewed scientific literature tackles very specific ATS applications such as RSS (47) or the integration of operative systems (36).

No piece of research seems to focus straight on the impact of COTSS on the provision of ATS systems to date. This research gap is worth filling given the impact that ATS systems may have on the economic development of a country as explained in Section 1.

To conclude this section and based on the reviewed literature, Figure 2.3 summarizes the main benefits and downsides that come along with the involvement of COTSS in general-domain and safety-critical applications where aviation and ATS are included.

2.2 Case Selection

Bringing COTSS into play at the time the SACTA project was being devised would have been unrealistic given the technological and political circumstances of the moment. Today, those circumstances are totally different and drawing on COTSS as a means of upgrading certain functionalities of SACTA sounds more plausible now; mostly if the ANSP (AENA) struggles to reduce the high costs that the system provider (Indra) may impose to carry on with the tailored evolution of the software. This hypothesis may be used as a starting point to undertake research focusing on how COTSS impacts on the provision-procurement models of advanced ATS. However, some notes on the selected methodology will explain further down why no hypothesis is to be tested through the proposed piece of research.

Cases in which state-owned or governmental ANSPs are involved would be of particular relevance due to the strict public procurement policies this kind of ANSPs have to stick to and the lack the flexibility of the private procurement, which complicates even more the processes. Furthermore, state-owned or governmental ANSPs raise special interest insofar as public money is directly or indirectly at stake. The procurement of high-tech ATS systems by state-owned ANSPs takes usually place through large public procurement tenders as it occurs with the tendering of projects for the development of large infrastructures for the state.

Some of the criteria that justify the study of a particular case of instance according to Oates (33) are generalization, opportunity, convenience and novelty. The relevance of a case study to dig into the impact of COTSS on the procurement of ATS systems in AENA is underpinned by such criteria:

- **Generalization**: Despite the complexity of the context and the peculiarities of the homogeneous network-centric approach of SACTA in Spain, the insights and outcomes of the proposed research may be of great interest for other governmental or state-owned ANSPs and ATS systems providers. They could take advantage of a new conceptual framework in order to enhance their relationships and procurement/provision processes, thereby minimizing the likelihood of future technical and organizational problems that might jeopardize the safe and efficient provision of ATS. DFS (Germany), SENEAM (Mexico) or AAI (India) are some examples of governmental and state-owned ANSPs managing similar volumes of air traffic as AENA across the world (source: Civil Air Navigation Services Organisation (CANSO)).

- **Opportunity**: As far as the dilemma bespoke-COTS is concerned, this seems to be the right time to initiate the research according to some representatives of AENA directly involved in the management of SACTA. In their view, the issues with COTSS have multiplied in the last few years and apparently there is a lack of well-grounded methodology to support decision makers in that regard.

- **Convenience**: Key actors in the evolution of SACTA in AENA have already conveyed their interest to analyze the impact of COTSS on their daily activities with SACTA from a scientific point of view, and hence they have showed themselves willing to provide information to that end.

- **Novelty**: As already exposed, the model of SACTA in AENA possess certain peculiarities that make it unique. Just to mention some, the very conception and development process and its circumstances as well as the fully integrated network-centric approach across the country are good examples. Therefore this represents an atypical case if we compare it with many similar ANSPs in the world, which use different ATS systems provided by different companies within the airspace of responsibility.

2.3 Objectives and research questions

The objective of the research proposed herein is twofold and can be outlined as follows:

1. To comprehensively analyze and thoroughly describe the case of AENA and SACTA from the point of view of how COTSS has influenced the procurement model and other strategic processes concerning the management of ATS systems in Spain.
2. To propose a conceptual framework on the procurement of ATS systems by governmental and state-owned ANSPs based on the findings obtained through the development of the first objective.

   The research question, whose answer would fulfill the objectives above, can be formulated in the following way:
   How is COTSS influencing the current and future procurement model of SACTA, the Spanish ATS system?

It is expected that questions like the following need to be answered in order to fulfill the first objective of the research:

- Has AENA ever implemented or considered the integration of COTSS from a provider other than Indra so far?
- Which criteria were used by AENA to justify considering or not considering COTSS from a different provider with the purpose of keeping evolving SACTA?
- What consequences or outcomes have such decisions brought about so far?
- Has the provider Indra ever integrated or considered using COTSS in SACTA?
- Which criteria were used by Indra to justify considering or not considering COTSS for SACTA?
- What consequences or outcomes have such decisions brought about so far?

- Has AENA ever considered resorting to a COTS or COTS-based ATS system?
- What are the sociopolitical, technical and economic determinants involved in the response given by AENA to similar approaches or proposals?

2.4 Research Plan

2.4.1 Methodology

Concerning the methodological base of choice to support the research, case studies are well defined and categorized by Yin (52, 53) and Oates (33) following similar lines of thought. We believe that the specific type of in-depth case study which better fits the characteristics of this initial proposal is the **contemporary descriptive-exploratory**. Descriptive because one of the main goals of the research is to thoroughly detail as much as possible about the chosen instance putting focus on the context. The exploratory nature of the case study is accounted for by the need to iteratively refine or redirect the objectives of the research according to the last findings, and in addition, the wish to come across relevant research questions or hypotheses to be used in future studies. With regard to the time approach, it seems that the majority of relevant events to the case are happening now, have recently happen or are about to happen. A contemporary or short-term study is therefore the best option. However, the contribution of some aspects of a historical study is foreseen since they may help us better understand contemporary events.

It is important to point out that to follow a case-study approach through qualitative methods does not necessarily implies that a hypothesis is to be tested or proved. Hypothesis may rather emerge once the research has been completed from the very insights and findings. Clear and concise research objectives are however defined in Section 2.3, also in the the form of a research question.

The usage of the Grounded Theory (7) may also come in handy insofar as it provides a procedural and methodological apparatus through which an initial inductive analysis on the case could be performed. This inductive analysis has the aim of revealing the interest aspects of the case through its very analysis; to put it in other words, it enables that new relevant aspects to the study can come up during the research, thus modifying to a certain extent the focus and the objectives of this preliminary proposal.

Nevertheless, it is important to note that some principles of the Ground Theory would not be applied to this case. For instance, the research is not devised as to start without preconception about the matter at all. Instead, some initial ideas about the case have already been identified and exposed. Therefore, it can be asserted that the role of the Ground Theory that is being proposed here is merely as a source of some methodological tools that we believe will contribute to strengthen the rigor and validity of the research outcomes.

The techniques used to collect data are of utmost importance in order to successfully undertake this piece of inductive research following a qualitative approach. The principal techniques to be used are listed below:

- Interviews (mainly addressed to those roles from the provider, customer and final users involved in the management of issues derived from the use of COTSS such as Engineering, Software Assurance, Safety, Quality Assurance, Verification, Engineering-Operations Liaison or Maintenance.)
- Analysis of internal documents to the permitted extent (e.g. meetings minutes, technical reports, strategic lines, contracts, agreements, procurement tenders, business cases, etc.)

Other alternative techniques might be used though (e.g. survey questionnaires).

Eventually, another methodological aspect that has to be defined is the perspective of the research. Our intention is not to focus the perspective on one of the roles involved, but rather to carry out an objective global study of the case, which in turns requires an integral perspective approach analyzing every single key role involved. Such key roles have been identified as follows:

- Role 1 - **Customer**: Engineering personnel (AENA).
- Role 2 - **Current provider**: Indra.

- Role 3 - **Potential future providers**: Thales, Raytheon Company, Lockheed Martin, Harris Corporation, etc.
- Role 4 - **End user**: ATM personnel (AENA).

Therefore, this methodological approach will follow a sequential analysis of the key roles defining different research phases. The insights obtained at one phase will feed next phases and so the focus of the research is expected to vary depending on these new inputs.

2.4.2 Data analysis tools

In order to enable the analysis of qualitative data that will be collected by means of the techniques mentioned in 2.4.1, Computer-Assisted Qualitative Data Analysis Software (CAQDAS) is expected to be utilized.

These tools proved to be very useful when trying to establish relations between conceptual categories or codes and the content as stated in (27), increasing the versatility of the research process and enabling the gradual creation of a theoretical framework.

2.4.3 Evaluation Methodology

The Evaluation Guides proposed by Oates (33) will be used as a method to self-assess the execution of the research as well as the design itself. Such guides comprise a number of questions whose answers should determine to which extent the research findings meet the academic requirements and whether the quality of the evidences provided to support the claims made is enough or not. The questions included in the Evaluation Guides that turn out relevant for the self-assessment of this research are methodologically oriented and encompass the following aspects:

- Case Study
- Interviews
- Qualitative Analysis

2.4.4 Research schedule

Objectives	1st year											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phase 0 - Body of knowledge study	■	■	■									
Phase 1 - State of the art analysis			■	■	■	■	■	■				
Phase 2 - Research plan definition								■	■	■		
Phase 3.1 - Customer's perspective Preparation of data collection											■	■
Phase 3.2 - Customer's perspective Execution of field work												
Phase 3.3 - Customer's perspective Analysis of collected data												
Phase 4.1 - Current provider's perspective Preparation of data collection												
Phase 4.2 - Current provider's perspective Execution of field work												
Phase 4.3 - Current provider's perspective Analysis of collected data												
Phase 5.1 - Potential future provider's perspective Preparation of data collection												
Phase 5.2 - Potential future provider's perspective Execution of data collection												
Phase 5.3 - Potential future provider's perspective Analysis of collected data												
Phase 6.1 - End user's perspective Preparation of data collection												
Phase 6.2 - End user's perspective Execution of data collection												
Phase 6.3 - End user's perspective Analysis of collected data												
Phase 7 - Global data analysis and definition of theoretical framework												
Phase 8 - Thesis writing-up												

Table 2.4: Proposed research schedule during the first year of doctoral program

Objectives	2nd year											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Phase 0 - Body of knowledge study (Completed)												
Phase 1 - State of the art analysis (Completed)												
Phase 2 - Research plan definition (Completed)												
Phase 3.1 - Customer's perspective Preparation of data collection (Completed)												
Phase 3.2 - Customer's perspective Execution of field work	■	■	■									
Phase 3.3 - Customer's perspective Analysis of collected data			■	■	■	■	■					
Phase 4.1 - Current provider's perspective Preparation of data collection							■	■				
Phase 4.2 - Current provider's perspective Execution of field work									■	■	■	
Phase 4.3 - Current provider's perspective Analysis of collected data												■
Phase 5.1 - Potential future provider's perspective Preparation of data collection												
Phase 5.2 - Potential future provider's perspective Execution of data collection												
Phase 5.3 - Potential future provider's perspective Analysis of collected data												
Phase 6.1 - End user's perspective Preparation of data collection												
Phase 6.2 - End user's perspective Execution of data collection												
Phase 6.3 - End user's perspective Analysis of collected data												
Phase 7 - Global data analysis and definition of theoretical framework												
Phase 8 - Thesis writing-up							■	■	■	■	■	■

Table 2.5: Proposed research schedule during the second year of doctoral program

Objectives	3rd year											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Phase 0 - Body of knowledge study (Completed)												
Phase 1 - State of the art analysis (Completed)												
Phase 2 - Research plan definition (Completed)												
Phase 3.1 - Customer's perspective Preparation of data collection (Completed)												
Phase 3.2 - Customer's perspective Execution of field work (Completed)												
Phase 3.3 - Customer's perspective Analysis of collected data (Completed)												
Phase 4.1 - Current provider's perspective Preparation of data collection (Completed)												
Phase 4.2 - Current provider's perspective Execution of field work (Completed)												
Phase 4.3 - Current provider's perspective Analysis of collected data	■	■	■									
Phase 5.1 - Potential future provider's perspective Preparation of data collection			■	■								
Phase 5.2 - Potential future provider's perspective Execution of data collection				■	■							
Phase 5.3 - Potential future provider's perspective Analysis of collected data					■	■	■					
Phase 6.1 - End user's perspective Preparation of data collection							■					
Phase 6.2 - End user's perspective Execution of data collection								■	■			
Phase 6.3 - End user's perspective Analysis of collected data									■	■	■	
Phase 7 - Global data analysis and definition of theoretical framework							■	■	■	■	■	
Phase 8 - Thesis writing-up	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.6: Proposed research schedule during the third year of doctoral program

3

Thesis advisors and relation to the UOC

3.1 Dr. Enric Guaus

Enric Guaus is a researcher in sound and music computing at the Music Technology Group, Universitat Pompeu Fabra (UPF), and professor at the Sonology Department, at the Escola Superior de Musica de Catalunya (ESMUC). He obtained a PhD in Computer Science and Digital Communications (UPF), in 2009, with a dissertation on automatic music genre classification. His research interests cover music information retrieval and human interfaces for musical instruments. He is also a consultant professor at Universitat Oberta de Catalunya (UOC) and collaborator at different Master's programs.

3.2 Dr. Josep Maria Marco-Simó

Josep Maria Marco-Simó's R&D activities focus on the study of the processes of providing ITSS. His main research interests are practices in the selection of ITSS suppliers and management of relations with them, mainly in the public sector. He also specializes in information systems and ICT-related curricular design. Josep Maria Marco-Simó is a member of the UOC's Information and Communication Systems and Services (ICSS) R&D group.

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