A METHODOLOGY USED FOR THE DEVELOPMENT OF AN AIR TRAFFIC MANAGEMENT FUNCTIONAL SYSTEM ARCHITECTURE

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ABSTRACT

The Air Traffic Management (ATM) system provides a safe, economical, efficient, dynamic and integrated management of air traffic and airspace through the collaborative integration of humans, infrastructure (technology and facilities) and organisations. At present, it is widely accepted that the ATM system is one of the leading complex socio-technical systems in terms safety performance. To maintain this reputation, safety management of the ATM system needs to be able to cope with not only rising travel demand, but also the increased automation, the tighter coupling between its component elements and greater complexity of the ATM system itself. As a way of ensuring this, in Europe the European Union Regulation 1035/2011 requires the Air Navigation Service Providers (ANSPs) responsible for the provision of ATM, to describe and model their systems by accounting for the functional interactions between the equipment, procedures and human resources of the ATM system. However, despite the number of available models of the ATM system, none of them meets this requirement. Typically the existing models focus on the technical functions and describe the system usage via operational scenarios. Therefore this paper proposes a novel methodology used for the development of a functional system architecture − Model of ATM Reality In Action (MARIA) − with the aim to provide a sound base for system analysis, including safety, namely by describing the whole system and the interdependencies between its functions. By overcoming the limitations of the existing models MARIA has the potential to improve understanding of the ATM services safety, system resilience and meet the requirements of the Regulation 1035/2011. Lastly, the methodology applied in the ATM domain presented in this paper is equally transferable to systemic modelling of other complex socio-technical systems.

Keywords: ATM, Safety, Regulation 1035/2011, SMS, functional model, ANSP, complex socio-technical systems

I. INTRODUCTION

The Air Traffic Management (ATM) system provides dynamic and integrated management services of air traffic and airspace through a collaboration of humans, information and technology (ICAO, 2005). To achieve sustainability and business continuity these services provided by the ATM system need to be safe, economical and efficient. While the focus of this paper is on ATM system safety, the impact of the other Key Performance Areas (KPAs) on safety needs to be recognised and assessed accordingly. This can only be achieved through a holistic approach towards ATM safety management.

In ATM and aviation in general, safety is defined as (ICAO, 2009, p. 2-1, ICAO, 2013, p. 2-2) "*the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management*". In this paper, the 'acceptable' or 'tolerable' level of risk or Target Level of Safety (TLS), refers to very generic and relative societal expectations in terms of commercial aviation safety (or ATM). The TLS corresponding to the ATM system is equal to 1.55E-08 per flight hour (EUROCONTROL, 2001a), which classifies the ATM system as ultra-safe, given the widely accepted 1E-6 threshold (Hollnagel, 2011, Dekker, 2014). Over the years, this figure has plateaued showing just how difficult it is to enhance safety in an already ultra-safe system (EASA, 2016). However, even in such systems accidents still can and do happen and these are increasingly difficult to predict. This is because ultra-safe systems are designed to encompass numerous safety barriers including (Hollnagel, 2004): physical (i.e. locks for switches on critical equipment), functional (i.e. safety nets), symbolic (i.e. visual or audio alerts and warnings), and incorporeal (i.e. Safety Management Systems (SMS)). While these barriers improve the safety of the ATM system, they also create difficulties in anticipating and detecting those complex and multi-faceted accidents that bypass all the system barriers (EUROCONTROL, 2007), e.g. as found to be the case in the notorious Überlingen Mid-air collision (BFU, 2004).

In this paper, risk is defined according to the ICAO (2013, p. xii) definition as "*the predicted probability and severity of the consequences or outcomes of a hazard*", and a hazard ICAO (2013, p. 2-24) "*as a condition or an object with the potential to cause death, injuries to personnel, damage to equipment or structures, loss of material, or reduction of the ability to perform a prescribed function*". Though the concepts of a hazard and its severity are straightforward in the estimation of risk, the same cannot be said for estimation of probability of a hazard (Leveson, 2015). The difficulty can be associated with the following (Johnson, 2003, Lundberg et al., 2009, Hollnagel, 2014, Leveson, 2015): i) the tendency to assume the "*symmetry between the past and the future*", which implies that factors that existed at the time of an accident can always be found in retrospective analysis, factors that were present in an accident in the past will be present in the future as well and the mechanisms of accident propagation do not change over time; ii) limited scientific validity of methods used for probability calculations; iii) the inability of calculations to account for "*as done*" operations of the system as opposed to "*as imagined*"; and iv) a number of biases, the main of which include confirmatory bias (tendency to confirm the pre-conceived hypotheses on occurrence causation), and bias in predicting cumulative causes (tendency to assume the proportionality between the contributing factors but that seemingly small (irrelevant) factors can bring about severe consequences (i.e. the Butterfly effect)). Consequently, as noted by Leveson (2015), in major accidents such as Chernobyl, Challenger and Überlingen (EUROCONTROL, 2010), the probability of an accident was estimated to be 1E-09 or less, and yet these accidents happened.

This brings into question the confidence placed and reliance upon these risk estimates in the day-to-day operation of the ATM system (and other ultra-safe systems alike). Recent research in safety (Leveson, 2004, Hollnagel et al., 2007, Dekker, 2012, Hollnagel, 2012, Leveson, 2012, Underwood and Waterson, 2013, Dekker, 2014) associates the stagnation of safety enhancement and the inaccuracy with risk estimation in the inability of practitioners' to grasp the complexity of the ATM system in terms of: i) its dependencies, ii) functional interaction, iii) variability (endogenous and exogenous), iv) system dynamics and the migration to a state of heightened risk over time. This approach to the modelling of a system is often referred to as a systemic approach (Hollnagel, 2004, Hollnagel et al., 2007, Underwood and Waterson, 2013).

Importance of such a systemic approach to safety management in ATM has been recognised by both the state-of-the-art and academic safety literature. Woltjer and Hollnagel (2009) and De Carvalho (2011) applied a systemic approach to safety management in retrospective analysis of aircraft accidents. Similarly, Herrera and Woltjer (2010) carried out a comparative analysis of a retrospective analysis of an aircraft accident using a complex-liner versus a systemic method. Systemic approaches have also been applied in the field of safety assurance. Fleming et al. (2013) describe an application of a systemic safety analysis of a new NextGen procedure and compares the obtained results with the more traditional safety methods whereas Woltjer et al. (2015) developed and applied a methodology capable of including Resilience Engineering principles in the methodology used for safety assessment and design of the ATM system. Leveson (2015) proposed a systemic approach to identifying leading indicators and has designed a risk management structure to generate, monitor and use the results. Yang et al. (2017) developed a methodology for modelling of system functions, formalization of functional variability and interactions, and verification of safety requirements. Upon careful consideration, it became evident that the existing literature predominantly focuses on a case-study approach that tends to demonstrate the benefits of systemic methods over the traditional methods in different types of system analysis. So far no attempt was made to develop a detailed model nor a methodology of a systemic "*as done*" ATM model.

Similarly, the European regulatory system recognises the need for a systemic approach to safety in the ATM system. In particular, the EU Regulation 1035/2011 (European Commission, 2011) requires the Air Navigation Service Providers (ANSPs) to describe and model their systems by accounting for "*the equipment, procedures and human resources of the ATM functional system, the interactions between these elements and the interactions between the constituent part under consideration and the remainder of the ATM functional system.* However, to date there is no ATM model that fulfils these requirements.

This paper proposes a hybrid methodology that integrates two well-known methods for qualitative data analysis – Template Analysis, and for functional modelling – Structured Analysis and Design Technique (SADT). Template Analysis was used to analyse the collected qualitative data that was further organised using the SADT, into the ATM functional system architecture. In addition to the methodology, the paper summarises the output of the methodology known as the Model of ATM Reality In Action (MARIA) and discusses its applications. MARIA was developed by NAV Portugal, the ANSP of Portugal, to provide a sound basis for safety analysis, namely by describing the whole system and the interdependencies between its functions in order to meet the requirements of the EU Regulation 1035/2011. In doing so, MARIA offers a systemic understanding, description and analysis of the ATM system in which safety is seen as a property of a system, rather than a property of the components that comprise the system (Hollnagel et al., 2007, Carayon et al., 2015, Flach et al., 2015, Robertson et al., 2015) which has a great potential to improve safety risk management in the ATM system. While the subject of the paper is limited to ATM system safety, the methodology can be adapted to other complex socio-technical systems and can be applied to analysis of system properties other than safety, such as capacity and punctuality.

II. BACKGROUND

Holistic system understanding and description is typically the first step in the process of modelling of any complex socio-technical system. A considerable effort has been invested into development of an ATM system model by the aviation industry, and this section reviews the major such models. Readers interested in development of a functional system architecture of the day-to-day services in complex socio-technical systems other than ATM are advised to review the literature on available system models in their respective domains.

The Integrated Risk Picture (IRP) model developed by the European Organisation for the Safety of Air Navigation (EUROCONTROL) Experimental Centre (EEC) supports both the qualitative and quantitative modelling of ATM accident risk. The IRP model's structure corresponds to five major types of accidents in which ATM was found to play an important role in either causing or preventing accidents (EUROCONTROL, 2006, Perrin et al., 2007, Perrin and Kirwan, 2009, Fowler et al., 2011): mid-air collision, runway collision, taxiway collision, Controlled Flight into Terrain (CFIT) and wake turbulence accident. Furthermore, each accident category is modelled using Fault Tree, Event Tree and Influence Model methodologies. T While the IRP model offers a very detailed and comprehensive representation of risks in which the ATM system can contribute to a specific set of aviation accidents, it has certain limitations. Firstly, it does not clearly provide a description of a functional system nor does it allow for the representation of an existing architecture, both of which are mandatory requirements for an ANSP. Secondly, due to its focus on failures, it does not support the systemic modelling of the ATM system as it fails to account for any functional interaction, variability (endogenous and exogenous) and system dynamics. Finally, due to the limited amount of data on historical incidents and accidents, the probability estimates from this model should be treated with caution, as previously discussed in the Introduction.

The IRP model has lately evolved into an Accident-Incident Model (AIM) (Fowler et al., 2011, EUROCONTROL, 2013b). While using the same methodological approach used in the development of the IRP, AIM is wider in scope. Given the same methodological approach, the limitations of IRP model are equally valid for the AIM.

The Overall ATM/CNS Target Architecture (OATA) is an architectural framework which encompasses inter-dependencies and interfaces between all automated systems (including aircraft, airlines and airports) and their interaction with the humans required for the provision and support of

ATM services (EUROCONTROL, 2001b, Felici, 2006). The architecture was modelled using a top-down approach. It describes components of the automated systems while the humans are accounted for only when analysing particular scenarios. Furthermore, the OATA represents a target architecture for 2010 of how the ATM system is "*imagined*" (Hollnagel, 2012) to operate and not necessarily how it "*did*" in that year nor how it "*does*" now.

As a decision aid tool towards the optimised and coordinated deployment of the future European ATM Concept of Operations (SESAR) (SESAR Joint Undertaking, 2007a, 2007b, 2012), the European ATM Architecture (EATMA) was developed based on the North Atlantic Treaty Organization (NATO) Architecture Framework (NAF) (NATO, 2016). The EATMA is organised into four different layers (EUROCONTROL and SESAR Joint Undertaking, 2016): Capability, Operational, Service and System to describe an "*as imagined*" future ATM system. The EATMA architecture provides a high-level functional approach to ATM, including the necessary human and technical resources needed to realise these functions and establishes the interfaces between different functions/stakeholders at each layer. However, upon a careful review by the authors it was found that EATMA does not provide a holistic view of all system functions and their dependencies across all four layers. Consequently, the lack of this harmonised view of the human and technical functions erodes integrated analysis such as the hazard identification and causal analysis.

The United States of America (USA) has developed their corresponding National Airspace System Enterprise Architecture (NASEA) Model which aims to facilitate the planning, coordination, integration and replacement of ATM systems and capabilities for both the present and the future ATM system of 2025 (FAA, 2016). The NASEA model accounts for actors, systems, operational activities, functions, data/information and was developed using an adaptation of the Department of Defence Architecture Framework (DoDAF). NASEA provides three different ATM architecture sets as a function of different timeframes: "*as-is*", "*mid-term*" and "*long-term*". The "*as-is*" architecture that describes the current ATM system does not seem to undergo frequent revision processes as the latest version dates back to 2011. Furthermore, the NASEA methodology has yet to be published to enable a detailed review and to assess the transferability of the model and how closely the "*as is*" model describes the "*as done*" ATM system.

None of the existing models supports systemic modelling nor do they meet the requirement of the EU Regulation 1035/2011 (European Commission, 2011) either by failing to provide a holistic view of the ATM system or by failing to account for system interactions (Table 1). Nevertheless, above outlined ATM model requirements and the existing models were used to inform the requirements for the development of the MARIA (see Table 1) as described in the following section.

Table 1: Characterisation of the existing ATM models in terms of systemic properties

Requirements for a systemic ATM model	
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III. Methodology

Ensuring safe operations is an aim of every Air Navigation Service Provider (ANSP) and to do this they provide services by means of a complex, adaptable and dynamic socio-technical system undergoing frequent changes. While such a system calls for a systemic approach to its modelling, none of the existing ATM models take this approach. Instead, these models focus on the modelling of the technical function in isolation from human and organisational functions, where system usage is described via operational scenarios. To account for both of these limitations and to meet the regulatory requirement contained in the EU Regulation 1035/2011 (European Commission, 2011), the Portuguese ANSP − NAV Portugal - has developed a Model of ATM Reality In Action (MARIA) to capture the "*as done*" functional top-down representation (model) system architecture of the day-to-day ANSP services. Three requirements underlie the development of MARIA to ensure its transferability and use by people without experience of modelling and or knowledge of the rules for any modelling involving diagrams: simplicity, clarity and readability (i.e. the ease with which it is understood, without unfamiliar aspects).

A. Methodological considerations

This section discuses three candidate methodologies: Business Process Modelling Notation (BPMN), Functional Resonance Analysis Method (FRAM), and Structured Analysis and Design Technique (SADT), that were considered during the development of MARIA and discusses both their advantages and limitations with respect to the aim of MARIA.

Business Process Modelling Notation (BPMN) is a methodology that ensures a standardised notation for capturing business processes (OMG, 2006). Nevertheless, in practice some characteristics of BPMN significantly increased the complexity of the modelling process. For instance, it was not possible to indicate the decision criteria in every decision box for certain cognitive processes due to their stochastic nature (i.e. decisions vary from one Air Traffic Controller (ATCO) to another and are highly dependant on the context). Furthermore, BPMN processes need to have a start and an end to every process, which is adequate when dealing with one object at a time, but not for services. The BPMN notation is also rather extensive and complex and requires dedicated training prior to its usage for both modelling and review. Due to these limitations that apply to all complex socio-technical systems (including ATM), the BPMN methodology was discarded.

The Structured Analysis and Design Technique (SADT) dates back to the 1970s (Ross and Schoman, 1977) when it was primarily developed for software engineering applications. Over time, SADT has become one of the most widely used system modelling methods applied in numerous industries including logistics, banking and aeronautics (Marca and McGowan, 2006). SADT supports the description of the functional system and the data flows between functions in the system. Functions can be described by their inputs, outputs, controls and mechanisms.

The Functional Resonance Analysis Method (FRAM) is used for engineering resilience in a system through analysis of "*as done*" everyday operations (Hollnagel, 2012). FRAM also takes a functional approach to system modelling, where a function is graphically represented using a hexagon and is described with up to six aspects: Input (I), Output (O), Precondition (P), Resource (R), Time (T) and Control (C).

It is apparent that many similarities exist in a functional description between SADT and FRAM. The definitions of Inputs and Outputs completely overlap, whereas the aspects of Control and Precondition in FRAM correspond to Control in the SADT method. Furthermore, the Resource aspect in FRAM corresponds to the Enabler aspect in SADT method, while the Time aspect in FRAM does not exist in SADT. The higher number of aspects in FRAM further increases the complexity of the functional system description and often causes semantic discussions due to subjectivity in its interpretation. Furthermore, complexity in the description and analysis of a FRAM model exponentially increases with the increase of the number of functions in the models, especially for the nesting of functions (Hollnagel and Hill, 2016). This has been evidenced at numerous FRAM workshops between 2012 and 2014 (FRAMily Meeting, 2012, 2013, 2014) and during a FRAM tutorial 2015 (Praetorius and Studic, 2015). The poor specification coupled with its inability to account for the variable weight assigned to each of the six aspects outweighs any potential benefits gained from using FRAM's higher level of granularity in the system description. And while the Time aspect of FRAM is beneficial in system analysis, since the aim of this paper is to develop a functional system architecture of day-to-day operations in the ATM system and not to carry out any analysis, the Time aspect has not been considered at this instance.

After detailed consideration of benefits and limitations of all three methods for the development of functional complex socio-technical system architecture applied in the ATM domain and in line with the aim of MARIA and its requirements, SADT was chosen as the basis for this development.

To meet the aim to model the "*as done*" operations of the ATM system, it was necessary to complement the SADT method with a qualitative data analysis method required for both the identification and structuring of the collected qualitative data and to map these with the various aspects in the SADT method. Due to the nature of qualitative data analysis, i.e. of incremental systematisation of previously existing and on-going information collected through data coding, Template Analysis (Cohen et al., 2011) was chosen. This methodology is widely used in the field of qualitative data analysis e.g. for further details see (Cassell and Symon, 2004, King et al., 2004, Cohen et al., 2011) and has previously been successfully applied by the authors in functional modelling of day-to-day ground handling services (Studic et al., 2016, Studic et al., 2017).

Template Analysis (King, 1998) starts with a list of a priori codes, known as the initial template. Next, the units of analysis (i.e. sentences, paragraphs) are compared to the codes in the initial template. If the unit of analysis can fit into the pre-defined code, it is subsequently assigned to it. Otherwise, the taxonomy is refined either by creating a new code, or by amending/deleting the existing code(s).

During the process of coding, relationships between categories are organised hierarchically. The process is iteratively repeated until the whole set of data is assigned to the corresponding codes, i.e. when the final template is created.

B. Modelling scope

The scope of MARIA, defined prior to the study, was to comprise all the ATM functions under the responsibility of the ANSP as illustrated in Figure 3. These include all the functions necessary to ensure a continuous, safe, efficient and cost-effective ATM services, by all the airspace sectors, to all the aircraft. Therefore, all of the services that are not within the responsibility of NAV Portugal (i.e. inputs and outputs originating from an aircraft or an external organisations such as the International Civil Aviation Organisation (ICAO), EUROCONTROL or other ANSPs) are out of the scope and belong to the model's exterior (Figure 3).

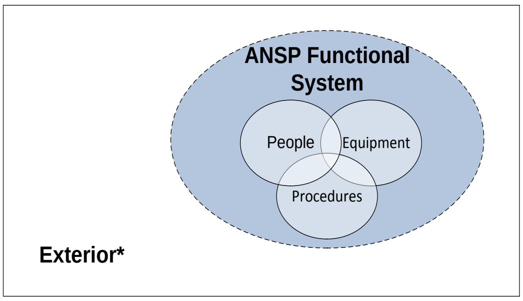


Figure 1: Model scope

Following the definition of its scope, the development of the functional system architecture was conceptualised in two phases: 1) functional model description and 2) description of the system architecture. The former aimed to depict ATM system functions (while focusing on the human functions) and their coupling, while the latter aimed to map these functions with different elements of the system architecture (while focusing on the technical functions and their enablers). For instance, in the first phase of MARIA development, a function is identified (i.e. "*communication*") whereas in the second phase the identified function is mapped with different implementations of the corresponding function in line with the system architecture (i.e. "*air-air*", "*ground-ground*" and "*air-ground*" communication). These two consecutive development phases informed the structure of data sampling and validation, as explained further.

The scope of MARIA raised further questions related to the required level of granularity used to depict the model. These are addressed in detail in the Preparatory work, Data sampling and Data analysis Sections below.

C. Preparatory work

To augment the research and development team's knowledge of everyday operations at NAV Portugal, given their engineering rather than operational background, an understanding of "*as imagined*" ANSP services was required prior to the development of an "*as done*" ATM model. In so doing, a Template Analysis methodology was deployed.

The preparatory work comprised of a combination of the expert knowledge of the two interviewers, a literature review and an exploratory interview. Based on their knowledge and experience, the team drafted a set of preliminary ATM functions. To increase completeness (further discussed in subsection F.) and establish relationships between the different functions, this set of functions was augmented with information about functions determined during the relevant ATM documentation review process, including:

- Existing ATM models including the previously summarised IRP, AIM and OATA;
- Human performance modelling (Rasmussen, 1986, Hollnagel, 1993, Weick, 1995, Cacciabue, 2004, Cook et al., 2007, Hollnagel, 2012);
- ICAO documentation on ATM (ICAO, 2001), global ATM Concept of Operations (ICAO, 2005) and safety management (ICAO, 2009);
- EUROCONTROL documentation on human factors (EUROCONTROL, 1996, 1997, 1998, 1999, 2000) and safety assessment methodology (EUROCONTROL, 2009).

Table 2 contains the definitions of nine functions that comprise the final template of the Preparatory phase of the MARIA development, whereas Figure 4 depicts the relationships (arrows representing the flows of information) between the functions (blocks). The strict SADT formalism was not used at this phase because the complexity of most of the functions and the number of data flows would make the SADT diagrams unreadable.

Table 2: Definitions of top-level functions in the MARIA model

ID Nr.	Function	Description
F-1	Airspace management	Design of airspace structures and airspace management procedures. Planning and coordination activities for airspace usage. Managing the flexible use of airspace.
F-2	Flow & capacity management	Flow and capacity management contribute to a safe, orderly and expeditious flow of air traffic by ensuring that ATC capacity is utilized to the maximum extent possible, and that the traffic volume is compatible with the capacities declared by the appropriate ATS authority.
F-3	Provide meteorological information	Ensure meteorological information from the vicinity of the airports and in the en-route airspace.
F-4	Provide aeronautical information	Ensure the flow of information necessary for the safety, regularity and efficiency of international air navigation.
F-5	Manage traffic	Prevent collisions while expediting an orderly traffic flow.
F-6	Respond to anomalies	Respond to foreseen abnormal situations, either internal (e.g. technical systems) or external (e.g. aircraft). **Note:** Only anomalies for which there already exists a plan of action are covered in the nominal functioning mode.
F-7	Alert	Notify appropriate organizations regarding aircraft in need of search and rescue aid, and assist such organizations as required.
F-8	Manage operational room	Ensure that the operational room working conditions are adequate to safely handle the current and foreseen traffic flow.
F-9	Technical support	Provides the technical infrastructure to support operational services, which includes the aggregation of technical system enablers used to provide the ANS services and support ATCOs in their daily jobs.

While the results of the preparatory work identified the top nine functions and the corresponding flows, further research was necessary to develop these initial functions and flows in more depth whilst still capturing a holistic integrated view of the "*as done*" ATM service provision. Therefore, based on the recommendation by Hollnagel et al. (2014) for capturing "*work as done*", interviews and observations of front-line operators were conducted. This further required a pilot survey to formulate interview questions and the definition of an ideal sampling methodology. An air traffic controller (ATCO) with over 20 years of operational experience was interviewed in order to formulate and test a follow-up pilot survey before administering interviews and defining an ideal survey sample. Based on the knowledge acquired during this interview, which tested draft question formulation, their organisation and structure, the team of interviewers refined and redrafted the questions that led to the final version.

The interviews were organised in two parts: one acquiring information about the human and the other about the technical functions. This was due to the different nature of the functions and implications related to access of data. Additionally, for both types of functions, probes were developed with the objective of providing information about different aspects of functions required for the SADT methodology. The final draft of interview questions and probes is presented below:

- Part I: Human functions
    - Presentation of the aim of the modelling activity.
    - Tell us what you do?
    - Tell us what you need to do the work (inputs / constraints)?
    - Tell us what you produce and to whom?
- Part II: Technical functions
    - Presentation of the aim of the modelling activity.
    - What is the function used for?
    - What are its interactions with other elements?
    - Tell us what type of equipment exits for the function?

- o Are there constraints to this function, e.g. regulation?

Finally, as an output of this pilot study, an ideal sample for the follow-up interviews was defined. The following criteria had to be met:

- a minimum of one participant per function, either working in a role that includes the execution of a particular function or the head of the unit in charge of that particular function;
- for any function that may differ in its execution from one operational site to another, include a minimum of one participant for every type of variability (i.e. Area Control Centre (ACC) vs. a Tower);
- where a participant's job can be transferred across multiple functions, e.g. the ATCO trainer has knowledge and experience in Manage traffic, Manage operational room, *Respond to anomalies* and *Alert* function in Figure 4, a single participant can be used to acquire information for all functions carried out during his day-to-day activities;
- a minimum of ten years of operational experience for each participant.

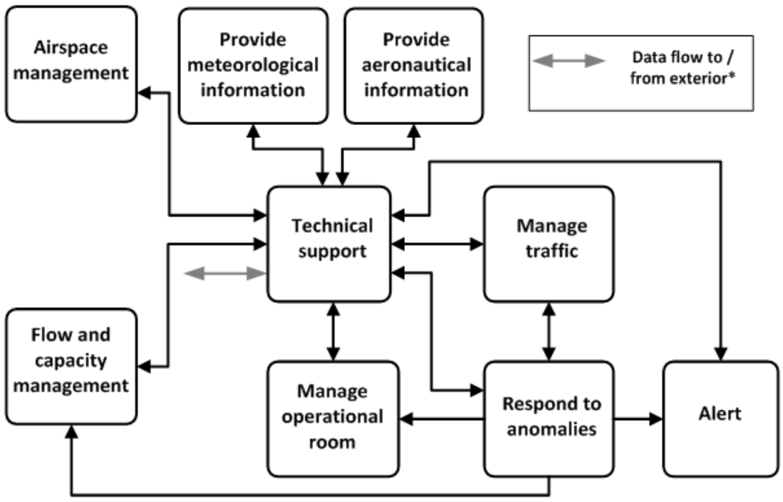


Figure 2: Relationships between top-level functions in the MARIA model

D. Data sampling

Following the establishment of a sound understanding of "*as imagined*" ATM services and the identification of the top-level ATM functions, it was necessary to compare, modify and expand on these functions such that they reflect more closely actual everyday ("*as done*") operations of the ANSP.

Following the outlined data requirements, a non-probabilistic sampling strategy, a characteristic for qualitative research (Cohen et al., 2011), was conducted whilst accounting for the requirements predefined in the Section above.

For each of the two phases of the MARIA development, the participants were selected using the requirements of an ideal sample established in the preparatory phase of the study. In the functional system description phase, 14 subjects (two female and 12 male), aged between 40 and 60 years, with operational experience ranging between 20 and 35 years were interviewed. All the participants were of an operational background (OPS). In the system architecture description phase, 21 subjects (3 female and 18 male), aged between 30 and 60 years, with operational experience ranging between 10 and 35 years were interviewed. In this phase, nine participants were of an operational background (OPS) and 12 had an engineering background (TEC). All the participants volunteered to participate in the study without any financial incentives. Each participant was guaranteed confidentiality and the ability to withdraw from the study at any time and a summary of their characteristics is given in Table 3.

Table 3: Interviewee characteristics

MARIA Development Phase	Interviewee characteristics			
	Job function	Number	Age	Experience
Functional system description	OPS	14	>40 years	>20 years
	TEC	0	N/A	N/A
System architecture	OPS	9	>40 years	>20 years

description	TEC	12	>30 years	>10 years

E. Data collection

The data collection was based on interviews with the aim of "*obtaining systematic description, prediction, or explanation*" (Cohen et al., 2011, p. 411). An interview based approach was selected as this method could support higher levels of flexibility in the questioning/probing (Tuckman, 1972) deemed necessary for the development of MARIA. Furthermore, standardised open-ended interviews (Patton, 1980) were selected in order to collect rich information about the ATM functions and their couplings. Data collection quality was accounted for by the use of a clear, simple, unambiguous and unbiased vocabulary as used by Arksey and Knight (1999) in the design phase off interview questions.

The data were collected between February 2012 and May 2013, with 28 participants interviewed (N.B. some of the interviewees appeared in both phases, and hence the total number will not match the total number in Table 3). The number of interviews was determined based on the complexity of initial set of nine functions (defined in Table 2). For certain functions, a single interview was sufficient. For other functions, as an insufficient amount of information for the model was captured during the first interview, either due to the complexity of the function as is the case of Flow and Capacity Management, or due to its extension as is the case of Provide Aeronautical Information, or due to the unclear function scope which was the case for Airspace Management, further interviews were required to mainly clarify the scope and the interfaces with other functions and with the exterior. For all the functions, MARIA has the following built in stop-rules, such that the data collection and analysis should continue until:

- all functions are explained in terms of their scope, purpose, phases (i.e. tactic, pre-tactic, strategic), actor and sub functions;
- all interfaces between functions are explained.

In total three interviewers in two teams of two performed the interviews. This approach was deemed necessary since one team member left the ANSP during the period in which the interviews were conducted. All three interviewers had engineering (e.g. computer engineering and electrical engineering) and software engineering background and had 3, 15 and 20 years of experience in the domain. Furthermore, the interviews were always conducted in an isolated environment (i.e. a room with closed doors). The time taken to conduct an interview ranged from 50 minutes to 2 hours. The interviewer made textual notes and graphical illustrations to establish the couplings between the functions in the ATM system. After each interview the team reflected upon the notes and graphical illustrations, which were sent by mail for validation by the interviewee in the following few days. The feedback from the interview was considered to be a part of the internal validation process (further discussed in the Section G. on Validation), to confirm that the team's understanding was correct and that the used terminology was adequate.

F. Data analysis

The set of preliminary ATM functions elicited during the Preparatory phase of this study was used as a basis for a further Template analysis (King, 1998), primarily based on the notes and graphical illustrations derived from the interviews. To illustrate the coding process, an exert of the data coding of notes taken during the interview on February 29, 2012 is given below, whilst Figure 5 illustrates the graphical illustrations taken during the interview. The participant was in a role of an ATCO on-job trainer and was describing activities necessary to the Respond to the anomalies function.

<u>The aim of this session was describe the Alert service capturing how an ATCO deals with anomalous situations. It was the first time this subject was addressed.</u>

<u>Question</u>: What do you do when an emergency happens?

Note: This question was part of the modelling of the activities to Manage Requests or Assist Pilots. The name was not yet defined at the time.

Follow the ASSIST check list:

"***A****cknowledge* ***-*** *Inform that the emergency is understood*

S*eparate – Keep traffic away from emergency aircraft*

S*ilence (on the frequency)*- *Restrain from talking on the frequency*

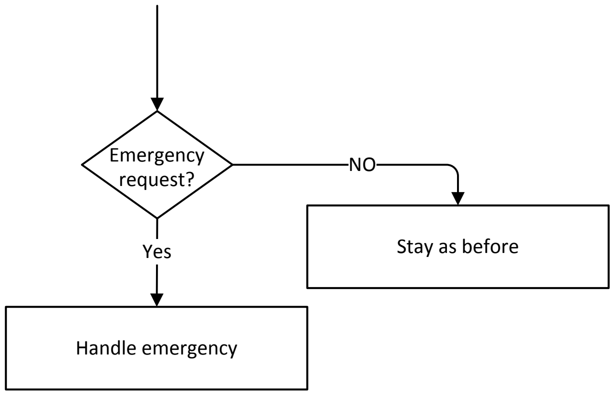
I*nform*

S*upport*

Time

Reference: Procedure – ICAO 4444 chap 15, paragraph 15.1"

Figure 3: A graphical note taken during an interview related to Respond to anomalies function



<u>Results of the analysis</u>:

In line with the aim of MARIA, the objective of this analysis was to identify and capture in a systematic way all the functions, and their couplings, relevant to managing traffic required to prevent an aircraft accident. The functional description resulted in the description of its generic steps:

Generic steps:

Handle Emergency – At the end of the Preparatory work phase, the function Handle Events along with the following sub functions: Transfer position, Handle requests, Respond to anomalies, Respond to alarms, Accept flight and Assume flight illustrated in Figure 6, were identified. Further interview data was collected from two ATCOs, one working in an airport control tower and the other in an ACC, to develop the sub-function Respond to anomalies. During this process it was found that the followed process is: if the request is an emergency, apply defined procedure using the Acknowledge, Separate, Silence (on the frequency), Inform, Support, Time (ASSIST) checklist. For instance, at an aerodrome: apply Airport emergency plan (e.g. Distress or Urgency call from flight crew, flight crew reports short of fuel, aircraft squawks emergency code, radio communication failure, Unlawful interference). If it's not an emergency, evaluate the request and the current workload. The collected information was integrated into the MARIA structure as illustrated in Figure 7.

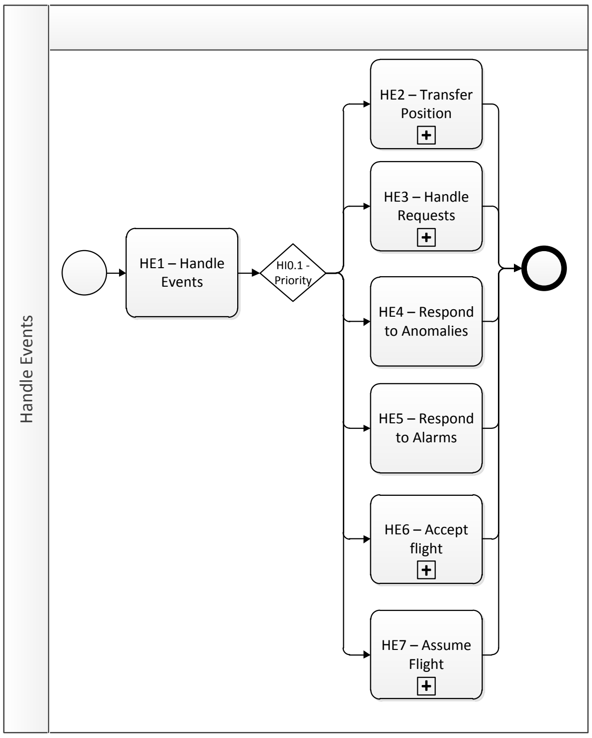


Figure 4: Structure for Respond to anomalies in Manage Traffic

Furthermore, while in the Preparatory work phase the Respond to anomalies function was identified as belonging to the Manage traffic function (under Handle events function), following the interviews it was found that this understanding was incomplete. This was because the Respond to anomalies function applied not only to the anomalies reported by the aircraft but also to anomalies detected by the ATCO (e.g. stray aircraft) and to anomalies reported by the technical system or the supervisor (e.g. system failures). Anomalies that were unforeseen and contained/mitigated by a corresponding procedure are not captured in MARIA. To reflect this, the function Respond to anomalies was redefined as follows: "*Analyse problem and respond according to situation and applicable procedures*".

Figure 7 illustrates the function "*Respond to anomalies*" within the wider context of the final MARIA. It can be seen that the ASSIST checklist and ICAO doc 4444 (highlighted in orange), identified in the interviews, were controls to the function. The remainder of the couplings between the functions and the flows was acquired through information collected during interviews (i.e. notes) that were iteratively coded, structured and restructured during the whole data collection and analysis process. It can also be seen that "Aircraft Problem", addressed during the above mentioned interview, is just one of the possible inputs (triggers) of the "Respond to Anomalies" function now covering also situations identified by the ATCO, e.g. Unreported aircraft, and technical problems as System Failure among other possible abnormal situations.

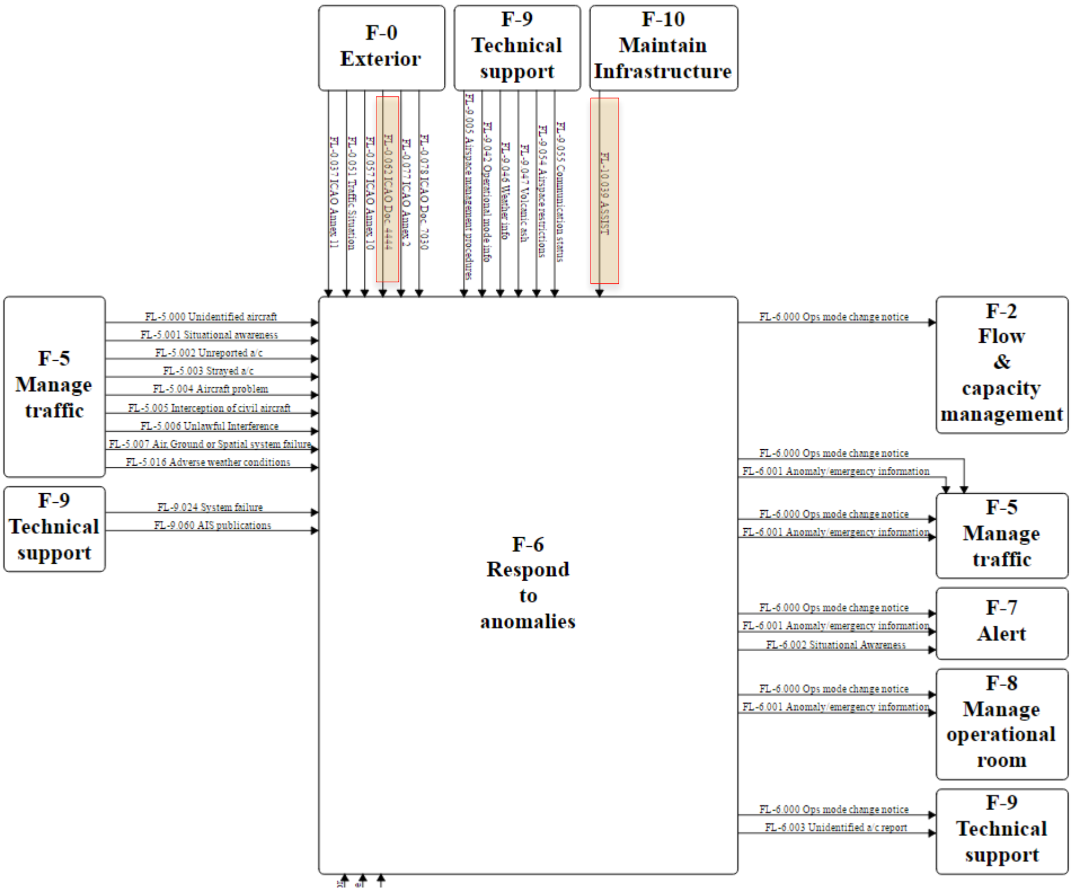


Figure 5: Respond to Anomalies function representation using SADT

Due to the complexity of the system, both top-down and bottom-up coding was carried out with the aim of developing a comprehensive ATM system architecture. Initially, a top-down approach was used to derive a functional system description as described in the Preparatory work section. During the interviews, the details were captured and added to the top-level structure using a bottom-up approach. This combined approach is used extensively in model development, as it is often the case that some particular aspects inadequately correspond to the pre-existing top structure. The whole data coding process was repeated iteratively in data collection, analysis, validation and implementation.

In light of the information flows gathered through the interviews, functions and their couplings were further combined, divided, modified, refined and amended. Hierarchical relationships that explain functional substructures and couplings between the functions were established. For instance, during this process, an additional top-level function was created, function F-10 Maintain Infrastructure. The new function was deemed necessary to account for the support of the remaining nine functions (belonging to the top-level of the MARIA hierarchy) in the provision and maintenance of required infrastructural resources (e.g. to keep all the internal documentation up to date) that was not found during the Preparatory work phase.

The model's traceability was ensured through the creation of a data dictionary. For instance, communications from the ATCO to the aircrew were classified as either an instruction or a request. Instructions were classified as: Clearances, Collision avoidance, Conflict Resolution, Identification, Sequencing or Transfer (frequency change), whereas requests were not be further decomposed.

Due to the complexity of the MARIA model in the SADT format, it was deemed necessary to code it into an electronic readable language for the purpose of assuring its consistency and completeness. Yet Another Markup Language (YAML, 2016), a human-readable data serialisation format, was chosen because it is easily editable and readable by humans, allows for comments to be integrated, is widely used and several libraries are already available to process it. During the translation process, SADT diagrams were seen as a set of nodes for the functions and arcs for the data flows. The coding approach enabled functions and their hierarchy to be defined and used as source and sink of the data flows. This approach resulted in a graph where the nodes were functions and the arcs were data flows, conveying a structure where graph theory can be applied.

Translating the captured data from the SADT into the YAML format created a form of a knowledge database that has the potential to be enlarged in order to both to introduce new functions or data flows and to insert further knowledge such as function characteristics. Tools were developed to automatically check the consistency and completeness of the knowledge database and to produce views (discussed in the Results Section).

Consistency refers to the agreement in labelling functions and their aspects in the model (Hollnagel, 2012) and was checked by uniquely identifying and associating each function. Its identification reflects also the hierarchy in the function decomposition tree.

Completeness refers to the exhaustiveness in the couplings between the aspects of the function. This rule states that "*no aspect should occur for one function only*" (Hollnagel, 2012, p. 60). It implies that every object, function or flow, can be either at the top of the hierarchy or has a parent and was ensured by automatic checking in the MARIA framework. All flows are uniquely identified and have the same aspects: start, end and hierarchical links. The start and end are always references to existing functions. The flow hierarchy is in accordance to the function decomposition.

G. Validation

The credibility and representativeness of MARIA was tested through validity checks. In the SADT and IDEF0 methods, these checks are conducted through a reader/author cycle review in which the author(s) submits the model supported by required documentation, including the diagrams and/or related text, to reviewers to comment (Feldmann, 2013). Following the completion of the review process, the comments are returned to the author(s) who then amends the model and the supporting documentation to reflect the received comments. The process is iteratively repeated with each reviewer.

Both internal and external validity checks (Cohen et al., 2011) were conducted during MARIA validation. Internal validity aimed at demonstrating the consistency, neutrality and dependability (Onwuegbuzie and Leech, 2007b) of MARIA as judged by the participants of the research. External validity aimed to test the transferability (Cohen et al., 2011) of MARIA by SMEs who did not have an input in the model and factors development.

Internal validity checks were split into two parts, one for each phase of MARIA development. The first part was carried out during the functional system description phase, following each new data collection all 28 SMEs/participants were asked to comment and verify the outputs of their interview records. Once the functional system architecture was completed, the second phase of internal validation was initiated. In this phase, 25 SMEs working at NAV Portugal (10 of operational and 15 of engineering background) reviewed the system architecture documentation. Due to the scale and the complexity of the model, each SME was asked to focus on his/her area of expertise, enabling tables were developed mapping each SME to their areas of expertise. However all SMEs were asked to review the global views, i.e. high level of abstraction, encompassing the whole system, and other high-level information. The structure used in the second phase of internal validity checks was repeated in external validation. In total, two SMEs from Eurocontrol and four from SESAR Joint Undertaking (SJU) reviewed MARIA documentation and provided their feedback. The summary of SMEs' characteristics is given in Table 4.

Table 4: Internal and external validation SME characteristics

MARIA Development Phase	**Internal validation SME characteristics**			
	Job function	Number	Age	Experience
Functional system description	OPS	3	>40 years	>20 years
	TEC	3	>40 years	>20 years
System architecture description	OPS	7	>40 years	>20 years
	TEC	12	>30 years	>10 years
MARIA Development Phase	**External validation SME characteristics**			
	Organisation	Number	Age	Experience
Functional system description	Eurocontrol	2	> 40 years	> 20 years
	SJU	4	> 30 years	> 10 years
System architecture	Eurocontrol	1	> 40 years	> 20 years

description	SJU	0	N/A	N/A

All internal and external SMEs provided feedback that was constructive. The comments were predominantly related to the semantics including clarifications of definitions, functional descriptions and flows below the top four levels due to lack of the expected granularity. All the comments were incorporated into the final version of MARIA presented in the following Section. Furthermore, one of the outcomes of the validation process was SME feedback about the potential uses of MARIA which include:

- Frame safety assessments;
- Assess the impact of changes;
- Assess the impact of failures;
- Define the safety requirements for constituents;
- Introduction training for new staff.

In addition to the formal validation process, the MARIA model has been presented at numerous conferences (EUROCONTROL, 2013a, 2014, 2015b), international meetings (EUROCONTROL, 2015a, FRAMily Meeting, 2015), stakeholders meetings (Deutsche Flugsicherung GmbH (DFS), Letove prevadzkove sluzby (LSP)) and internal NAV Portugal presentations where it received interest and positive feedback from the participants. It was also presented to two European Aviation Safety Agency (EASA) auditors on October 9th 2014, in the scope of a follow-up audit. The feedback demonstrated interest and support for the use of the MARIA approach in ensuring compliance with regulation EU 1035/2011.

Finally, MARIA undergoes a validation process, i.e. at regular intervals, through its numerous applications across the organization. With every new MARIA application, this ensures that the appropriate questions are raised and the resulting improvements are integrated, thereby further reinforcing the validity of MARIA.

IV. Results

MARIA attempts to provide a system description, covering people, procedures, equipment, regulation and the external environment. It describes both the system functions and the architecture with all its mechanisms of the Lisbon Flight Information Region (FIR). However, following the processes of internal and external validation it can be stated that this functional model can be extended to a generic ATM system with small adaptations, requiring the system architecture to be adapted to local systems, human tasks and their organisation.

In terms of dimension, there is a maximum of seven levels of decomposition for the functions. The following table provides information of MARIA's current dimension.

Table 5: Model dimensions

Entity	Nr.	Remarks
Flows	1672	Covering all levels
Low level	763	Excluding aggregation flows
Nodes	526	Covering all levels
Low level	399	Excluding aggregation nodes
People	23	Roles of human actors
Technical	89	Technical function (under F-9)
Equipment	232	List of existing equipment
External	8	Functions performed by others
Human	42	Human functions
Procedure	5	Functions producing rules

The model is available on the NAV Portugal intranet for consultation and the entry page, where all the existing functions are shown and can be accessed, is shown in Figure 8. Furthermore the enablers can be viewed, providing a list of the existing equipment and of the different roles of the responsibilities of people captured in MARIA. All the information is structured in line with the decomposition approach that was followed during the modelling.

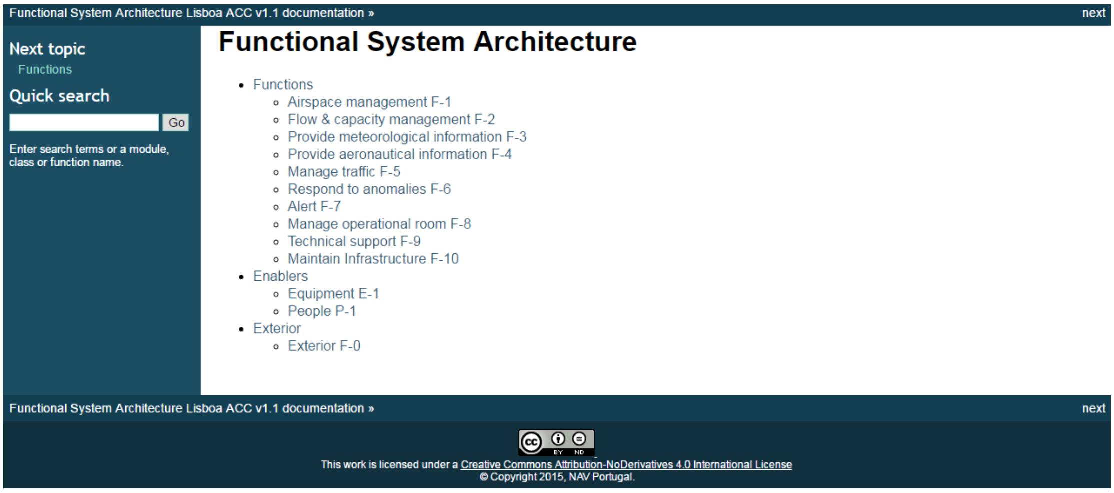


Figure 6: MARIA for Lisbon ACC entry page

The current model is instantiated to provide the system and architecture description of the Lisbon ACC and five local towers. Instantiation is a facility available in the current MARIA framework where, by configuration, functions and data flows can be inherited or filtered out from the used reference model.

Figure 9 and Figure 10 present an example of the Flow and Capacity Management function in the Lisbon ACC and in the Faro Airport Control Tower architecture respectively. It can be seen that part of the responsibilities for this function in Faro are delegated.

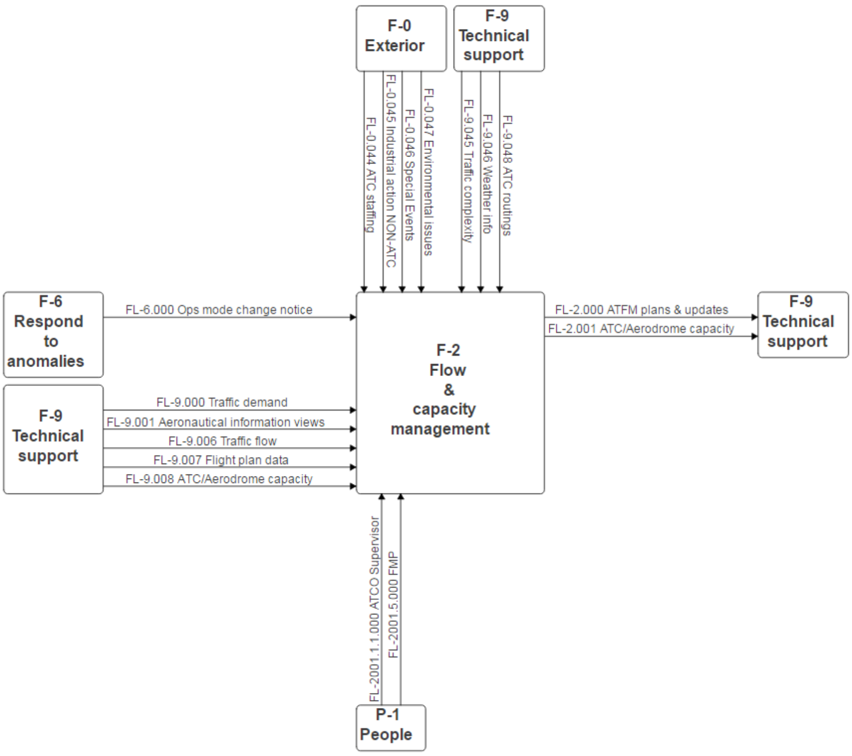


Figure 7: Flow & capacity management in Lisbon ACC

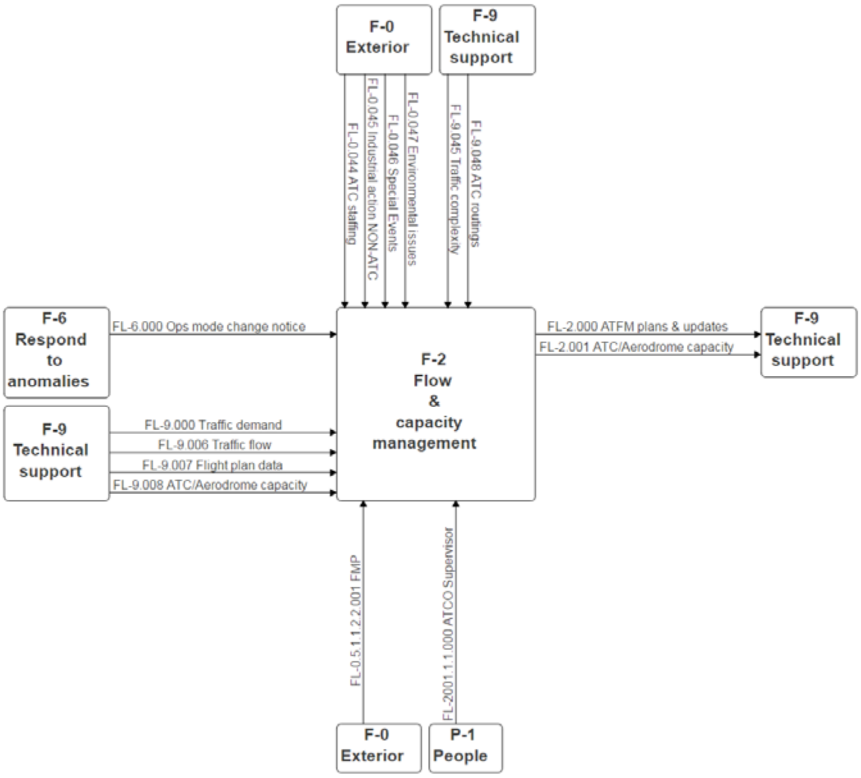


Figure 8: Flow & capacity management in Faro Tower

As can be seen from the example above, every function is detailed individually, one per page. Every page contains exactly the same structure and information: Definition, Identification, Flows and Sub-functions. There are facilities to navigate and search within the model and each function has its own diagram independent of its level of detail.

The enablers can be viewed, providing a list of the existing equipment and of the different roles of the employees at NAV Portugal and covered in MARIA. All the information is structured in line with the decomposition approach that was followed during the modelling.

The list of equipment is structured around the following categories, shown as sub-functions: ATM, Surveillance, Radio Navigation, Communication, Meteorological, Network, Auxiliary Means and Time. For each of these categories, further detail is available stopping at the level where one gets into the design of the equipment itself, for example the WAM (Wide Area Multilateration System) or the TX/RX for a Primary frequency. There are currently 120 equipment nodes in the Lisbon ACC model for instance.

For the employees, the following categories are defined: Air Traffic Services Operations (comprising ATCO Supervisor, ATCO Executive and ATCO Support), Network Management, Flight Data Operator with all the different qualifications required for Aeronautical Publications, Support staff and FMP (Flow Management Position).

The MARIA framework offers the following automated functionalities: loading, checking, filtering, and documentation production. The automatic generation of documentation creates graphics, as the one in Figure 7, web pages in html format, and open document format. The automation is done using Python (PYTHON, 2016) a widely used scripting language.

Finally, it should be noted that this model is subject to a continuous improvement process. This is achieved through the normal operations surveys, the results of which are used to calibrate the model and thus align it with work as done as much as possible.

During these surveys, a trained controller observes the work of his colleagues and fills in a check-list with the practices that were predefined to be monitored and the number of times that they should and are applied during the observation period. System analysts map these observed practices to the model in terms of the function(s) they belong to, the inputs that are used to trigger a practice and the outputs. Typically, the results of this analysis identify missing sub functions, missing flows of information and further detail in some on the information flows.

V. Application

This paper describes a methodology used for the development and presentation of a functional complex socio-technical systems model, showcased in one of its potential applications – in modelling of the day-to-day ANSP services. Nevertheless, while this section discusses potential applications of MARIA in the ATM domain, similar applications may be used in system modelling in other domains such as the transportation industry, oil and gas industry, nuclear industry, construction industry and healthcare.

Following the development of a systemic system understanding, description and presentation of the ATM system, through MARIA, numerous types of analyses can be carried out on the resulting model. Depending on the type of analysis the model, should be complemented with additional data. For instance, MARIA enables both reliability and systemic safety analysis by accounting for the functional description and couplings of the ATM system. While reliability analysis, based on Safety-I principles, could be carried out using the ANSPs data on existing failure probabilities, the Safety-II principles that underpin MARIA recognise that reliability of a complex socio-technical system does not equate to safety (Leveson, 2012), thus work is under way to develop a different method, initially relying on qualitative data (Leveson, 2015), to systemically model safety of the ATM system using MARIA. In addition to safety, this model can also be used for the analysis of delays and their propagation from the perspective of an ANSP, where the time aspect (dimension) should be populated. Another example would be its use in prospective safety analysis where, in addition to the functional model, factors that affect variability of human and technical functions should also be modelled. While some of these applications are in the development process and will be addressed in the future, this section discusses some of the currently implemented applications of MARIA.

In addition to providing a global architecture description of the services provided by NAV Portugal, another obvious application is its use in the provision of a local view of the services and functions performed at each location/unit. Prior to MARIA, a component-based equipment description existed but not the functional system architecture. Furthermore, from the interviews, it was found that ATC towers knew their local "*as done*" services but were unaware of services that are performed centrally on their behalf. Since any type of system analysis (including safety) can only be complete if done at the system level, local knowledge of system implementation including their interaction with other organisational units is of upmost importance in understanding the impact of interventions and the need to coordinate them. Therefore this application of MARIA provides a major step forward towards the understanding and modelling of ATM functions, their interactions as well as interactions between these functions and its environment, required under the EU Regulation 1035/2011 (European Commission, 2011).

An area in which MARIA has demonstrated its effectiveness lies in systemic change management, in particular in the domain of logging and solving Problem reports and Change requests. Previously, this has been done in an ad-hoc manner i.e. the same problem would be associated to different problem area and department (i.e. Maintenance department or Internal system development department) depending on the person who recorded it. In addition, problems were reported in multiple systems, without any connection between them and using different taxonomy keys. For instance, a technical problem with an operational impact would be recorded in the Toolkit for ATM Occurrence Investigation – Risk Analysis Tool (TOKAI - RAT from Eurocontrol), the maintenance database and also in the projects department problem-reporting database. When communicating a problem reported to the Maintenance Department and inserted in their system to the internal system development team, information was lost and association with the areas of expertise was numerous times incorrectly conducted, resulting in delays in addressing the reported issues. Some could even get lost for several days.

Delays in problem reporting to the software support indicated a flaw in the corresponding process. The main problem was in the classification of occurrences and reports due to both systems having different classification schemes, thus allowing for different interpretations. Seeking to identify a systemic solution to the identified problem, MARIA was applied. Taking the functional approach to problem solving, all problem reports and change requests were catalogued according to the functions in the model, not lower that level 2, or to a specific enabler (to limit the complexity of the reporting system). It should be noted that an enabler is usually associated to a function, or a very small set of functions, so the function(s) can be automatically determined. Therefore, if the problem was on an enabler, e.g. server X failed, it was clearly associated with the enabler type of server X. But if it was reported by an ATCO from the control room, it would not have referred the enabler but the function that was affected, e.g. ensure air surveillance. This convention consequently eliminated one of the flaws in the process, namely ambiguous problem logging, providing in turn a better and more meaningful data on the problem areas.

The convention is currently being extended into a new problem reporting software application for the Internal systems development. This required a migration of all the previous problem reports and change proposals into the new convention. The definition of this migration criterion was a demanding proof of concept that this approach would achieve its goals. To achieve this, a conversion table was built without any difficulty for translating any of the reported problems coming from operational systems according to MARIA. Furthermore, the Maintenance department also adapted their problem reporting software to report the fields that allow direct mapping to the MARIA functions or enablers. Finally, by establishing of an automated link between these two problem reporting systems, the loss of information and the delays caused by bad association of reports with the areas of expertise were resolved.

While this is only the direct benefit of the use of the structure within MARIA for logging and solving Problem reports and Change requests, there is a potential for additional benefits. For instance, associating changes with functions will allow safety assessments to consider the changes to a function as a whole and not simply for a component-by-component change. This supports the definition of safe change paths. The approach also enables the uniform handling of all problems/changes in the system and ensures a harmonised approach to the safety assessment of change impact.

Finally, the new problem reporting software application could also be used for monitoring the efficiency of problem solving and the stability associated with different functions in the system and corresponding interfaces. By mapping the recorded problems and changes to MARIA over time, the stability of a function can also be measured by the number of changes associated with it.

VI. FURTHER DEVELOPMENTS

In outlining the detailed process above, a few limitations are worth noting. Firstly, a recommended minimum of three respondents Onwuegbuzie and Leech (2007a) for each of the top nine functions was not met during the interviews. This was particularly prominent for the ATCO tower position due to lack of availability. The limited expertise from tower control was nevertheless compensated by a detailed and iterative validation process and continuous improvement of the model through normal operations surveys. Secondly, MARIA predominantly accounts for tangible and recordable functions and flows with the exception of the functions Maintain situational awareness. However, for the process of continuous monitoring, calibration and improvement, it was found that only recordable flows of information could be monitored and a further data collection process was initiated to operationalise the concept of "*situational awareness*" and map it with recordable functions and flows in MARIA. Nevertheless, the impact of intangible factors through organisational functions and performance variability (see Table 1) is highly important in a complex socio-technical system such as ATM and should not be dismissed. Therefore, a taxonomy of Performance Shaping Factors (PSF) is under development to complement the MARIA functional system architecture. Finally, the high level of granularity in MARIA, reflecting the complexity of the ATM system, is likely to increase the time resources needed for different types of analytical applications. Therefore, in the future it will be necessary to consider the trade-off between the level of granularity and the available time resources required for each type of analysis.

The full potential of MARIA will be demonstrated in the future work that will consider initially the analysis of delays and their propagation from a perspective of an ANSP; and the use of MARIA in prospective safety analysis. While MARIA is currently just a static ATM functional system architecture, future work will also add a dynamic dimension to it. Several approaches were considered:

- Modelling the dynamics and the unknown, both via FRAM and BBN (Bayesian Belief Networks). The major challenge will be to get the necessary information, such as the conditional probabilities. After a start, validation will be required as well as the definition of the monitoring requirements to guarantee that the model is well calibrated and adapting to change.
- As the execution of day-to-day "*as done*" services is not bimodal, Boolean logic is sometimes limited for analysis. A function has several states and flows. These aspects can be modelled with the use of fuzzy logic, a possible expansion MARIA that will allow better identification of failure impact and failure causes.
- Having the model coded as a graph opens possibilities to the application of existing graph theory methods such as for model checking, path identification which are usable for failure propagation and change impact assessment, and to identify non-events.
- Simulation strategies have to be studied. The integration of dynamics and the calibration of the model will allow, with appropriate simulation, the identification of weak and strong points.

- The applicability of agent based modelling, an emergent area in the study of complex systems, used in social and financial modelling, will have to be further investigated. This modelling is mainly used to detect emergent behavior.

VII. CONCLUSION

Stagnation in safety enhancement and inaccuracy in risk estimation associated with the ATM system has been recognised by both the academic and regulatory communities. It is often associated with the practitioners' inability to grasp the system's complexity by accounting for the interactions between the equipment, procedures and human resources. However, despite the numerous models of the ATM system, none of them meets this requirement for a variety of reasons, e.g.

- IRP and AIM focus on modelling of most frequent accident types;
- EATMA focuses on modelling of specific four layers of the ATM system;
- NASEA predominantly focuses on "*as imagined*" ATM system and is not supported by a published methodology.

In this paper we proposed a methodology and a functional system architecture – MARIA – of the ATM system with the aim to capture "*as done*" functional top-down model of the day-to-day ANSP services which is simple, clear and readable by untrained people. We found an absence in the literature of either a methodology or a model that would offer guidance to ANSPs on how to meet the system description and modelling requirements set in the EU Regulation 1035/2011. This paper therefore proposed a methodology based on SADT and Template Analysis to derive MARIA. Most notably, this is the first time to our knowledge that an ATM system model is derived from the data and capable of modeling "*as done*" ATM operations and is a subject to a continuous improvement process in order to bridge the gap between the work "*as imagined*" and "*as done*".

Furthermore, MARIA is currently the most exhaustive functional model of the ATM system composed of 526 nodes (functions) and 1672 flows (couplings) to date. While it is early in its implementation phase, the initial application of MARIA provided compelling evidence in favour of system approach to logging and solving Problem reports and Change requests. Based upon this, the authors recommend MARIA be used by ANSPs in order to meet the EU Regulation 1035/2011.

Finally, in addition to the ATM system, numerous complex socio-technical systems, e.g. the oil and gas, health care sector and construction, can be modelled by the proposed methodology outlined in this paper. In order to achieve this, it would be necessary to functionally model these systems with care to model the work "*as done*" following the steps undertaken in this paper.

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