# Modeling ATM day to day operations

## A functional model of the ATM system

Paula Luisa Santos, Paulo Monteiro
Projects and engineering department
NAV Portugal
Lisbon, Portugal
Email: paula.santos@nav.pt, paulo.monteiro@nav.pt

***Abstract*— How can one say that current systems of Air Traffic Management (ATM) systems are safe and resilient? What is the current knowledge and understanding of these systems? Why is it necessary to know them better?**

**The Model of ATM Reality In Action (MARIA) is a knowledge database and an automation framework developed by NAV Portugal to answer the above questions and to provide a sound base for safety analysis, namely by describing the whole system and the interdependencies between its functions. It is coded as a graph giving additional possibilities of automatic analysis. It has undergone extensive validation and is considered mature. Experimental work has been done on hazard and cause identification with success.**

**MARIA is neither a business nor safety model. It is built to allow several perspectives of analysis depending on the aim at hand. It may be used in simulations to identify strong and weak points, to evaluate risk mitigation strategies and for other purposes. Modeling the dynamics and the unknown are areas of planned study using the emergent methods for the modeling of complex systems.**

**Having a repository covering all that is done to provide an ATM service, in a systematic and uniform way, structured in a top-down manner, with the human as an integral part of the system, allowing automation of analysis and representation are significant advantages to improve understanding, safety and resilience of the ATM services. Sharing this knowledge database and adding the contributions from other models and interested partners will be beneficial for the ATM world.**

***Keywords-* System modeling; safety; resilience; complex systems; ATM functions; ATM information flows**

## I. Introduction

Have you ever wondered looking above your heads into the skies how safe should we feel down here? The busiest airports handle more than 100 flights per hour during peak hours, and there were on average more than 100 000 flights per day around the globe in 2014, this is what makes it to say that accidents and incidents are rare; that current systems of Air Traffic Management (ATM) are safe and resilient. But to what level are they known? What is the current knowledge and understanding of these systems? Why is it necessary to know them better? This paper argues that, in order to better understand a system or phenomena a model, i.e. a simplified version of reality, is a useful tool and as safety is a property of a system, not a property of the components that comprise the system [1], to analyze it, a global picture is required. This is the starting point for the work being presented.

The ATM model presented in this paper, Model of ATM Reality In Action (MARIA), was developed by NAV Portugal to answer the above questions and to provide a sound base for safety analysis, namely by describing the whole system and the interdependencies between its functions. The following goals were defined at the start of this endeavor:

- Give a global view of the system (people, procedures and equipment)
- Show the dependencies between functions / processes
- Build a description of the system architecture
- Be the reference for future safety assessments
- Come up with a systematic and reproducible hazard identification method
- Help the definition of risk mitigation strategies

Therefore, this paper will begin by giving some background on what falls under the field of ATM and the limitations of current approaches to ATM systems that led NAV Portugal to this modeling work. On a second chapter, the analysis methods, as well as the process to build MARIA are described, covering also the modeling decisions and the aspects that differentiate it from other existing models. The results of this work, its current status on a theoretical, as well as on experimental level, are presented next. The evolution presents ideas on possible future work. The conclusion will gather our main findings, and what those findings allow us to foresee as key next steps into more secure/resilient ATM systems and international cooperation.

## II. Background

For the purpose of this work an ATM system is defined as all that is required to expedite and maintain a safe and orderly flow of traffic during all flight phases and comprising the interaction between people, procedures and equipment.

Although the current practices contribute to the safety of aviation, they are regulated and described as if in isolation, but for European safety regulation that requires a total system approach. In other words there is a lack of an integrated view of the human and technical elements in the ATM domain. This lack jeopardizes safety assessment and the definition of risk mitigation strategies. NAV Portugal aimed at doing safety assessments at system level and not for isolated parts of the system. A global system view was a precondition for that work and thus NAV Portugal invested in building MARIA.

From a management point of view for safety as well as for business, the existence of a system model provides a basis for analysis and a reference.

There are already relevant models available for the work at hand, although none that could be used to describe the whole system meaning "*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*" (Regulation EU 1035/2011). They failed either by missing the big picture or how it all interacts.

Ensuring safe operations is an aim of every Air Navigation Service Provider (ANSP). The services are provided by a complex, adaptable and dynamic social-technical system undergoing frequent changes. None of the other models treated the system as a set of functions and most focus on the technical functions considering humans as actors, and describe the system usage via operational scenarios. NAV Portugal decided to model its own services in a top-down manner, covering all the functions that were identified at the top level in a uniform way.

The Integrated Risk Picture (IRP) model, now evolved to Accident Incident Model (AIM), [3][4] describes functions and is centered on human factors. Its aim is to measure risk. It is presented as a fault tree composed of all the functions that when failing can lead to an accident and was enhanced to cover SESAR new functions. It does not clearly provide a description of a system nor does it allow the representation of an existing architecture, which are mandatory requirements for an ANSP. AIM is composed of seven models, three for mid-air collision (En-Route, TMA (Terminal Area) and Oceanic) and one for each of the remaining ICAO defined accidents. The matching of MARIA with AIM was successfully done meaning that all functions in AIM that exist at NAV Portugal in the Lisbon Flight Information Region (FIR) were covered and the functions not covered were known but did not apply to the way NAV Portugal works. The AIM model covers also aircraft, which is treated as an external element to the services provided by the ANSP.

The Overall ATM/CNS Target Architecture (OATA) was studied and used as an initial reference for the ATM technical support functions. The ATM Information Reference Model (AIRM) is used as a common reference for the different models developed as part of SESAR and covers an Information Model and a Logical Data Model. The European ATM Architecture (EATMA) models the system in four different layers: Capability, Operational, Service and System [5]. It is very hard to get a global view of system functions here understood as an entity that processes inputs and provides information to other functions, independent from how they are ensured, either manually or automatically. The lack of this harmonized view of the human and technical functions erodes integrated analysis such as the hazard identification and causal analysis.

The National Airspace System (NAS) As-Is and Mid-Term models from FAA are similar to this one in that they use IDEF0, are centered on functions and information flows and provide several views [6]. The Mid-Term data model uses Unified Modelling Language (UML) class diagrams. The As-Is model already describes dynamics via sequence diagrams (event trace). The possibilities for automated analysis could not be assessed. The team considers that positive synergies could be realized by cooperation in future work.

## III. THE MODELLING PROCESS

MARIA was developed capturing the work performed daily at NAV Portugal to provide ATM services via interviews with the people actually doing the work.

The approach was to first collect information from existing documentation to allow a better understanding by the interviewers of the subject and thus allow a better lead and structure of the interviews. ICAO and EUROCONTROL documentation, both on system and human factors, was used, as well as the local operational procedures and manuals. The face to face started in March 2012 and lasted until May that year. Adding detail for the architecture definition started in May 2012 and was done in parallel with the development of the framework. A first version of the generic architecture was released at the start of 2014. The local architecture descriptions were built and distributed for validation by operational and maintenance staff from the sites in second quarter of 2014.

The regulation EC 552/2004 on interoperability of the European Air Traffic Management Network (EATMN) requires, to avoid misunderstandings, a clear mapping of systems and constituents. Using the model to build this mapping is providing additional verification and validation.

TABLE I. STAFF IN DEVELOPMENT AND VALIDATION

| **Activity** | **Involved People** | | |
|---|---|---|---|
| | **Ops** | **Tech** | **External** |
| Intial interviews | 12 | 8 | |
| Review | 12+2* | 8 | 3+ Eurocontrol |
| Map to AIM | 2* | 5*+2 | 5* Eurocontrol |
| Get Architecture | 5+2* | 8+ | |
| Review Generic Architecture | 7 | 8+2* | 2+ Eurocontrol |
| Review Local Architecture | 8* | 7*+2 | |
| Structure for regulation 552/2004 | | 3+1* | |

* Not involved before
N+ More than N

Up to now, more than fifty people were involved and over 3000 work hours were invested.

NAV Portugal developed MARIA based on the day- to-day activities modelled top-down, starting with very high level functions, such as aeronautical information management, which are systematically decomposed down to the level where the resources performing them can be identified. The level of abstraction is kept uniform at each level of function decomposition. This way it is possible to ensure that at each level the description covers all parts (is complete), and further decompose by areas of knowledge, thus facilitating verification and validation. The modularity of the model allows the addition of new blocks, derived either from new features or changes in scope.

In concept, as in the following figure, defining the scope looks quite easy, but this was not a fact.

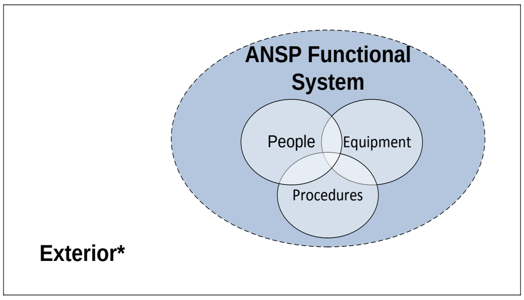


Figure 1. Model scope

From the start it was noticeable that most of the interviewees were lacking a high level view, each one knew exactly what they had to do, but not why it was done or how it was used. This means that information was captured in a bottom-up way and afterwards consolidated in a top-down model. The achievement of this abstract view is one of the major advantages of the work carried out.

The main goal of ATM is to prevent accidents. What does an ANSP do every day to prevent accidents? This is what has been modeled.

The main question to capture the functions was "What do you do for the safety of ATM?"

This question addresses the activities that are performed to have success, in line with the Safety II concept [7], and got a very good reaction from all participants – everyone enjoys talking about what they do.

The interviews were structured according to the following script:

- Presentation of the aim of the modelling activity, why it was being done and what was expected to be achieved;
- Tell us what you do, which was normally told with a lot of detail;
- Tell us what you need to do the work both information and tools, i.e. the inputs and enablers of their function;
- Tell us what you produce and to whom, i.e. the outputs and the link with other functions;
- Report by the interviewers of what was understood, at a very high level and in graphical form.

The list of the top level functions was prepared based on ICAO documentation and on the knowledge the modelling team had of the organization. It is represented in Figure 2 and is the following:

- Airspace management
- Flow and capacity management
- Provide meteorological information
- Provide aeronautical information
- Manage traffic
- Respond to anomalies
- Alert
- Manage operational room
- Technical support

The Respond to Anomalies Function aim is to handle foreseen abnormal situations, either internal (e.g. technical systems) or external (e.g. aircraft), but just the cases for which a plan of action already exists are covered in the nominal functioning mode. Manage operational room covers the opening and closing of sectors.

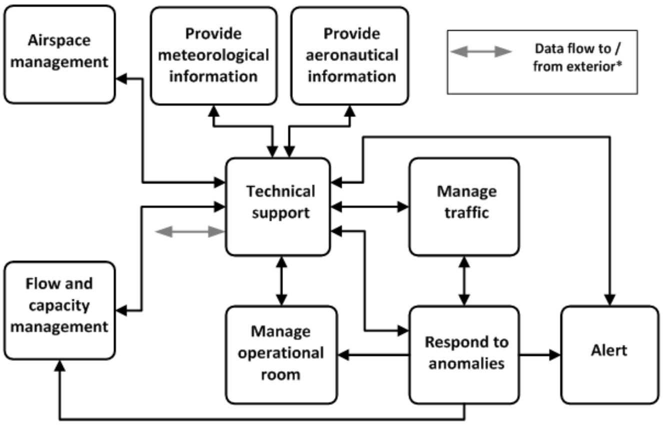


Figure 2. Top level functions

As would be expected and can be seen in the figure above, the Technical Support (F-9) is at the center of the whole system, connecting all other functions.

The first step was the description of the system functions and this was achieved with the nine top level functions already mentioned and the first level decomposition for manage traffic and technical support. Technical support was described using the knowledge of the system as implemented in the Lisbon FIR. Each Communication, Navigation and Surveillance (CNS) area has its own function: Ensure Communications, Provide Navigation Support and Ensure Surveillance. Other functions which are widely recognized are Ensure Meteorological Information and Flight Plan Management. As the concept of Human Machine Interface (HMI) has different meanings which can cause misunderstandings and here it was understood as all the possibilities allowing humans to interact with the equipment, including printers, headsets, displays and phones, a different designation was used. To avoid misinterpretations it was decided to call this function Presentation Support. There are also functions that group data from other functions and prepare it for presentation; this is the case of the association of surveillance data and flight plans. These aggregation functions are grouped in the Data Integration function. Finally, technical support is composed of ten functions, an exception to the maximum of nine which was targeted. The functions are:

- Ensure Communications
- Provide Navigation Support
- Ensure Surveillance
- Ensure Meteorological Information
- Flight Plan Management
- Coordination Support
- Automatic Traffic Monitoring
- Ensure Room Configuration
- Data Integration
- Presentation Support

The information gathered from the interviews described mainly the human functions and all the inputs required from the technical support function. The amount of information flows was such that manual checking was impaired. To ensure the consistency of MARIA, namely that all flows had a start and an end, a framework was developed. Each function and each data flow were assigned a unique identifier thus enabling referencing and automatic checking.

The description of the system functions does not cover the mechanisms that perform the function. This is only included in the description of the system architecture. It is considered that other service providers will be able to identify the functions and a big part of the data flows in their own systems, but the enablers vary from one implementation to another as each service provider will have its own architecture. In a presentation to several other ANSP this assumption was confirmed.

Starting from the system description, covering the top level functions and the first level decomposition of some of the functions, they were further decomposed until a specific enabler could be identified. The human functions were decomposed to a level where specific training or rating requirements could be specified

For the technical functions a similar path was followed, they were decomposed up to the level where the mechanisms could be identified and were understood as a set of related equipment used to provide a specific function. Taking as example the function ensure communications, it covers both air-ground and ground-ground communications and this is the first level of decomposition. As these two sub-functions were still very broad, they had to be detailed even further. The air-ground communications was decomposed to the functions "Ensure Voice Communications" and "Ensure Aircraft Messages". At this level a set of enablers could be clearly assigned to each function. This approach was followed for all the technical functions.

Complementing the top-down approach followed to describe the functions, a bottom up matching of the existing equipment with the structure was performed. Each identified item was assigned to at least one function. The engineering, the maintenance and the project staff were interviewed to verify the list of equipment and provide the allocation to the existing function structure. This phase was also used to validate the structure and other elements in each function description, including the data flows and the constraints.

The definition of the MARIA's scope as all that is under the responsibility of the ANSP, introduced a clear border. There is data crossing this border, which implies that it does not start or end in a real function. A fictitious function designated as "Exterior" was added to refer to all that comes from or goes outside the scope.

The main difficulties with the modelling were:

- To define the scope;
- The lack of a global picture by most of the interviewed staff, each one knew exactly what had to be done but not the purpose nor how it would be used;
- The complexity of the system;
- Great interdependency and data diversity;
- Specific terminology;
- A lot of implicit knowledge.

### *A. Modelling decisions*

At the start it was unclear what to capture, should the service for one aircraft be described? Or the service per flight phase? As the service is provided all around the clock, it was decided that what was being done at any moment by all the staff should be described. To manage traffic the ATCO builds situational awareness, looks for conflicts, solves conflicts, answers to requests, provides information, and so on. And this is done at every control position and for every aircraft to which service is being provided.

To ease analysis the team decided to have a clear separation of the functions performed by people, the so called human functions, from the ones done by equipment, technical functions. Humans perform their functions using information provided by equipment, all information that is not passed directly from one person to another goes into and is distributed via a technical function. For instance, all printed information comes from a technical system and all communication, except for the example above, goes via a voice communication system. The decision to have this clear separation eases analysis, as different methodologies can be applied to each function type.

The results of the interviews were written using an existing analysis notation. It was decided to use the notation from Structured Analysis and Design Technique (SADT), similar to IDEF0 [2], to represent the top level functions and its inputs and outputs. Details of some of the functions were captured using Business Process Modelling Notation (BPMN), a much richer notation which permits recording the way work is done. BPMN requires a clear knowledge of decision criteria and a uniform (or even unique) way of performing the functions. The team started to model a human function – Manage Traffic. It was very hard to get explicit decision criteria, it is a cognitive process done by highly specialized and trained people that at every moment evaluate the situation and take a decision based on their experience, training and time. Even if there were explicit instructions for all these functions it would clearly be a "work-as-imagined" description, which is sometimes far from "work-as-done" [9], especially in critical situations, when the human has to handle unexpected situations.

SADT was used mainly as a notation, where each rectangle is a function receiving the information that is going to be processed or used (inputs) at the right edge, providing the results (outputs) from the left edge. The upper edge receives the information that conditions the execution of the function, e.g. regulation. The lower edge receives the resources that perform the function, be it people or equipment, and usually called mechanisms or enablers. As an example, the representation of the function "Conflict Resolution" is shown in Figure 3.

To facilitate understanding and depiction the number of boxes (functions) should be seven with nine as a maximum, which implies that the decomposition of any function must also follow this rule.

How to show the model? It soon became unfeasible to have a printed version of the full model even for some functions it became unreadable. To allow readability, when showing a function only the links to top level functions or to the function's own top level are represented (see Figure 3), so there is no "printable drawing" of the complete model (but the model is coded / accessible). A web page was created to access it and documents for system and architecture descriptions are automatically produced.

While doing the bottom-up validation a derived function, one that is necessary for the others to work well, was identified. It covers training, staffing, maintenance of documentation and equipment and all that is required to maintain the

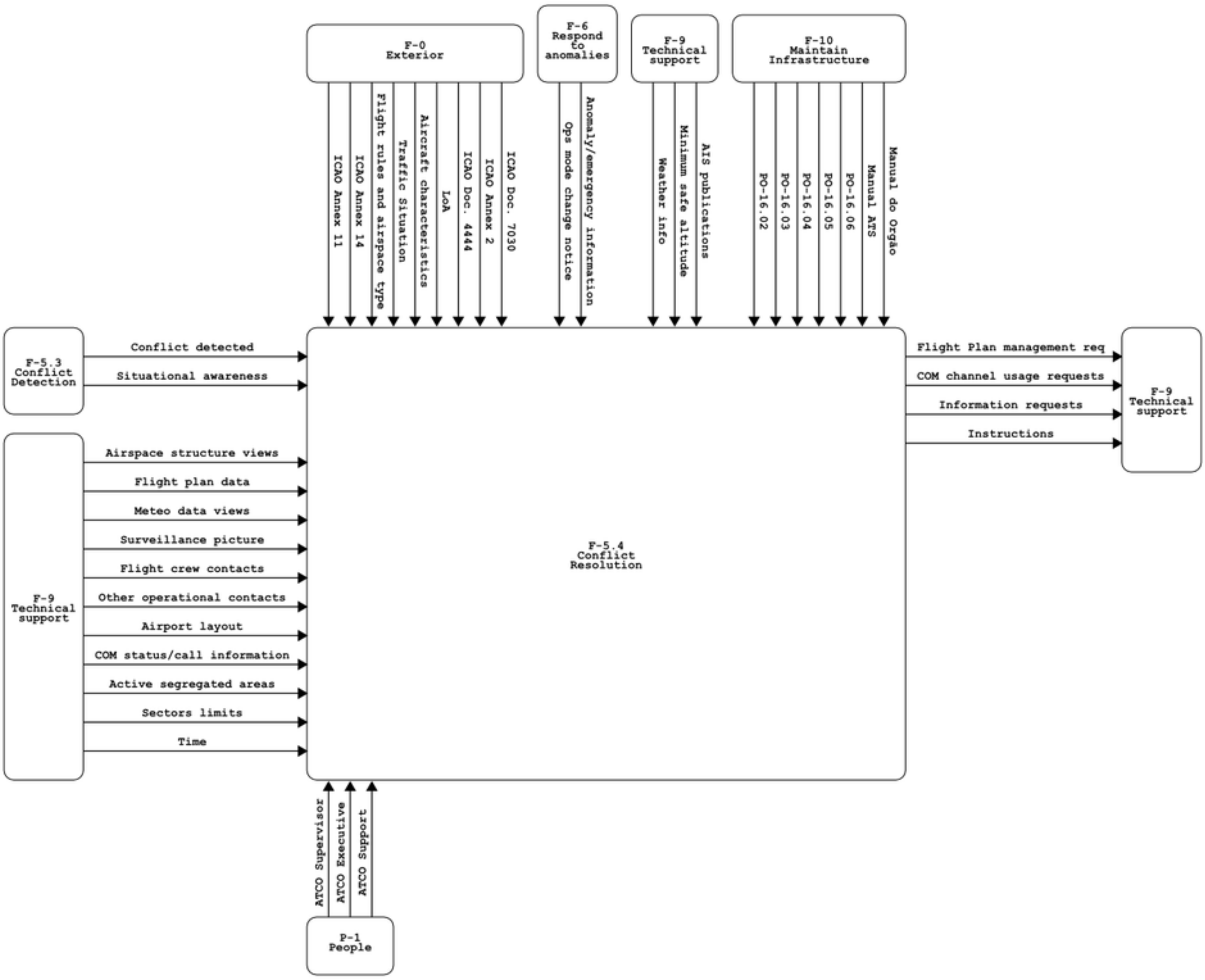


Figure 3. Conflict Resolution diagram

infrastructure. This function has been added and its decomposition is planned.

## IV. RESULTS

### A. *The model*

MARIA helps harmonization of the designation of functions which will facilitate the communication between ATM stakeholders. Inside NAV Portugal it is being integrated in the training of new staff and has been communicated to engineering and maintenance to foster harmonization and ease understanding.

The current version of the MARIA is the basis for the system description, covering people, procedures, equipment, regulation and external environment and is starting to be used for safety analysis and impact assessment. It describes both the system functions and the architecture with all its mechanisms. The knowledge database describes a generic model, with all functions and enablers for the Lisbon Flight Information Region (FIR). From this base the architecture for each unit, understood here as a site where NAV Portugal provides air traffic services, in the Lisbon FIR can be obtained. To describe the architecture of each unit, the following assumptions were taken: each unit has a subset of the model functions which means that some functions might be deactivated; the enablers for each function may differ from site to site; some functions are performed centrally which means that the unit receives the results of these functions from the “Exterior”; there are enablers that support functions at several units and are only mapped at the unit which has the responsibility to maintain them. The architecture description for all units can be now automatically obtained and the local architecture of all the NAV Portugal control units of the Lisbon FIR was done in this way.

The impact of equipment failure can be derived from the model in terms of the functions directly and indirectly impaired at each unit. This information will be used to adapt the monitoring indicators.

In terms of dimension there is a maximum of seven levels of decomposition for the functions. Each node has as properties: Name, Parent, Unit, Extras and Type (optional); each flow is described by: Name, Parent, Origin, Control, Destination, Enabler, Extras and Unit (optional). The following table provides information MARIA’s current dimension.

TABLE II. 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 |

### B. *The framework*

The fact that there are a lot of unknowns about any representation of the system constrained the development of the framework by imposing that it should be open allowing the easy addition of new properties to the existing descriptions, and new areas or systems, e.g. the aircraft functions.

All functions, data flows, connections and hierarchy were coded in YAML [10], a human-readable data serialization format. YAML 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. This data is considered to be a knowledge database which can easily be enlarged 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 of the knowledge database and to produce views.

Currently the framework provides the following automated functionalities: loading, checking, filtering, and documentation production. The automatic generation of documentation creates graphics as the one in Figure 3, web pages in html format, and open document format. The automation is done using Python [11], a widely used scripting programming language. The checking functionality automatically verifies that the knowledge database is coherent, that all flows have a start and an end, all functions and flows have a parent except for the top level ones, the functional decomposition does not loose or create flows. It also checks that for each unit the coherence exists.

SADT diagrams can be seen as a set of nodes for the functions, and arcs for the data flows. The coding approach defines functions and their hierarchy and uses them as source and sink of the data flows. This approach results in a graph where the nodes are functions and the arcs are data flows, conveying a structure where graph theory, with all its potential, can be applied to perform analysis.

The current version is static, lacking information on dynamic properties of the system. Functional Resonance Analysis Method (FRAM) [2] is proposed to model complex socio-technical systems and is based on SADT adding two new “sides” to the function description, namely time and preconditions. These two new properties describe dynamics and thus adding these new features to the functions is a way to integrate dynamics in the existing model. The main difficulty will be to obtain this information for the existing system. Adding it in the current knowledge database will be straightforward. Variability is another FRAM characteristic associated with the system dynamics, used to explain why functions can become coupled and how this leads to unexpected outcomes. It is a function property relevant for the outputs and studies are needed to find the best way to add this knowledge to the model.

TABLE III. SADT – FRAM MAPPING

| SADT | FRAM |
|---|---|
| Input | Input |
| Output | Output |
| Control | Control |
| Enabler | Resource |
| --- | Time |
| --- | Precondition |

### C. *Trials*

A study was done to verify if MARIA could be used to identify Hazards. Considering that hazards should be identified at service level, thus one should look at the border of the system. A subset of the system outputs in the model is shown in the following picture:

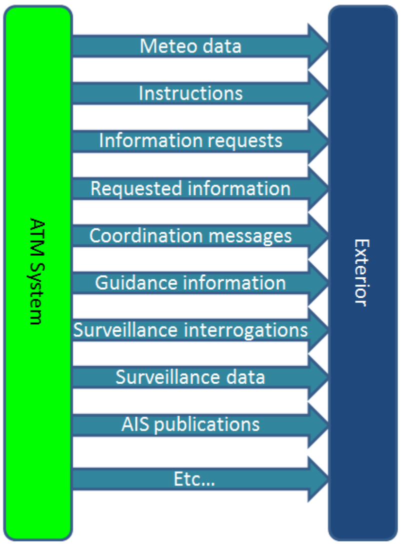


Figure 4. System outputs

An ATM unit is providing the following services as described in ICAO PANS-ATM: Air traffic control including separation, vectoring, monitoring and watch; flight information service to provide traffic information and alerting services. This means that the outputs of the ATM unit to the exterior are providing data for separation, vectoring, traffic information and alerts.

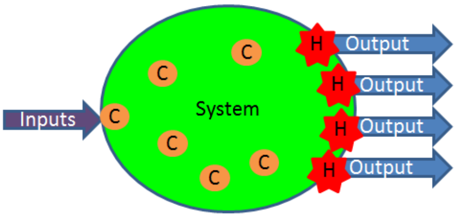


Figure 5. Causes and Hazards

One can see the ATM unit as a data provider (outputs) and a data consumer (inputs). The absence of an output or a bad output can lead to a hazard. The possible cause can be the absence or a corrupted input to the ATM unit or a wrong internal behavior as shown in Figure 5. An FHA (Functional Hazard Assessment) session for the Lisbon ACC (Area Control Center) used MARIA and AIM as a base to identify hazards as is usually done at NAV Portugal: find the ways that a function can fail (failure modes) and what the possible consequences are. Checking against the model it was found that some hazards were missing while others were outside the scope of the ATM unit. Combined failures, including the complete failure of the ACC, were not identified. Failure of resolution of vertical aircraft deviation due to inadequate pilot response to ATC is not a hazard with ATM contribution. This indicates that the two approaches are complementary and should be used in combination.

This study pointed out that additional data flow decomposition could be useful to allow better separation of the contents, for example, the "Instructions" flow is enough for some analysis, but for hazard identification it would be better to see "Instructions" as a composition of "Conflict Resolution Instruction", "Collision avoidance Instruction", "Sequencing Instruction", and so on.

An experiment was done to check if causes of hazards could be automatically extracted from the model. Considering that the absence of an output or a bad output can lead to a hazard, it was checked whether it was possible to automatically generate a fault tree using the model. Starting with the output associated to the hazards and going backwards in the model, one can find the source of this output and the function responsible for it. Then one can iterate further to get the complete fault tree. Let's picture an example of a hazard: Failure of collision avoidance due to inadequate or non-existent instruction to the pilot. It is a problem with the flow "Instructions" coming from the "Technical Support" function. Going deeper to the root of the instructions the enablers that can cause this failure are identified and also the functions that are originating the instructions, including the function Manage Traffic. At the end the complete fault tree is obtained and then using exiting algorithms the minimal cut set is calculated.

Fault trees were automatically generated with success by a dedicated functionality from the framework. To have better results each output should be linked to the inputs as well as the enablers required for its generation and not to all the function inputs and enablers.

### D. *Differentiating aspects*

The definition of the scope, covering all that is done to provide a safe ATM service, having a top-down approach, treating human as part of the system and not as an external entity using the system are differences to the existing models.

The systematic and uniform description of every function using an existing notation that can be mapped in a graph, allowing for mathematical processing and automation of analysis and representation are a significant advantage for analysis.

MARIA is independent from the underlying technology or implementation as it only covers the functions and the information flows.

The possibility to plug in new knowledge on top of the model without affecting it, allows other views to be envisaged.

## V. EVOLUTION

The modelled system is a combination of human resources, procedures and equipment organized to perform air traffic management (ATM). It is a complex socio-technical system thus having the properties of an intractable system [2], so any representation will always be incomplete, having unknowns. With this in mind it is considered that the MARIA is already mature enough for several purposes and will be enhanced whenever new applications integrate additional knowledge.

Modelling the dynamics and the unknown are areas of planned study, 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 reality is not black and white, Boolean logic is sometimes limited for analysis. A function has several states and a flow also. These aspects can be covered 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 following figure depicts the existing knowledge and framework database and possible evolution plug-ins, covering the three layers:

- The model in green
- The coded knowledge inside the dark blue box
- The automated view inside the turquoise box and reliant on the coded knowledge

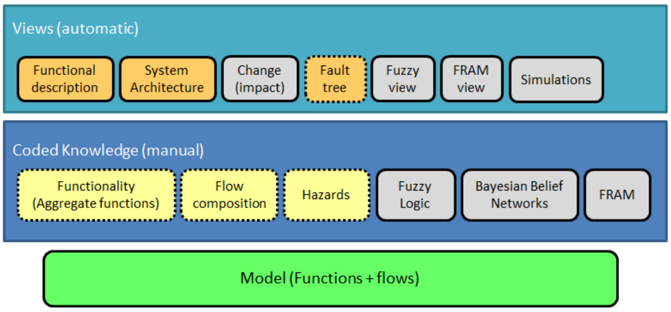


Figure 6. Potential MARIA evolution

Notes on figure above:

- Green, yellow and orange boxes: Already existing
- Straight line: Finished
- Dotted boxes: Work started
- Grey boxes: To be added

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.

The used approach allows for expansion, both by adding new aspects such as variability or dynamics and by adding new functions of further detail.

The current MARIA version does not cater for the dynamics but is a solid basis for further enhancements. It covers the services provided by an ANSP, and decomposes them to the level where responsibilities can be attributed to a single equipment or person. The separation between cognitive and technical functions is a strategy that proved to make it easier to achieve this decomposition in a straight forward manner.

## VI. CONCLUSION

MARIA is a knowledge database and an automation framework providing a global view of the ATM system, covering the high level, abstract functions, and their decomposition to the system's building blocks (components) and their interactions. It is an answer to the need for a better knowledge and understanding of current ATM systems, and a basis for safety assessments being done at system level.

Its wide communication and usage in training will solve the problem identified during the interviews, allowing people to know why and to whom their work is done, having a high level picture of the business they are in.

MARIA covers all that is done to provide a safe ATM service, treating the human as part of the system and responsible for functions, while depending on the technical support, aligned with the view of most practitioners in this area. The extensive validation provides confidence that it is mature. Initial trials have been carried out showing the potential of this knowledge database. New insights can be added enriching both the model and the possibilities of analysis.

Having a repository covering all that is done to provide an ATM service, in a systematic and uniform way, structured in top-down manner, with the human as an integral part of the system, allowing automation of analysis and representation are significant advantages to improve understanding, safety and resilience of the ATM services. Sharing this knowledge database and adding the contributions from other models and interested partners will be beneficial for the ATM world.


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## Biographies

Mrs. Paula Santos has been working in ATM since 1990, in the areas of HMI development, Surveillance, quality of internal software developments and safety, first as a contractor and since 2002 as internal staff. She holds an Engineer degree in Electrical and Telecommunications from Instituto Superior Técnico (IST) (1986) where she taught mathematics (1985-1987). She worked in banking systems before coming to ATM. She is responsible for the surveillance data processing systems and represents NAV Portugal in the associated international fora. She is leading the implementation of regulation EC 482/2008 and other associated regulatory requirements.

Mr. Paulo Monteiro has been working in ATM since 1996, in the areas of HMI development and systems engineering, first as a contractor and since 2002 as internal staff. He holds an Engineer degree in Electronics and Telecommunications from Universidade de Aveiro (UA) (1995) and post-graduation in Software Engineering from Universidade de Lisboa (UL-FCT) (2000). He has participated in SWIM-SUIT and is now working in SESAR.