# A SYSTEM WIDE INFORMATION MANAGEMENT ARCHITECTURE PROPOSAL FOR BRAZILIAN SCENARIOS

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## ABSTRACT

The System Wide Information Management (SWIM) aims to provide information sharing and integrate technologies related to Air Traffic Management (ATM), increasing the airspace security and the level of decision-making. The two main examples of SWIM implementation are SESAR, in Europe, and NextGen, in the USA. In Brazil, despite the initiatives related to ATM information processing, such as SAGITARIO and SIGMA, a deployment of a SWIM ecosystem is still required for the implementation of interoperable services. This work presents a review of the main concepts of SWIM and an architecture proposal for the implementation of Brazilian SWIM.

**Keywords**: System Wide Information Management, Air Traffic Management, SWIM Architecture, SWIM Registry, interoperable services.

## 1. INTRODUCTION

Over the last decades, air traffic demand has increased all around the world, and this trend is predicted to continue during the next years. As a result, new air traffic flow management solutions are being developed as described in global air navigation plan (GANP) of the International Civil Aviation Organization (ICAO) (ICAO, 2013). For this purpose, different programs have started to enhance navigation solutions such as the Single European Sky ATM Research (SESAR) in Europe, and the Next Generation Air Transportation System (NextGen) in U.S. These programs converge in promoting the evolution of air traffic management (ATM) into an automated, integrated, and interoperable environment.

In this context, arises the SWIM concept, which comprises standards, infrastructure, and governance enabling the management of ATM information and exchange between qualified parties via interoperable services (ICAO, 2015).

The scope of SWIM, illustrated in Figure 1, includes the information exchange standards and the infrastructure required to exchange information between SWIM-enabled applications. SWIM-enabled applications consume or provide SWIM information services using SWIM standards.

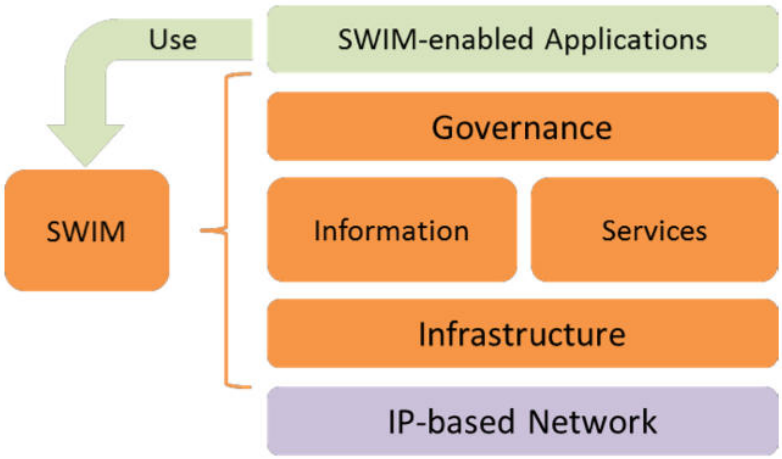



**Figure 1**: The Scope of SWIM (ICAO, 2015).

SWIM contributes to: improved decision making by all stakeholders during all strategic and tactical phases of flight (pre-flight, in-flight and post-flight) through more availability of quality data and information; more flexible and cost-effective communications by the application of common standards for information exchange; and loose coupling which minimizes the impact of changes between information producers and consumers (ICAO, 2015).

Global interoperability between service providers, aerodromes, industries and other stakeholders does not require the same functional architecture of the SWIM in all the SWIM implementations. Therefore, each SWIM enterprise implementation may develop different architectures. It is anticipated that some architectures will be implemented based on Regional Air Navigation Agreements, following appropriate coordination with affected SWIM stakeholders (ICAO, 2015).

This work aims to present an architecture proposal for the implementation of SWIM in Brazil. In the following sections, concepts about SWIM will be presented. Then, one of the main current implementations, aligned with the SWIM concept (NextGen), will be cited, focusing on the particularities that contribute to the Brazilian environment. Finally, the SWIM architecture proposal for the Brazilian scenario will be presented.

## 2. SWIM GOVERNANCE

The implementation of SWIM represents a challenge for the ATM community. Chief limitations are: systems have not been designed and implemented to be globally interoperable within globally-agreed parameters; many interfaces, which were designed to support point-to-point or application-to-application exchanges, have limited flexibility to accommodate new users, additional systems, new content or changed formats; message-size limitations and a non-scalable approach to information exchange with the present infrastructure; the current variety of systems and exchange models makes it challenging to devise security frameworks across systems and stakeholders so as to support the increasing need for open and timely data exchange whilst at the same time respecting the legitimate security concerns of all stakeholders; and currently, most organizations manage their ATM information in partial isolation leading to duplication and inconsistencies (ICAO, 2015).

The obstacles listed above can be overcome by creating an environment for interoperability between applications, which can be achieved on a global scale with common information exchange models, use of common services for information exchange and use of appropriated technology and standards. Governance is an important ally in achieving the necessary interoperability within SWIM.

SWIM governance is characterized by the people, policies, and processes required for leading, communicating, guiding, and enforcing the stakeholder organizational behaviors needed for global interoperability (ICAO, 2015).

Governance is essential in a tightly coupled environment such as SWIM, where services are provided and consumed by multiple entities. Furthermore, governance establishes the processes to ensure that appropriate rules, policies and standards are followed, and defines the chains of responsibility, authority, and communication, as well as measurement and control mechanisms to enable participants to perform their roles and responsibilities.

The infrastructure, standards and management of information all need to be governed. Examples of this governance include the need to: define who is involved in the approval and in the evolution of standards; define the processes to be followed; define the SWIM infrastructure to be provided by members; establish a common set of regulatory policies and standards; promote semantic and structural interoperability among stakeholders by developing a common set of semantic and structural artifacts (e.g. taxonomies, ontologies, controlled vocabularies); and define and establish governance structures at global, regional and local levels (ICAO, 2015).

The focus of this work is on the infrastructure necessary for the implementation of SWIM considering the Brazilian scenario. In the next sections, we will present the concepts needed to understand the functionalities that are the responsibility of the infrastructure layer, which should be fully aligned with the governance activities defined in the SWIM context.

## 3. SWIM IMPLEMENTATION

### 3.1. SERVICE-ORIENTED ARCHITECTURE (SOA)

Service-Oriented Architecture (SOA) is a general concept or paradigm for “organizing and utilizing distributed capabilities that may be under the control of different owners” (OASIS, 2017). While there is no formally agreed definition of SOA, it is generally considered that partitioning of functionality into unassociated, self-contained and, therefore, reusable services that can be discovered by potential users is a key feature that discriminates SOA from more traditional architectural paradigms.

In the SWIM context, a service orientation is used for represent and define information exchanges between SWIM stakeholders, that is, an information provider publishes and exposes its services for the use of information consumers; this is done via interconnected registries which list the services and the specific details for consuming them. One of the benefits of SOA is the

promotion of “loose coupling”. Loose coupling means that an information provider has a reduced impact on the information consumer. Dependencies are minimized allowing components and services to operate with as little knowledge as possible of other components or services (i.e. a consumer should need to understand only what is absolutely required to invoke a service and no more) (ICAO, 2015).

Therefore, the SOA concept applied to SWIM will allow, among other benefits: the delivery of services in a more agile way; cost reduction through the reuse of existing technologies; and the development of simpler systems with lower maintenance and integration costs with widely used industry standards.

## 3.2. SWIM FRAMEWORK

The SWIM framework is based on a layered interoperability framework, each layer having its own functions, pattern matching, and interoperability mechanisms.

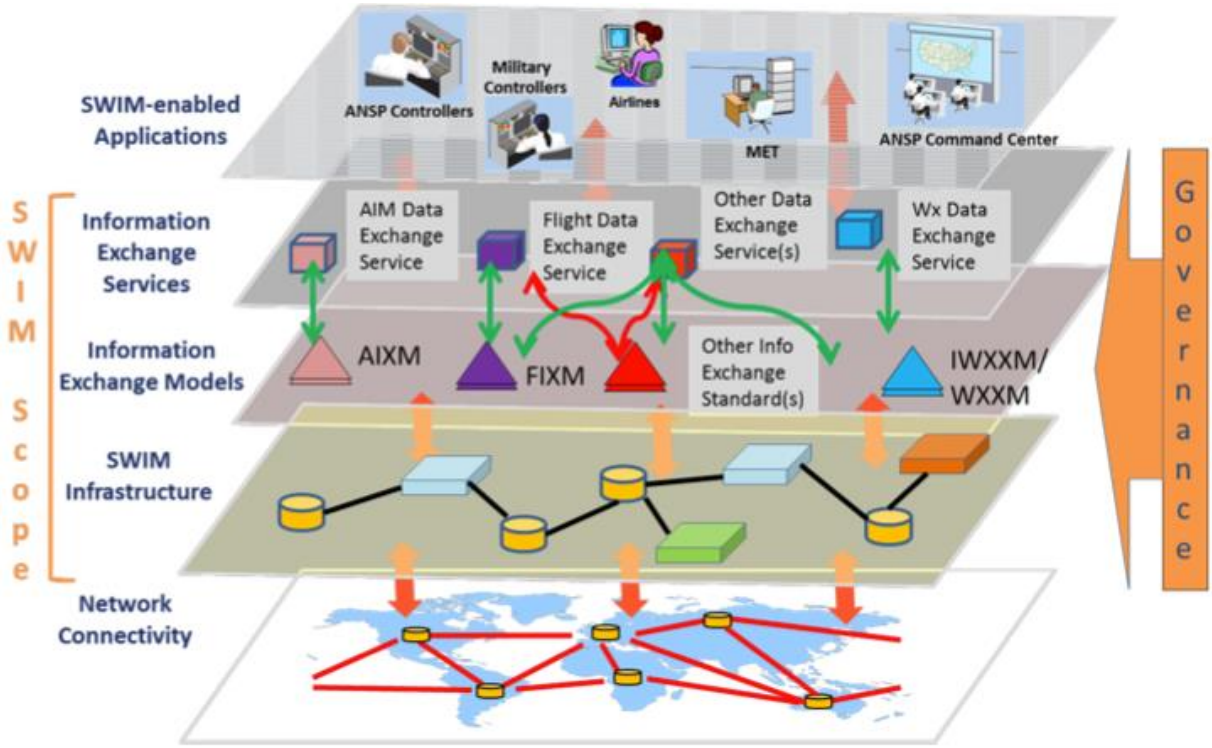



**Figure 2**: SWIM Global Interoperability Framework (ICAO, 2015).

The SWIM interoperability framework (see Figure 2) comprises the following layers: SWIM-enabled applications of information providers and information; information exchange services defined for each ATM information domain and for cross-domain purposes; information exchange models using subject-specific standards for sharing information for the above information exchange services; infrastructure provides the core services for sharing information; and network connectivity provides consolidated telecommunications services.

The scope of SWIM is limited to the three middle layers (i.e. Information Exchange Services, Information Exchange Models, and SWIM Infrastructure) and to the governance of these layers (ICAO, 2015). The purpose of each layer in the SWIM interoperability framework is described as follows:

a) SWIM-enabled application: comprises the systems able to request an information service. Semantic interoperability based on a common understanding of the information used is required.

b) Information Exchange Services: the characteristics of the requested information service are described in a technology-neutral manner.

c) Information Exchange Models: the characteristics of the data being used by the information exchange services are described, including a description of the information content, structure and format.

d) Infrastructure: provides core SWIM services such as interface management, messaging, service security, and enterprise service management. At this layer, application level messages required to deliver the requested information service are implemented in accordance with a defined protocol for interoperability with the service deliverer through interface management functions that also manage performance requirements.

e) Network Connectivity: the message is transported over a global network, where it is delivered to a specified recipient responsible for providing the application-level message to the recipient SWIM enabled application.

Table 1 provides an overview of the functions and patterns associated with the different layers of the SWIM framework, including an initial set of candidate patterns (additional patterns may be added as needed).

***Table 1: Overview of SWIM framework's functions and standards***

| ***Layer of framework*** | ***Functions or sub layers*** | ***Candidate standards, models, implementations*** |
|---|---|---|
| SWIM-enabled Applications | | ATS, ATFM, Airline Ops |
| Information Exchange Services | Service interoperability, interface definition | OGC CS-W, WSDL, WADL, WFS, WMS, WCS |
| Information Exchange Models and Schemas | Aeronautical, meteorological and flight information, semantic interoperability | AIXM, WXXM, IWXXM, FIXM, FIXS, AIXS, WXXS |
| SWIM Infrastructure | Policy, interface management (service registration), data representation, messaging, transport, service registry | AIRM, RDF/RDFS, OWL, DDS, JMX, SNMP, XML, XSD, SOAP, JMS, DDS, HTTP, MQ, UDDI |
| Network Connectivity | Secure network connectivity, naming and addressing, identity management, incident detection and response | IPv4, IPv6, DNS |

It is clear that "one size fits all" may not be the most desirable solution at a global level as different stakeholders will be driven by differing performance expectations and circumstances. As a result, a global SWIM will be achieved through the inter-operation of potentially a variety of implementations. In this context, the concept of the SWIM region arises, which comprises a region bounded by an influence area of a given governance structure - standards, policies, etc. (ICAO, 2012).

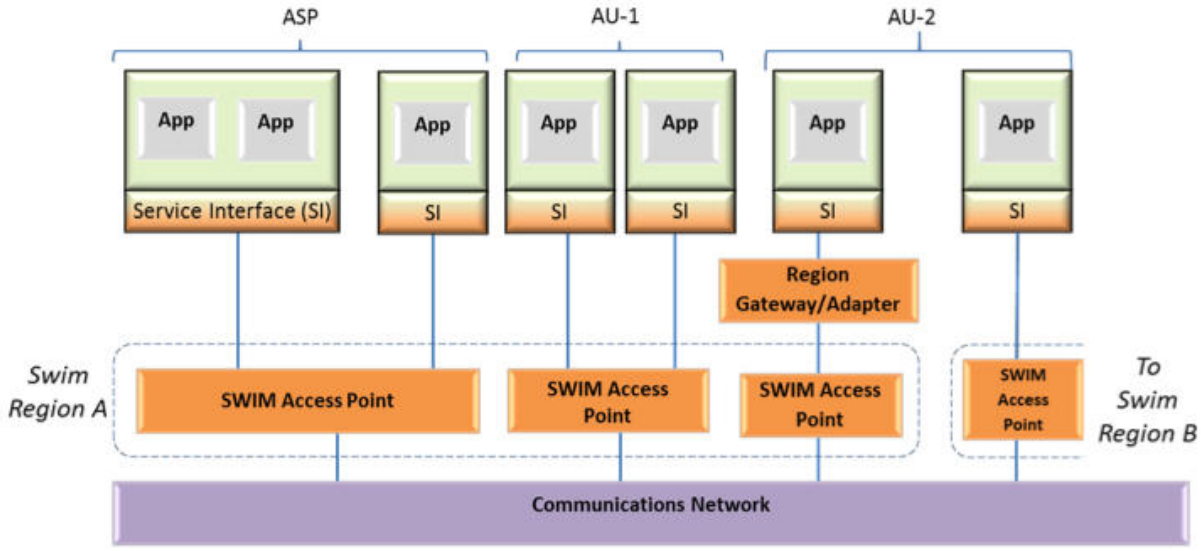



**Figure 3**: Illustration of Enterprises and SWIM Region (ICAO, 2015).

Within a SWIM Region, a collection of participants may choose to inter-operate using standards established for that particular SWIM region. In turn, each enterprise may organize itself with whatever standards it deems appropriate to apply internally, provided they can interoperate with the SWIM region standards. Furthermore, a much richer set of services would likely be available within an enterprise. Provider/consumer systems belonging to an enterprise will connect to SWIM via SWIM access points, which are logical entities that provide SWIM core services such as messaging, interface management, security, etc. (ICAO, 2015).

### 3.3. FAA SWIM PROGRAM

In 2007, the Federal Aviation Administration (FAA), a national authority with powers to regulate all aspects of civil aviation in the United States, established the SWIM Program to implement a set of Information Technology principles in the National Airspace System (NAS) and provide users with relevant and commonly understandable information.

In the past, the state of the art for connecting two systems required a fixed network connection and custom, point-to-point, application-level data interfaces. Current NAS operations depend upon these legacy information systems with some systems entirely unconnected. The Federal Aviation Administration (FAA) identified a need to reduce the high degree of interdependence among systems and move away from the proliferation of unique, point-to-point application interfaces (FAA, 2017).

Figure 4 illustrates FAA's SWIM architecture in terms of the key components required to implement the interoperability framework.

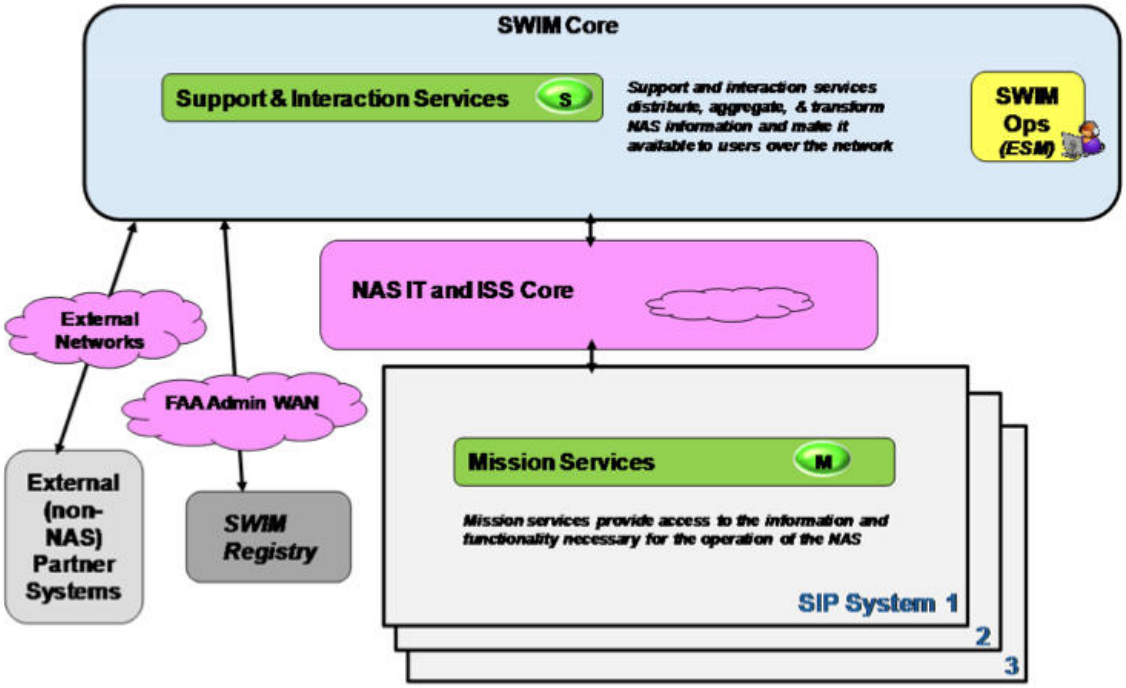



**Figure 4:** Overview of SWIM architecture (MITRE, 2009).

The SWIM architecture components illustrated above are grouped into six main areas (MITRE, 2009):

a) Enterprise Messaging Bus (EMB): is a set of components that allow NAS systems and services to interoperate by connecting them together in a loosely coupled manner;
b) Web Hosting: includes web application hosting platforms that can be used to support the operation of NAS interaction services;
c) Collaboration: describes architecture components to support the collaboration functions;
d) Interface Management (Registry): includes governance and publishing/discovery of service information activities, represented by the NAS Service Registry/Repository (NSRR);
e) Enterprise Service Management (ESM): includes service fault and performance monitoring and reporting, policy enforcement, Service Level Agreement (SLA) compliance checking and service scorecard generation; and
f) Security: describes not just the controls that will be used to secure SWIM systems and information content, but also how SWIM contributes to the overall security of the NAS.

## 4. SWIM PROPOSAL FOR BRAZILIAN SCENARIOS

### 4.1. SWIM REGISTRY BRAZIL

The SWIM Registry Brazil, developed by TransLab (UnB), with collaboration of Boeing and ICEA/DECEA, SWIM authority in Brazil, can be considered as the first effective step for the development of Brazilian SWIM (TransLab, 2017).

Achieving interoperability across all ATM areas requires governance. The SWIM registry is the key element which brings SWIM related interoperability artifacts together and enables policy enforcement where required. It allows information providers to publish services and information consumers to find appropriate services based on the information exposed by the registry. Furthermore, the registry brings together qualified parties as trusted partners. Finally, the registry enables collaborative lifecycle management enabling participants to progressively plan and engage (ICAO, 2015).

The SWIM Registry Brazil provides the Brazilian ATM community with essential functions of the SWIM concept, highlighting (TransLab, 2017):

a) Searching for information about available services;
b) Service publication/registration by providers;
c) Service subscription, which enables interested stakeholders to receive communications about changes in specific services;
d) Service lifecycle management, contemplating all phases, from conception to its disuse; and
e) Policy search/subscribe, representing an efficient communication in the context of governance.

## 4.2. SWIM ARCHITECTURE FOR BRAZILIAN SCENARIOS

The SWIM infrastructure may have distinct architectures (functional, physical). Therefore, a generic architecture concept is desirable enough to accommodate different implementations. This concept of architecture is known "SWIM access point".

A SWIM access point is a logical entity that bundles a number of technical capabilities (e.g. messaging, security, logging, interface management, etc.). The SWIM infrastructure is the collection of the SWIM access points that will be implemented by information providers as well as by information consumers. The options of implementation of SWIM access points are shown in Figure 5 (ICAO, 2015).

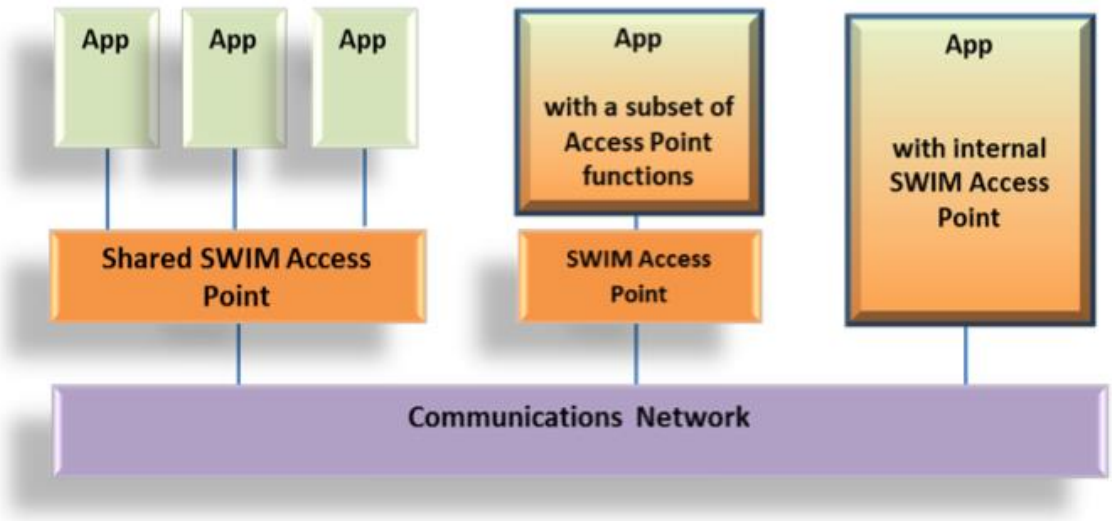



**Figure 5**: SWIM Access Point Implementation Options (ICAO, 2015).

SWIM distinguishes between SWIM application services (SAS) and SWIM core services. SAS are available – i.e. visible, discoverable, usable – to authorized systems. The service application interface of a system is the functional component that makes SAS services available to other authorized systems in a manner that conforms to the technical standards identified by SWIM.

On the other hand, the SWIM core services are not visible to other systems but are fundamental mechanisms that enable consumption of services and information sharing. These core services are solution agnostic (not limited to a single process or solution environment) and have a high degree of autonomy so that they support reuse (ICAO, 2015). The core services are:

a) Interface management, which provides a standard interoperable means for description, access, invocation, and manipulation of resources to enable compatible communications between ATM information providers and consumers;

b) Messaging includes functions that support message exchanges and enables message routing and the distribution of content, as well as functions for efficiently and reliably delivering that content across SWIM in a secure fashion;

c) Service security provides functions that are used by systems and core services to ensure that SWIM services are provided in accordance with established security policies. These functions include authentication, authorization, confidentiality, integrity, and access control functions; and

d) Enterprise service management (ESM) supports the management of the information services associated with providers and consumers, as well as the management of supporting SWIM core services themselves. ESM includes the monitoring and control of faults, configuration, accounting, performance, and security.

Finally, the technical architecture of SWIM provides a view of the standards used, emphasizing the use of web services standards, as they are widely used standards in the context of SOA to improve interoperability and flexibility. The intent of the SWIM architecture is to allow other standards to be used when necessary, while maintaining the general principles of SOA. For this, SWIM components must be able to include information about provided services using a variety of different technologies and standards. Likewise, the basic components of SWIM should be designed, as far as possible, so that a variety of different technologies and standards are supported (ICAO, 2015).

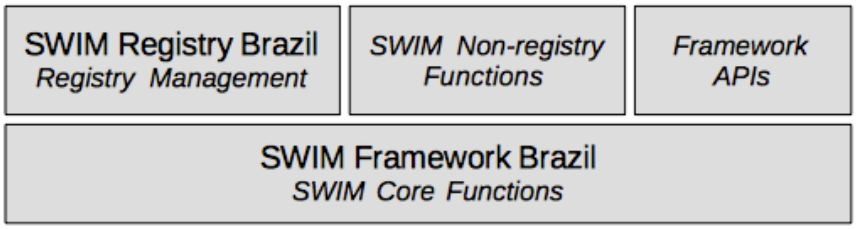



**Figure 6**: SWIM Framework for Brazilian Scenarios

The implementation of SWIM in Brazil is beginning with the SWIM Registry and establishing other activities supported by SWIM, differently from the other main projects (FAA and EUROCONTROL). In this way, it is possible to plan the adoption of a framework, SWIM-BR, shown in Figure 6, which provides a set of functions to SWIM community, that:

a) Are complementary or integrated to the SWIM Registry;
b) Belong to the core functions group of the SWIM infrastructure layer, but which are not part of the scope of the SWIM Registry; and
c) Can be gathered in APIs that allow the creation of SWIM access points by ATM members.

The three types of functions described above correspond to the different ways of viewing the functionalities that must be present in the infrastructure layer of SWIM, as described in section 3. Thus, the SWIM-BR framework should contemplate three distinct scenarios: support to SWIM Registry Brazil; provision of infrastructure layer functions that are not implemented in SWIM Registry Brazil; and provision of libraries that enable applications to communicate directly with SWIM, according to the concept of access point.

In the first scenario, many of the functions of the infrastructure layer, such as service management, publishing and service discovery, among others, are already present in SWIM Registry Brazil. However, it is necessary to implement basic functions of the SWIM framework that allow the full use of SWIM Registry Brazil and its integration with the SWIM access points that will be implemented.

In the second scenario, the SWIM-BR framework should provide basic SWIM functions that are not implemented in SWIM Registry Brazil, such as performance management, messaging, security, auditing, among others.

Finally, in the third scenario, the focus is on applications being able to communicate directly with the SWIM infrastructure, implementing a SWIM access point internally to the application. In this case, it is necessary to provide a set of libraries, APIs and other connectivity mechanisms that deliver the basic functions of SWIM and allow a correct integration with SWIM-BR.

The proposal presented may represent a modernization of the *Sistema de Controle do Espaço Aéreo Brasileiro* (SISCEAB), a set of units and facilities that aims to provide regularity, safety and efficiency of traffic flow in airports and airspace, through its adherence to the SWIM standard. An example of the opportunities that will be opened is the incorporation of the Airport-CDM concept that will improve operational efficiency, predictability and timeliness for the ATM network and aerodrome stakeholders (Costa, 2014).

### 4.3. ATM SEMANTICS IN SWIM CONTEXT

The volume of aviation data generated by industry and government sources has grown steadily over the past decade as an increasing number of data providers have begun publishing their data through various digital distribution methods. This trend has been a boon to those in the industry who use data to improve aviation systems, derive cost savings, enhance safety, and analyze bottlenecks. However, along with additional data comes increased data management complexity (Keller, 2016).

Managing data from multiple sources in a consistent and coherent fashion can be a significant challenge for any enterprise. Typically, data models are developed to manage the data generated, used, and stored by a given enterprise. A data model encodes the structure, format, and constraints on stored data values, as well as their relationship(s) to real-world entities that give rise to the data. Unfortunately, aviation data providers can employ quite different data models, and these data models can vary along various dimensions: data encoding format; data field naming; data semantics; spatial and temporal resolution; measurement unit conventions; and data organization principles (Keller, 2016).

The use of ontologies has advantages when compared to traditional data models: they serve both as a specification and implementation language, since they describe objects at the abstract level and current instances, which is not the case with UML, XML and SQL; its modularization makes incremental changes relatively simple; are constructed on principles of formal logic, which can be used to extract inferences based on rules of logic; RDF and OWL ontologies are developed for the distributed web environment (repositories); and data and metadata can be manipulated using the same graph-based language (SPARQL) (Keller, 2016).

The SWIM Registry enables its users to search and discover services provided by different providers, but the identification of services that can be used in a complementary way requires enormous research effort. Ontology can be applied in this context, making the composition of services a transparent activity for users.

According to the W3C, ontology is the technology that provides the basis for constructing the semantic web because it contains a common set of terms for describing and representing domains. Automated tools can use the stored data more consciously, and can better manage knowledge. In order to a correct semantic interoperability, we need shared sources of precisely defined concepts, exactly where ontologies play a fundamental role (Santos, 2016).

Although some ontology languages offer ways of mapping one ontology to another, they do not have a way of classifying the similarity between concepts or making plausible inferences about mapping between them. Providing this feature is an important step in making the semantic mapping problem a less expensive, tedious and error prone process.

The Bayesian probability theory provides a means to represent and learn about a variety of uncertain data, being a natural candidate for providing the probabilistic framework for the semantic web. The PR-OWL (probabilistic-OWL) makes use of Bayesian theory to represent uncertainty in the semantic web, providing a structure for reasoning and learning of data in the context of the web in an interoperable way, so that the probabilistic ontologies that were constructed for different purposes would have a common underlying architecture guaranteeing the exchange of information in a useful and meaningful way (Santos, 2016).

The PR-OWL and the extension PR-OWL 2 RL (Costa, 2005) are examples of proposed approaches for the treatment of uncertainty in the semantic web, and that can also be applied for the treatment of uncertainty in the context of aviation data.

## 5. CONCLUSION

The present work aims to present an architecture proposal for the implementation of SWIM in Brazil. As a way of introducing the main SWIM concepts, some sections were dedicated to the definition of the concept of governance, a fundamental discipline for the creation of a collaborative environment composed of several actors with different objectives, and for the description of the proposed interoperability framework by ICAO.

The second part of the work applied the concepts detailed previously to the Brazilian scenario. Firstly, SWIM Registry Brazil was described, the first step in the implementation of SWIM in Brazil, and the proposed SWIM-BR framework, which will implement the basic functionalities of SWIM framework. Finally, a section has been devoted to ATM semantics in the context of SWIM, which may represent a major evolution in the way services can be used.

The implementation of a project as large as SWIM is not an easy task and requires dedication and collaboration of all participants in the ATM environment. Thus, the present work proposes to be an initial step so that other SWIM products, essential to its operation, can be developed.

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