# Development of SWIM Registry for Air Traffic Management with the Blockchain Support

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***Abstract*— System Wide Information Management (SWIM) including SWIM Registry for Air Traffic Management (ATM) has been successfully developed and applied in Europe and United States. The most of developing countries have just started to study the employment of SWIM conceipt, which its establishment is required prior to the development of SWIM Registry. In this paper, we introduce the experience of the development of SWIM Registry Brazil, which comprises the study of the architecture, components, services and data accessing. In order to encourage consumers and providers to participate in the SWIM community, we developed a prototype of SWIM Registry Demonstration for the Brazilian ATM society. We propose a model based on Blockchain for managing services currently provided by Brazilian ATM in order to certificate operations which are performed by consumers, authorities and involved stakeholders. The proposed model is ecpected to provide services for SWIM Registry with integrity, efficiency, security and authenticity, which are fundamental for the proper operation of Brazilian aviation system.**

## I. INTRODUCTION

Over the last decades, air traffic demand has increased all around the world and this trend is predicted to continue for the next years. As a result, new Air Traffic Management (ATM) solutions are being developed as described by the global air navigation plan (GANP) of the International Civil Aviation Organization (ICAO) [1]. 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 United States. These programs converge in promoting the evolution of ATM into an automated, integrated and inter-operable environment [2] [3].

The System Wide Information Management (SWIM) concept comprises standards, infrastructure, and governance enabling the management and exchange of ATM information between qualified parties through inter-operable services [4]. One of the services incorporated in SWIM Registry Brazil refers to the storage and secure access of information. In order to provide secure resources for registration and access of the information in SWIM Registry, we studied the employment of the well-know blockchain technology in support of ATM SWIM Registry Brazil implementation.

A blockchain is essentially a distributed database of records, or public ledger of all transactions or digital events that have been executed and shared among participating parties [5]. Each transaction in the public ledger is verified by consensus of a majority of the participants in the system. Once entered, information can never be erased. The blockchain contains a certain and verifiable record of every single transaction ever made [5]. The main hypothesis is that the blockchain establishes a system of creating a distributed consensus in the digital online world. This allows participating entities to know for certain that a digital event happened by creating an irrefutable record in a public ledger. There are tremendous opportunities in this disruptive technology and the interest of the research community and the industry is constantly increasing [5].

This paper aims to present the development of SWIM Registry in Brazil using the blockchain technology and it is organized as follows. Section II describes the SWIM framework. Section III presents the SWIM Registry Brazil. Section IV describes the Blockchain method and its incorporation to SWIM Registry Brazil. Section V demonstrates a case study by considering the application of the blockchain to the context of the SWIM registry. Section VI provides the conclusions and discusses possibilities for future work.

## II. System Wide Information Management - SWIM

The System Wide Information Management (SWIM) is an oriented-service environment for representing and defining information exchanges between authorized stakeholders. The SWIM stakeholders work as information providers by publishing and exposing services for information consumers. The communication among stakeholders and consumers are carried out by interconnected registries, which list the services and the specific details for consuming them. One of the benefits of this service orientation approach is the promotion of “loose coupling”, in which an information provider is almost independent to the information consumer. Such dependencies are minimized by providing little knowledge as possible concerning other components or services, so that consumers need to understand the requirements when invoking services [4].

The SWIM framework is a layer-based interoperability framework, in which each layer presents specific functions, pattern matching and interoperability mechanisms. Particularly, SWIM comprises the following layers: SWIM-enabled applications of information providers and information; services for information exchange defined for each ATM information domain and for cross-domain purposes; information exchange models using subject-specific standards for

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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 such layers [4]. The purpose of each layer in the SWIM interoperability framework is described as follows:

1) 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.
2) Information exchange services: the characteristics of the requested information service are described in a technology-neutral manner.
3) Information exchange models: the characteristics of the data which are processed by the information exchange services are described, including a description of the information content, structure and format.
4) Infrastructure: provides core SWIM services such as interface management, messaging, service security, and enterprise service management. In this layer, the application level messages required to deliver the requested information service are implemented in accordance with a defined protocol. Such protocol allows the interoperability with the service deliverer through interface management functions that also manage performance requirements.
5) 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 II 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).

The SWIM Registry is the key element in SWIM that gathers features related to interoperability and allows the application of appropriate rules. It allows information producers to publish services and consumers find these services given the information available in the Registry [6]. The Registry aims to improve the visibility and accessibility of ATM-related information and services available in SWIM, allowing stakeholders to share a common SWIM view. It is the reference source for services available for SWIM applications. The Registry details the complete set of services, which are characterized by qualitative, consolidated and structured information, as well as its consumption conditions. Moreover, the Registry is the reference source for other information related to interoperability between services, such as information exchange models, infrastructure and policies.

## III. SWIM REGISTRY BRAZIL

The SWIM Registry is designed to fulfill these requirements. It is a single and consolidated source of references for ATM operation and development, which consists of services, applications, standards, policies and all ATM related information [4].

### A. SWIM Registry Architecture

The SWIM registry architecture consists of three main entities: service providers, service consumers and the regulatory authority [4]. Service providers are the organizations behind the implementation of SWIM related services. Service consumers refer to the organizations responsible for implementing SWIM enabled applications. They are accessed by SWIM enabled applications, as well as by other services. Applications are accessed directly by SWIM users to request specific information required to perform a given task. The SWIM regulatory authority supports the registration of services and applications in the registry. The regulatory authority is also responsible for publishing information related to services, such as standards, exchange models, policies etc.

In order to manage and catalog services properly, the SWIM Registry complies with some functionalities [4], in which the most important ones are listed below:

- Publish services in a standard manner;
- Search for SWIM related services and access their information;
- Manage updates and changes for services' information;
- Notify users and stakeholders of updates in services.

The task of publishing services is considered as the core functionality of the registry. The publication process follows previous agreed rules defined by the regulatory authority. The SWIM authority defines the policies that services comply in order to be recorded in the registry. This set of policies contributes to the governance and interoperability of SWIM.

Another core functionality of the registry is to enable consumers to query services. As a repository of services, the registry must offer a proper search engine with filters, allowing consumers to access its services. The registry architecture allows users to search for services by taking into account the number of attributes, such as ATM data categories, ATM activity categories, description, keywords, among others. The service discovery is closely related to the service registration in a way that registering useful services' metadata helps users to locate services in their search.

Management tasks when changing specific services in a clear and transparent manner is a desired feature of the registry architecture. This functionality can help users to distinguish services that have already migrated to the SWIM infrastructure from others and can enable users to check the progress of services in the SWIM platform. A notification system contributes to maintain the SWIM environment up-to-date [4]. For that purpose, the applications are upgraded when consuming applications are notified about updates in the provided services. Users can also be notified concerning updates the ATM related information, such as reference models, data exchange models and documentation. The system allows users to subscribe to services and other information of their interest to receive update notifications. Thus, users can observe updates in the list of subscribed services.

TABLE I
OVERVIEW OF SWIM FRAMEWORK'S FUNCTIONS [1].

| Layer of the framework | Function or sub-layer |
|---|---|
| SWIM-enabled Applications | - |
| Information Exchange Services | Service interoperability, interface definition |
| Information Exchange Models and Schemas | Aeronautical, semantic interoperability, meteorological and flight information |
| SWIM Infrastructure | Policy, service registration, data representation, messaging, transport and service registry |
| Network Connectivity | Security, naming and addressing, identity management, incident detection and response |

### B. SWIM Registry Brazil

The SWIM Registry Brazil is an endeavor to create a SWIM Registry for the Brazilian ATM environment and its associated project is currently hosted at TransLab at the University of Brasília.

SWIM Registry Brazil was designed in a way to grant access to users according to the role they played in the registry. The Department of Airspace Control (DECEA) is set to take the role as the SWIM regulatory authority, so being responsible for managing the registry and defining policies and standards in the SWIM environment. Airports, aerodromes, airspace companies, educational and research institutions, public agencies, among others, are the service providers and service consumers of the registry. TransLab supports the development and implementation of the SWIM Registry Brazil.

The SWIM Registry Brazil can be divided in three main subsystems: website, registry core system and registry administration system. The main purpose of the registry website is to spread news about current development stages of the registry and to attract users to the new platform. Its user interface web page is adjusted as simple as possible, so that regular users can get used with the role played by the registry and the types of services available in the platform. The registry core system includes the main functionalities of a SWIM Registry from the consumer and provider perspectives. First, users should request an account in the system. The regulatory authority approves the incoming request after an appropriate analysis and the user then able to access these functionalities. The registry administration system is responsible for supporting the activities of the regulatory authority, such as enforcing standards and policies among SWIM stakeholders by publishing and keeping updated all ATM related information.

The ATM-related information available in the SWIM Registry Brazil can be categorized as:

- List of SWIM services;
- Service description information;
- Reference models;
- Information exchange standards.

The users of SWIM Registry Brazil need the full list of SWIM services available in the platform so that they can search the suitable services. The list of services is filtered according to the services' attributes previously set by the user.

The service-related information includes all metadata associated to the service. The services' attributes are also used to support the search mechanism of the SWIM Registry Brazil such as: the service name, description, version, documentation, organization name behind the service implementation/support, regions where the service is available, ATM data category, ATM activity category, ATM flight phases, ATM stakeholders, among others. There are other specific attributes of the service, such as its technical description and its supporting documentation. It is worth to note that SWIM enabled applications can also be published and recorded in the registry. Applications should achieve certain requirements in order to publish their information in the registry as it happens with the services.

Reference models and information exchange standards are important to standardize the way information are represented by services. Using the same reference models as other services helps the reuse of well-known and well tested models. The usage of information exchange models is another example of standard models that can be reused over time. Some of the well-known standards for SWIM are AIXM for aeronautical data, WXXM for weather data and FIXM for flight data, and others. The participants of the registry environment in SWIM Registry Brazil can be categorized into users and organizations. Users only have read access to the SWIM Registry Brazil, while the organizations are responsible for publishing services or applications. Organizations are modeled by the following attributes: organization name, description, contact, list of SWIM related services list of SWIM enabled applications, among others. The SWIM Registry also maintains a list of SWIM related services and applications for each organization in order to support the community to contribute in the registry.

Other important feature available in the SWIM Registry Brazil is the subscription and notification subsystem. The subscription subsystem is designed for users to subscribe for specific services so they can receive updates associated with that list of services. Users can also subscribe for receiving registry updates to be aware of the registry's progress, such as new applications, services and organizations that joined the platform. Users can also subscribe for updates in the reference models, reference documents, data standards, infrastructure standards, news articles, among others. Finally, users can subscribe in the categories associated with service and application metadata, such as ATM data categories, ATM activity categories, ATM flight phases, ATM stakeholders, regions etc. In this sense, users can receive updates regarding the class of services related to the subscribed category, as well as receiving such updates in different time frequencies (daily, weekly or monthly).

### C. ICEA/UnB Demonstration of the SWIM Concept

In order to demonstrate the applicability of the SWIM environment and the SWIM Registry Brazil in the Brazilian ATM context, a proof of concept was set up by the Institute of Airspace Control (ICEA) and the University of Brasília (UnB). The proposed architecture is depicted in Figure 1 and consists of the SWIM Registry Brazil, two ATM services and an ATM application:

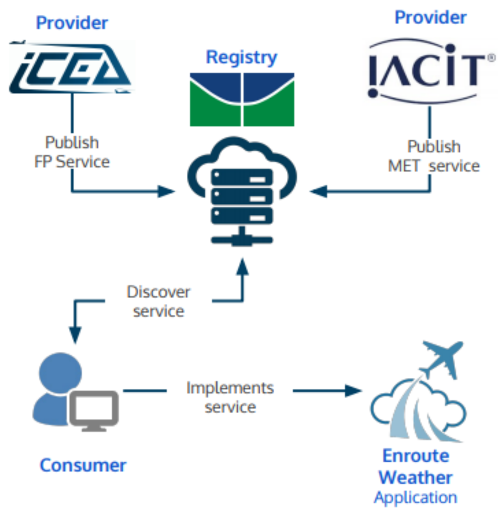


Fig. 1. Demonstration of the SWIM Concept.

The first service consists of aircraft flight plans recorded from February 2017 to August 2017. It is possible to assess the trajectories of airplanes according to their flight plans prior to the flight departure. The second service consists of meteorological data of convective cells located in Brazilian airspace during the same period of time. The presence of these convective cells defines an adverse weather condition in these locations. The application is responsible for consuming data from both services and plot the information about trajectories and convective cells in a single map. The goal of this application is to show the trajectories that were possibly influenced by meteorological events in a visual way.

This demonstration intends to show the interaction among the involved entities. Initially, the SWIM Registry Brazil is used by both services to publish their information. After that, the developer searches for specific services according to its needs in the registry. Finally, an application is implemented using the available services in a way that can be consumed by the final user.

## IV. Blockchain for SWIM Registry

### A. Basic Concept of Blockchain

Blockchain is a fundamental technology introduced by Satoshi Nakamoto and currently employed in the cryptocurrency Bitcoin [7]. Blockchain can be defined as a data structure working as a sequence of linked blocks, each one storing a finite set of transactions (operations or a data records). Each block presents a digital signature and it is referenced cryptographically by a hash value, which provides authenticity and identity for creating and verifying transactions. The chain structure of blocks is achieved since each block contains the hash value of its previous block (parent block), except by the first block of the chain, named genesis block.

The inclusion of every transaction within a block by two entities requires the verification by all nodes of the Blockchain network in order to guarantee integrity and security. The creation of a new block is necessary when the current last block of the chain is full and also requires the consensus and approval of all network nodes. In this case, the network assigns to specific entities, known as "miner nodes", the task for creating transactions within the blocks, as well as allocating new blocks and propagating them through the chain. The miner node is chosen based on the first network node to solve a difficult mathematical problem among several candidate network nodes. In Bitcoin, such mechanism is called of Proof-of-work and demands high computational processing, power consumption and it is extremely time-consuming.

The blockchain technology presents several interesting properties that explain its ever growing popularity. Blocks' contents are permanent, so that after a transaction is included into a block, it is impossible to make further modifications. The transactions are certified by each authority involved within the chain, which provide more security and reduces the chances of falsifications. Furthermore, all services in a blockchain network are performed in a distributed and decentralized manner, since there is not a central trusted entity validating the transactions and the involved participants. Its successful employment in Bitcoin has motivated the use of blockchain in other knowledge domains without being just involving cryptocurrencies [8], [9], [10].

### B. Blockchain for SWIM Registry Brazil

SWIM can be implemented using the blockchain technology, in which each service is managed by a particular blockchain. In this way, each stakeholder which is allowed to access blocks can insert and read information. According to the blockchain nature, the inserted registers within a particular block cannot be deleted, so the information stored is permanently available. Figure 2 shows the stakeholders of a particular service, in which are able to insert and access the data within the blocks. Figure 3 illustrates the implementation of a service related to the flight plan service.

As the data field of blocks depends on the knowledge domain in which the blockchain is modeled, we propose an appropriate modification in the data field, while the other fields are preserved. Based on the flight plan service, the data field has been modified to receive the flight plan information. Figure 4 shows the modifications of a block to incorporate the service information. In our implementation, the block received information related to the flight plans, according to National Center for Air Navigation Management (CGNA), containing name of the airline, the start date of plan's

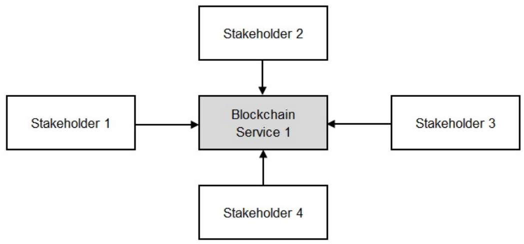


Fig. 2. Blockchain as a service for stakeholders.

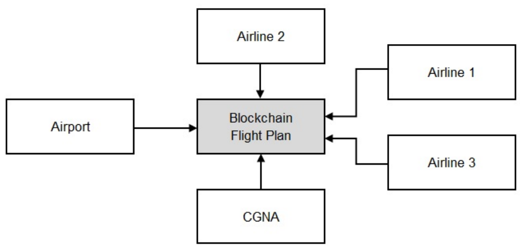


Fig. 3. Blockchain of the flight plan for airlines.

validity, among others. Only authorized persons can read or write data in the blocks, but the data to be inserted as a transaction need to be validated by the network (network consensus), in which the stakeholders of the blockchain must be aware and agree the information to be inserted in the block.


Fig. 4. Example of a flight plan block.

All users within the SWIM blockchain are known between each other. This aspect of the blockchain, alongside the employment of a hash function, guarantees more security to the data, once the access by unidentified users for read and write operations demands high computational processing. Figure 5 illustrates the authorized users of the network and a unidentified user. In this case, only the authenticated users are able to insert data and to view information already recorded within the block.

In the implementation of SWIM's blockchain, users should be registered with all necessary information. At the end of the registration process, a hash is generated as their signatures

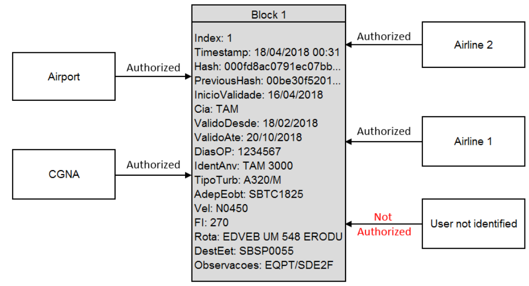


Fig. 5. Demonstration of access to block data

are required to access the blockchain. Each blockchain user needs a username, password and hashed signature to access the blocks. After they have logged in to the network, the user is allowed to input a fight plan in the block. However, this procedure must have the consensus of the other users. After registering the flight plan, the data is stored in the block alongside the user's signature. This user is allowed to access the data at other blocks. Direct queries can be performed regarding flight plans by knowing its hash value, so that only the data within the block is make available.

In the implementation, we create approaches for querying blocks and for inserting data. The user needs to log in to the system to access for reading and writeing operations in the blocks. In the first case, query can be done by checking the hash of the flight plan, so the hash is inserted and the query returns the flight plan of that hash or that does not exist.

## V. Algorithms and Case Study

The implementation of the blockchain is divided into some parts: the block design, the hash computation, the chain verification, the block mining and the proof-of-work process (Algorithms 1-3). First, the block design is the main concern of the blockchain technology, which stores information regarding the hash, the previous hash and the flight plan data. In this case, each stored transaction describes a flight plan. When a block is full the information is stored in the next block.

**Algorithm 1:** Calculate new hash based on block contents

**Data:** previousHash, timestamp, data
**Result:** calculateHash

```
calculateHash = functionHashSha256 (previousHash,
  timestamp, inicioValidade, cia, validoDesde, validoAte,
  diasOP, identAnv, tipoTurb, adepEob, vel, fl, rota,
  destEet, observacoes)
```

The hash is computed by means of the function `sha256`. This function is applied in the fields of the block, which are the previous hash, the timestamp and the flight plan data. After that, a hash is generated and stored in its field within the block. If a unauthorized user attempts to modify the block's data, the block's hash is updated, since the hash value of a block is computed by considering all the block fields. This modifies the hash value of all subsequent blocks, making the hashes invalid due to the different amount of initial zeros. In this case, the generation of alerts concerning modifications of hash values of blocks means that such modifications should be invalidated by the chain. The block mining is described by a two-step process: the first one refers to the difficulty level when computing the hash, which is determined by the amount of initial hash zeros; the second one is the amount of attempts to generate the hash according to the predefined difficulty level. Such amount is stored in a variable to be used in process called proof-of-work.

**Algorithm 2:** Mining Block

```
Data: Refer to difficulty level
Result: Block Mined
while (!hash.substring(0,difficulty) = target) do
    nonce++;
    hash = calculateHash;
```

The chain verification is an important process of the implementation for ensuring whether the chain is valid, i.e., if the blockchain follows the pattern. A chain is valid when the index field of each block in sequence, the previous hash field is the hash field of the previous block and the hash field follows the pattern determined in the mining with the minimum amount of zeros in the beginning. This verification ensures the security of the blockchain.

**Algorithm 3:** Determining the validity of the current blockchain.

```
Data: currentBlock, previousBlock
Result: Verify if the block is valid.
for i = 1; i < blockchain.size ; i++ do
    currentBlock = blockchain.get(i);
    previousBlock = blockchain.get(i-1);
    if (!currentBlock.hash =
      currentBlock.calculateHash) then
        return false;
    else if (!previousBlock.hash =
      currentBlock.previousHash) then
        return false;
    else if (!currentBlock.hash.substring(0, difficulty) =
      hashTarget) then
        return false;
    else
        return true;
```

## VI. Conclusions

This paper described the modeling of SWIM Registry Brazil with the adjustment and implementation of ATM services based on the Blockchain algorithm. As a new technology, Blockchain has been successfully used in Bitcoin. There are many advantages in the implementation of Blockchain, such as providing data security, authenticity check for users in the network, transparency in the information within blocks and an efficient information sharing. The employment of blockchain in services covered by SWIM Registry can improve its current characteristics and properties, bringing benefits to the stakeholders. There is also a better storage manner of flight plan data, and to be able to make inquiries in a better way that allows a more adequate planning for the interested ones. This implementation is an adapted form of the blockchain focused on SWIM Registry, which data related to flight plans are recorded as the transactions.

The implementation of blockchain in SWIM Registry regarding the flight data service is important due to the benefits of the technology, such as user verification and the access of information only by authorized users. The service of flight plan benefited from blockchain of the large data storage capacity, which allows users to have better access to the information contained and to be able to make a better planning with this data. Depending on the services, the use of blockchain promotes a better query and information sharing.

Future work is oriented to proceed with the implementation of other services related to SWIM using the adapted blockchain for SWIM Registry Brazil, such as the use of smart contracts to automatize blockchain. Furthermore, we intend to study the applicability of deep learning to make information sharing between stakeholders in an intelligent and fast manner.


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