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The Safety Level Analysis of the SWIM System in Air Traffic Management

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ABSTRACT: Safety level analysis is included in the paper in context of SWIM system in air traffic management. The example is given. It examines the limitations and drawbacks of current ICT systems used for air traffic management. Analyzing the development of communication systems for the management of general air traffic, it can be concluded that the development of the terrestrial segment of the exchange of information between the parties relating to the air traffic will fluctuate towards a solution based on a service-oriented architecture SOA. This architecture will be the basis for the implementation of the concept of an information exchange system SWIM.

1 INTRODUCTION

The need to increase airspace capacity is a problem existing for traffic engineers for many years. It is not without significance that there is continuous growth of air traffic, particularly over large urban agglomerations in Europe. Any action aimed at streamlining the process in aviation must, however, be consistent with the security policy in aviation, and hence with maintenance an adequate level of that security. Smoothing the process of increasing the number of aircraft in different sectors of airspace may be held only with the improvement of information transmission systems in these sectors (Stańczyk & Stelmach, 2013).

Constantly increasing volume of air traffic entails making modifications to the existing system of air traffic management. These measures concern both organizational changes, procedural and modification of existing ICT systems supporting the management of air traffic safety (Kierzkowski, Kowalski, Magott & Nowakowski, 2012). They provide an opportunity to exchange information between ground services, without which the existence of aviation would not be possible. Exchange between the ground services is bigger than 90% of the information relating to safety of the flight of aircraft (Kierzkowski & Kisiel, 2015). Collection of data about the state of atmosphere and airports, availability of services, the restrictions and the subsequent dissemination of different messages is possible thanks to the fixed network. To ensure safe flight of the aircraft it is essential to ensure communication of all services, such as aeronautical information, weather station, inspectors of particular areas, and many other airspace users. Network technology strongly influenced the present way of exchange of information in air transport (Laskowski, Łubkowski & Kwaśniewski, 2013). Development of aviation networks is focused on the integration of networks and services operating within the national air traffic control systems, and the future extension of these solutions. The paper presents selected issues related to network analysis and information exchange systems in the European air traffic management system. After analyzing the constraints and drawbacks of the existing ICT systems used for air traffic management we indicate the need to change the current "point - point" architecture to the system which exchange information using service-oriented architecture.

2 THE NEED FOR SWIM

Air Traffic Management (ATM) is defined by the International Civil Aviation Organization as a dynamic, integrated management of traffic and airspace - safely, economically and efficiently - through the provision of equipment and uniform services in collaboration with all stakeholders. The proper functioning of the ATM increasingly depends on providing timely, relevant, accurate, accredited and reliable quality of information to make decisions in the process. Sharing best integrated picture of the historical, real-time and planned or anticipated state of the traffic situation on the basis of the whole system will allow the ATM community conducting business in a more secure and efficient manner (Sumiła, 2012). That is how a SWIM system (System Wide Information Management) works, by exchange of information, through the combined set of domains providing or absorbing information. Thanks to SWIM, all information is shared and processed by the service, which must meet the applicable standards and operate in a manner accessible to all users. SWIM aims to improve the management of information, and thus the exchange of information in a wide range, providing support for the ongoing dialogue between the various partners. SWIM meets the safety requirements associated with the exchange of information. Moreover, it provides the exchange of relevant information much easier and cheaper. Aircraft operators will need to constantly update the data on which the ATM service providers and airport operators will have a better knowledge of the intention of flight (Siergiejczyk, Krzykowska & Rosiński, 2014). Thanks to that - controllers, pilots, dispatchers and others will have greater situational awareness with regard to flight status, weather, traffic and other relevant operational information (Sadowski, Siergiejczyk, 2009).

Analysis of the concept of SWIM (System Wide Information Management) enable to confirm that its implementation will require changes in current point - point architecture type (in area of exchange of information). It is assumed that entities may be geographically dispersed, but should have a valid and uniform information necessary to carry out tasks in specific areas of competence. The figures 1 and 2 show the current structure of the exchange of data (point - point) and a proposal for the future (eg. SWIM).

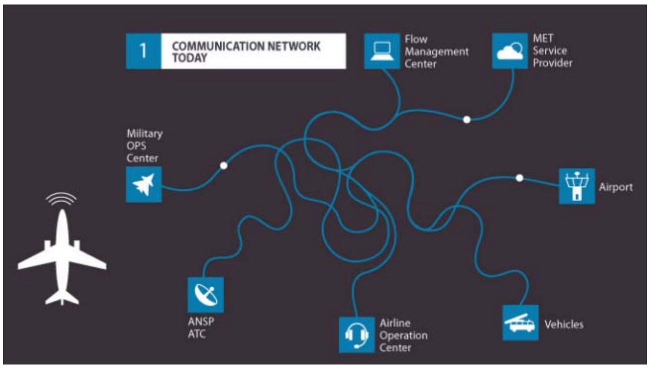


Figure 1. Current structure of the exchange of data

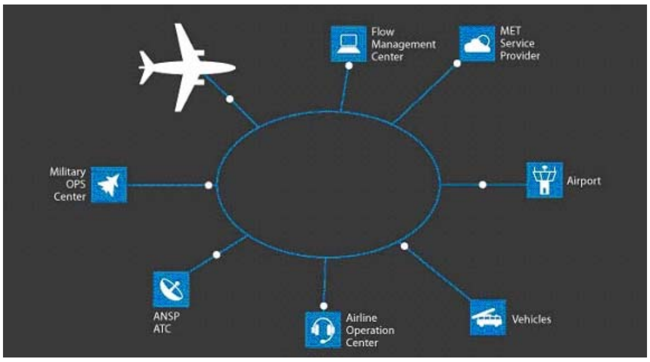


Figure 2. Future structure of sharing information

In addition, the exchange of information between users of fixed network seeks to create a service-oriented architecture SOA (Service-Oriented Architecture), which is the basis for the implementation of the concept of SWIM. SOA is an architecture that uses the definitions of interfaces.

3 ARCHITECTURE OF SWIM

In order to achieve the expected performance of the system - SWIM implementation should be guided by four basic principles:

- separation of the provision of information - distinction between providers of information from the sources of information;
- feedback of the system - each of the elements uses more or less knowledge about other components, in this way - barrier between systems and applications are removed and the interfaces are compatible;
- use of open standards / publicly available;
- use of service-oriented architecture (SOA).

Based on the above principles, the implementation of SWIM will introduce the following elements:

- **AIRM** (ATM Information Reference Model) - will ensure the implementation of each type of information through an ATM conceptually logical data models, among them there will be items such as airports, flight route, airspace, flight procedures and common definition of modeling taking into account the time and space;
- **ISRM** (Information Service Reference Model) - provide a logical division of information services required and their patterns of behavior, it will contain details about service charge, the pattern of

information exchange, quality of service (QoS), infrastructure for data exchange system;
- **IMF** (Information Management Functions) - includes functionality such as user identity management, disclosure of resources, aspects of security, including authentication, encryption and notification services;
- **SWIM Infrastructure** as a technical infrastructure (ground/ground and earth/ground).

Fig. 3 illustrates relationships within the transport telematics system, based on the exploitation-reliability analysis of dedicated SWIM.

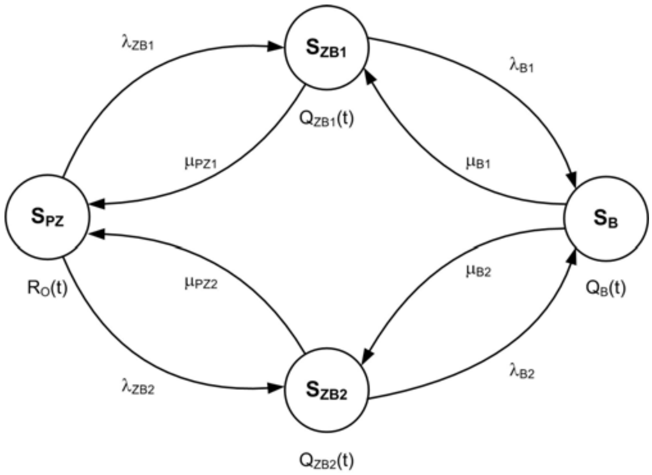


Figure 3. Relationships in the SWIM.

Denotations in figures:

$R_O(t)$ – the function of probability of system staying in state of full ability S_{PZ},
$Q_{ZB1}(t)$ – the function of probability of system staying in state of the impendency over safety S_{ZB1},
$Q_{ZB2}(t)$ – the function of probability of system staying in state of the impendency over safety S_{ZB2},
$Q_B(t)$ – the function of probability of system staying in state of unreliability of safety S_B,
λ_{ZB1} – transition rate from the state of full ability S_{PZ} into the state of the impendency over safety S_{ZB1},
λ_{ZB2} – transition rate from the state of full ability S_{PZ} into the state of the impendency over safety S_{ZB2},
μ_{PZ1} – transition rate from the state of the impendency over safety S_{ZB1} into the state of full ability S_{PZ},
μ_{PZ2} – transition rate from the state of the impendency over safety S_{ZB2} into the state of full ability S_{PZ},
λ_{B1} – transition rate from the state of the impendency over safety S_{ZB1} into the state of unreliability of safety S_B,
λ_{B2} – transition rate from the state of the impendency over safety S_{ZB2} into the state of unreliability of safety S_B,
μ_{B1} – transition rate from the state of unreliability of safety S_B into the state of the impendency over safety S_{ZB1},
μ_{B2} – transition rate from the state of unreliability of safety S_B into the state of the impendency over safety S_{ZB2}.

The state of full ability S_{PZ} is a state in which the properly functioning both SWIM (both AIRM and ISRM). State of the impendency over safety S_{ZB1} is a state in which the AIRM is unsuitable. State of the impendency over safety S_{ZB2} is a state in which the ISRM is unsuitable. State of unreliability of safety S_B is a state in which the AIRM and ISRM are unsuitable.

If the system is in state of full ability S_{PZ} and there occur the damage of the AIRM that takes the system to the state the impendency over safety S_{ZB1} with intensity λ_{ZB1}. If the system is in the state the impendency over safety S_{ZB1} it is possible to come back to state of full ability S_{PZ} under condition of providing the action to restore the state of full ability of the AIRM.

When the system is in the state of the impendency over safety S_{ZB1} and additionally there occur damage to the ISRM, the system is a transition to state of unreliability of safety S_B with intensity λ_{B1}. Backlinks transition from the state of unreliability of safety S_B to the state of the impendency over safety S_{ZB1} is possible only if there are taken actions of bringing back the state of full ability of the ISRM.

If the system is in state of full ability S_{PZ} and there occur the damage of the ISRM that takes the system to the state the impendency over safety S_{ZB2} with intensity λ_{ZB2}. If the system is in the state the impendency over safety S_{ZB2} it is possible to come back to state of full ability S_{PZ} under condition of providing the action to restore the state of full ability of the ISRM.

When the system is in the state of the impendency over safety S_{ZB2} and additionally there occur damage to the AIRM, the system is a transition to state of unreliability of safety S_B with intensity λ_{B2}. Backlinks transition from the state of unreliability of safety S_B to the state of the impendency over safety S_{ZB2} is possible only if there are taken actions of bringing back the state of full ability of the AIRM.

The system illustrated in fig. 3 may be described by the following Chapman–Kolmogorov equations:

$$\begin{aligned}
&R_0'(t) = -\lambda_{ZB1}\cdot R_0(t) + \mu_{PZ1}\cdot Q_{ZB1}(t) + \\
&-\lambda_{ZB2}\cdot R_0(t) + \mu_{PZ2}\cdot Q_{ZB2}(t) \\
&Q_{ZB1}'(t) = \lambda_{ZB1}\cdot R_0(t) - \mu_{PZ1}\cdot Q_{ZB1}(t) + \\
&-\lambda_{B1}\cdot Q_{ZB1}(t) + \mu_{B1}\cdot Q_B(t) \\
&Q_{ZB2}'(t) = \lambda_{ZB2}\cdot R_0(t) - \mu_{PZ2}\cdot Q_{ZB2}(t) + \\
&-\lambda_{B2}\cdot Q_{ZB2}(t) + \mu_{B2}\cdot Q_B(t) \\
&Q_B'(t) = \lambda_{B1}\cdot Q_{ZB1}(t) + \lambda_{B2}\cdot Q_{ZB2}(t) + \\
&-\mu_{B1}\cdot Q_B(t) - \mu_{B2}\cdot Q_B(t)
\end{aligned} \tag{1}$$

Given the initial conditions:

$$\begin{aligned}
&R_0(0) = 1 \\
&Q_{ZB1}(0) = Q_{ZB2}(0) = Q_B(0) = 0
\end{aligned} \tag{2}$$

Laplace transform yields the following system of linear equations:

$$
\begin{aligned}
& s \cdot R_0^*(s) - 1 = -\lambda_{ZB1} \cdot R_0^*(s) + \mu_{PZ1} \cdot Q_{ZB1}^*(s) + \\
& -\lambda_{ZB2} \cdot R_0^*(s) + \mu_{PZ2} \cdot Q_{ZB2}^*(s) \\
& s \cdot Q_{ZB1}^*(s) = \lambda_{ZB1} \cdot R_0^*(s) - \mu_{PZ1} \cdot Q_{ZB1}^*(s) + \\
& -\lambda_{B1} \cdot Q_{ZB1}^*(s) + \mu_{B1} \cdot Q_B^*(s) \\
& s \cdot Q_{ZB2}^*(s) = \lambda_{ZB2} \cdot R_0^*(s) - \mu_{PZ2} \cdot Q_{ZB2}^*(s) + \\
& -\lambda_{B2} \cdot Q_{ZB2}^*(s) + \mu_{B2} \cdot Q_B^*(s) \\
& s \cdot Q_B^*(s) = \lambda_{B1} \cdot Q_{ZB1}^*(s) + \lambda_{B2} \cdot Q_{ZB2}^*(s) + \\
& -\mu_{B1} \cdot Q_B^*(s) - \mu_{B2} \cdot Q_B^*(s)
\end{aligned}
$$

Solution to the above set of equations in the time domain is the next step in the analysis and is not discussed here.

Computer simulation and computer-aided analysis facilitate to relatively quickly determine the influence of change in reliability-exploitation parameters of individual components on reliability of the entire system. Of course, the reliability structure of both the entire system and its components has to be known beforehand.

Using computer aided allows to perform the calculation of the value of probability of system staying in state of full operational capability R_O. That procedure is illustrated with below example.

Example

The following quantities were defined for the system:

- test duration - 1 year (values of this parameter is given in [h]):

$$t = 8760 \ [h]$$

- reliability of AIRM:

$$R_{ZB1}(t) = 0{,}991278$$

- reliability of ISRM:

$$R_{ZB2}(t) = 0{,}999124$$

- transition rate from the state of the impendency over safety S_{ZB1} into the state of unreliability of safety S_B (failure of ISRM):

$$\lambda_{B1} = 0{,}0000001$$

- transition rate from the state of the impendency over safety S_{ZB2} into the state of unreliability of safety S_B (failure of AIRM):

$$\lambda_{B2} = 0{,}000001$$

Knowing the value of reliability $R_{ZB1}(t)$, transition rate from the state of full ability into the state of the impendency over safety S_{ZB1} may be estimated. Provided the up time is described by exponential distribution, the following relationship can be used:

$$R_{ZB1}(t) = e^{-\lambda_{ZB1} t} \quad \text{for} \quad t \geq 0$$

thus

$$\lambda_{ZB1} = -\frac{\ln R_{ZB1}(t)}{t}$$

For $t = 8760 \ [h]$ and $R_{ZB1}(t) = 0{,}991278$ we obtain:

$$\lambda_{ZB1} = -\frac{\ln R_{ZB1}(t)}{t} = -\frac{\ln 0{,}991278}{8760} = 0{,}000001 \left[\frac{1}{h}\right]$$

Knowing the value of reliability $R_{ZB2}(t)$, transition rate from the state of full ability into the state of the impendency over safety S_{ZB2} may be estimated. Provided the up time is described by exponential distribution, the following relationship can be used:

$$R_{ZB2}(t) = e^{-\lambda_{ZB2} t} \quad \text{for} \quad t \geq 0$$

thus

$$\lambda_{ZB2} = -\frac{\ln R_{ZB2}(t)}{t}$$

For $t = 8760 \ [h]$ and $R_{ZB2}(t) = 0{,}999124$ we obtain:

$$\lambda_{ZB2} = -\frac{\ln R_{ZB2}(t)}{t} = -\frac{\ln 0{,}999124}{8760} = 0{,}0000001 \left[\frac{1}{h}\right]$$

Assuming $\mu_{PZ1} = 0{,}1$, $\mu_{PZ2} = 0{,}2$ we obtain:

$$
\begin{aligned}
& R_0(t) = 2{,}49207424 \cdot 10^{-7} \cdot e^{-0{,}19968437 \cdot t} + \\
& +0{,}0000099999 \cdot e^{-0{,}100001 \cdot t} + \\
& +2{,}50788575 \cdot 10^{-7} \cdot e^{-0{,}20031682 \cdot t} + \\
& +0{,}9999895
\end{aligned}
$$

Finally, we obtain:

$$R_O = 0{,}9999895$$

Using equation (1) it is possible to determine the effect of the impact of values of the transition rate from the state of the impendency over safety to the state of full ability μ_{PZ1} and μ_{PZ2} on the value of the probability of the system staying in the state of full operational capability R_O. Intensity μ_{PZ1} and μ_{PZ2} should be understood as the inverse of time t_{PZ1} and t_{PZ2} that determine the recovery time to the state of full operational capability.

Technical infrastructure SWIM-TI (System Wide Information Management - Technical Infrastructure) interferes with the termination of the services rendered under the ATM systems supported by SWIM solutions, ensuring their productivity and increasing efficiency and safety. Systems that interact with SWIM cooperate with services specific to ATM systems, and their cooperation is supported by technical solutions offered by SWIM.

SWIM-TI infrastructure is a set of software components distributed in the network infrastructure, providing attributes for the collaboration between systems. These attributes are appropriate for the set of nodes in SWIM (endpoint entities) and common components (ensuring appropriate features in all distributed nodes in SWIM). Therefore, the idea of nodes in SWIM presents a set of features and capabilities of SWIM-TI infrastructure, allowing a given system the use of its solutions.

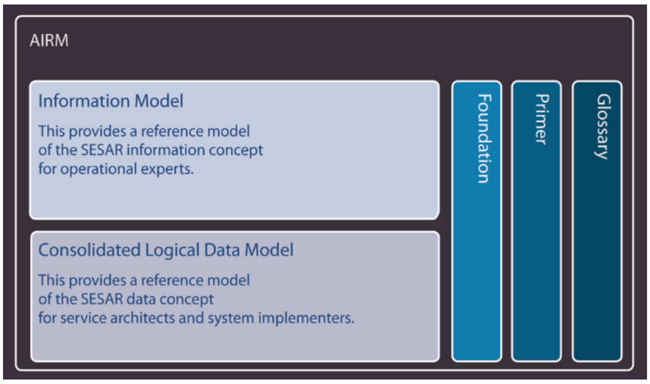
Examples of common components are:
- register used to enable sharing of information (metadata) about the services within the prescribed time,
- Public Key Infrastructure PKI, which aims to guide the structure of the trust of digital certificates.

Particularly important element of SWIM is AIRM - reference model considered as a model corresponding to other one developed in SESAR program (Single European Sky ATM Research). The SESAR program was designed to build a modern European air traffic management system. It is a technological and operational component of the initiative of Single European Sky (SES) resulting synchronized and increased capacity of the European airspace. As the founder of SESAR, together with the European Commission, EUROCONTROL plays a key role in all projects (Siergiejczyk, Krzykowska & Rosiński, 2015).

The basic objectives of the program include:
- the introduction of business trajectory, which can be described as the trajectory most common to the set released by performing flight;
- managing trajectory through which it is planned to implement a new approach to design and management of airspace, including:
  - preferred routes of flights;
  - advanced civil – military cooperation (flexible use of space);
  - division of space into controlled and uncontrolled.

The basic principle of the SESAR approach is that all technological achievements should provide the possibility of accomplishment the objectives of which are derived directly from operational requirements and support the growth of the overall air traffic management system performance. In fact, the CNS infrastructure (Communication, Navigation, Surveillance), will have to be more capable, and most importantly, more flexible than ever. The purpose of this is to ensure fact that technical limitations (Perlicki 2002, Perlicki 2012) does not slow down the development of advanced procedures and applications. CNS activities are an important investment in the SESAR program.

Figures 4 and 5 show the structure of the AIRM product and the planned dates for implementation.



This provides a reference model of the SESAR information concept for operational experts.

This provides a reference model of the SESAR data concept for service architects and system implementers.

Figure 4. The structure of the AIRM product

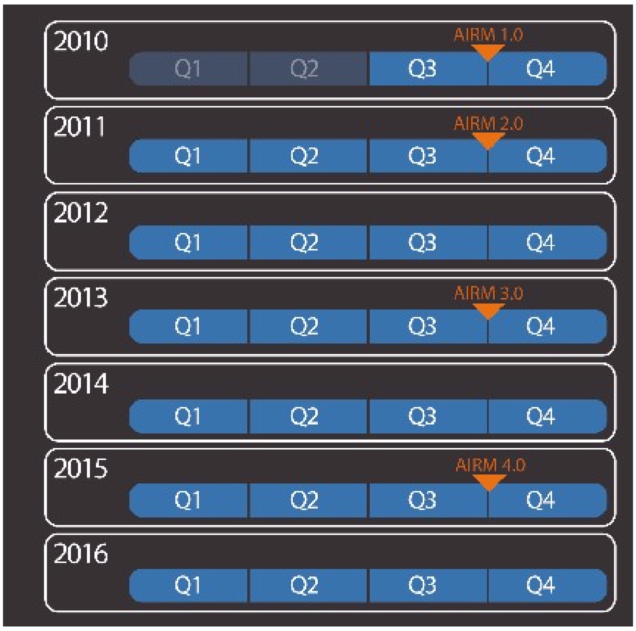


Figure 5. Implementation planned dates

The architecture proposed by SWIM can distinguish a series of mergers, such as shown in Figure 6 below.

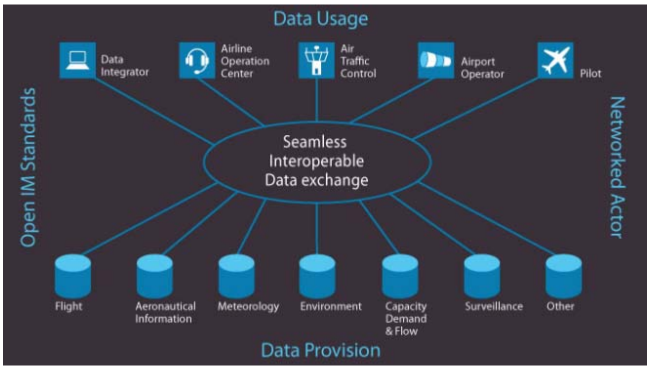


Figure 6. Diagram of service-oriented architecture

SWIM concept is to integrate the various players (ATM providers of air navigation services, airlines, airports, industry, standardization organizations and standardization) in the sense of information, not only in terms of the network but also the system and a B2B interaction.

4 APPLICATION AND BENEFITS FROM SWIM

European air traffic management system operates close to the limit of capacity and has to deal with the challenge of constantly growing demand in the field of air transport. In order to fulfill all the tasks set out by the European Commission and strengthening the air transport value chain, the requirements of airspace users must be better satisfied. Therefore, each flight must be done in strict accordance with the intentions of the owner, while maximizing network performance. This is the main principle driving the future of European ATM system, which represents the airspace user's intent in respect of the flight.

On the basis of the main objectives of the extensive SWIM system architecture the following applications can be provide (Dhas, Mulkerin, Wargo, Nielsen & Gaughan, 2000):

- **synchronized traffic** – it aim is to manage arrivals and departures and sequence aircrafts during flights and at the airports controlled areas, to optimize the flow of traffic and, consequently, to reduce the number of interventions in the part of air traffic control;
- **integration of airports** - is aimed at achieving full integration of airports as nodes in the ATM network, ensuring consistency of the process through joint decision-making;
- **support development of 4D trajectory** - is aimed at a systematic breakdown of the trajectory of the aircraft between the different players of ATM process ensuring fact that all partners have a common perspective of the flight and access to the most current data available for the appropriate performance of their duties;
- **common network management** and balancing liquidity and capacity - improved cooperative network management through dynamic, direct and fully integrated network operating plan NOP (Network Operations Plan).;
- **automation and conflict resolution** - aims to significantly reduce the burden on the flight controller tasks, while meeting the objectives of the SESAR program in the field of safety and environmental benefits, without incurring the provider's significantly higher costs.

In the implementation of SWIM process a number of products associated with the ATM will also be provided, it is shown in Table 1.

Table 1 shows the set of elements which, according to the FAA organization (Federal Aviation Administration) should be implemented as SWIM products. That is to say, the FAA tested by simulating a range of products, which could be components of SWIM. Some of them, after testing received statute "available" - expressing positive tests.

SWIM system creates a comprehensive solution tailored to the operational policy so as to gradually provide the correct information to specific entities in the right place and time. To the basic benefits of the implementation of the SWIM system we can include:

- availability;
- equality;
- flexibility;
- performance;
- quality, consistency and security of information;
- implementation and development;
- cost;
- orientation services;
- open standards;
- global application.

Table 1. Available via SWIM selected products for data exchange

Product	Description	Status
AIM FNS	Provides weather telegram NOTAM	After testing, not yet available
AIM SAA	Provides configuration information about airports	After testing, available
AIM	Aeronautical data	After testing,
CSS-Wx	Modernization and centralization of weather data	Not available
ITWS	Integrated Terminal Weather System - provides weather data graphically visualized	After testing
NCR	NAS Common Reference – Aggregation and integration of data depending on the airspace	After testing, partially available
SFDPS	SWIM Flight Data Publication Service - It provides the route data, data about the flight, flight plans, beacon codes	After testing, partially available
STDDS	SWIM Terminal Data Distribution System – Provides data on surveillance from the airports, data from the control tower about the situation on the surface	After testing, available
TBFM	Time Based Flow Management - Provides data on the flow of traffic depending on time	After testing, available
TFMS	Traffic Flow Management- Provides data on Air Traffic Management	After testing, partially available
WARP/ EWD	Weather and Radar Processor - The radar data and weather	After testing, partially available

SWIM system that integrates all the data related to air traffic management can provide a basis for the whole European ATM system. SWIM will support multiple business objectives of high strategic priority through the utilization of shared information. SWIM system may be a key factor in the operation of the SESAR program and can provide direct business benefits, operational and technical.

5 SUMMARY

The paper presents selected issues related to the analysis of network and information exchange systems in air transport. Examines the limitations and drawbacks of the current ICT systems used for air traffic management. Analyzing development of communication systems for the management of general air traffic, it can be concluded that the development of the terrestrial segment of the exchange of information between the parties relating to the air traffic will fluctuate towards a solution based on a service-oriented architecture SOA. This architecture will be the basis for the implementation of the concept of an information exchange system SWIM. SWIM system analysis include the list of advantages and applications of the system and the identification of infrastructure elements. SWIM concept has to integrate the different actors (ATM providers of air navigation services, airlines, airports, industry, standardization organizations and standardization) in the sense of information, not only in terms of network and system. Therefore it seems to be the best solution based on service-oriented architecture.

By being able to integrate all the data related to the management and control in the area of air transport, SWIM system seems to be part of supporting the entire European ATM system and its implementation may be necessary to its effective functioning. It includes support for information exchange between terrestrial objects and aircraft, as well as a ground only between objects. As a result of consistent data exchange technology between systems ATM software projects can be a unifying airspace in Europe SES (Single European Sky), and on a global scale.

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