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FRAM MODELLING OF THE TRANSFER OF CONTROL OVER AIRCRAFT

Summary. Aviation is the fastest growing but also the safest mode of transport. International aviation organizations give the highest priority to safety while creating aviation regulations. Therefore, a safety management system (SMS) has been created. Two approaches to assuring safety in aviation may be distinguished: Safety-I and Safety-II. Safety-I is the standard approach, focused on processing the information about malfunctioning features and system elements. On the other hand, Safety-II is a new approach to safety management, based on identifying the elements or functions of the system that work properly, which enables the system to confirm resilience to undesirable effects.

One of the methods utilized for the Safety-II approach in order to study complex sociotechnical systems is the FRAM (functional resonance analysis method). The method is focused on analysing daily activities in various conditions in order to create a model of work performance. The models created based on the FRAM can be used for risk analysis, accident investigations and predicting possible future events affecting aviation safety. This method allows us to simulate system constraints and uncertain states. It can also be used as support for the air traffic safety management processes based on the Safety-II approach.

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The following article presents a developed FRAM model for the transfer of control over aircraft. This model constitutes an example of a coordination scheme limited to basic activities of air traffic control (ATC) services, providing a general framework for the construction and operation of the FRAM model.

Keywords: transfer of control; functional resonance analysis method (FRAM); Safety-I; Safety-II; sociotechnical systems

1. FRAM

The FRAM is used to study complex sociotechnical systems. It was created and described by Erik Hollnagel [8], who noted that complex systems contain a large number of subsystems and components, whose performance variability is usually absorbed by the system with minimal effect on the overall system. The main sources of this variability are people, technology, hidden conditions and barriers.

Hollnagel stated that, as these elements are not related to each other linearly, they can lead to an accident. When component variations become too large to be absorbed by the system, the result becomes adverse. This refers to a functional resonance effect, which results from a situation in which the system is not able to function in a normal mode of operation because of the changes in everyday performance.

The FRAM model describes how the functions of system components are able to resonate and create hazards, which can get out of control and cause accidents.

1.1. FRAM principles

There are four main principles of the FRAM, as described below. These assumptions are based on the main concepts that are necessary to build a FRAM model of a system.

– The principle of the equivalence of success and failure - they have the same source and are caused for the same reasons. While risk management emphasizes error analysis and determines probability of failure, FRAM improves the system's ability to create resilient and flexible processes, as well as monitor and improve risk models. Success is a result of the abilities of individuals, groups of people and organizations to predict the variable risk before the failure occurs. Failure is a temporary or permanent deviation from this situation.
– The principle of approximate adjustments - everyday performance of sociotechnical systems must be adapted to current conditions in the workplace. It is practically impossible to create, in advance, detailed instructions that could be used in the future. The solution is to develop guidelines and procedures that could be used for a particular situation. Workplace operational conditions are changing in various ways, which means that employees must be constantly ready to change plans and be able to adjust the implementation of plans to reflect the changing conditions.
– The principle of emergency operations - it is impossible to explain the features of the complex system merely by describing the performance of its components. Variability in normal performance is rarely large enough to cause any accident or damage. However, the variability of many functions can combine unpredictably, resulting in complex effects. Both the damage and normal operation of the system are usually the result of logical events rather than random events, because they cannot be attributed to failures of individual system components. Sociotechnical systems are difficult to analyse because

they change and develop according to the conditions and requirements. It is not always possible to explain the specificity of a given event.
- The principle of functional resonance – a detected signal, which arises from the independent effect of the normal variability of many signals in a given environment. Placing these signals can produce a resonance, in turn producing a warning signal. This emphasizes the dynamics of the phenomenon, which cannot be described by simple cause-and-effect relationships. Figure 1 below depicts the principle of functional resonance.

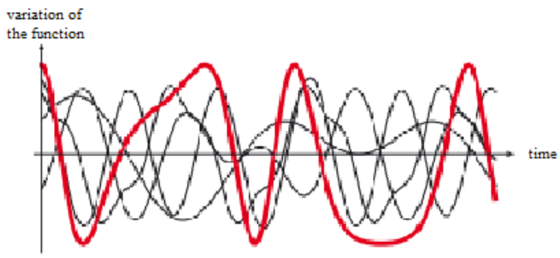

Fig. 1. FRAM functional resonance [8]

1.2. Stages of FRAM analysis

FRAM analysis consists of the following steps:
- Identification and description of the basic functions of the system, as well as characterization of each function by using the six basic parameters.
- Checking the completeness and consistency of the model.
- Characterization of the possible variability of the functions for the FRAM model, as well as possible current variations in the functions for one or more model examples.
- Definition of functional resonance, based on the relationships between functions and potential functional variables.
- Identification of resonance development monitoring in order to suppress the variability that may cause undesirable effects or enhance the variability that may lead to desired results.

FRAM models are made from FRAM functional units, which consist of six parameters listed below and presented in the Figure 2:
- Input
- Output
- Preconditions
- Resources
- Time
- Control

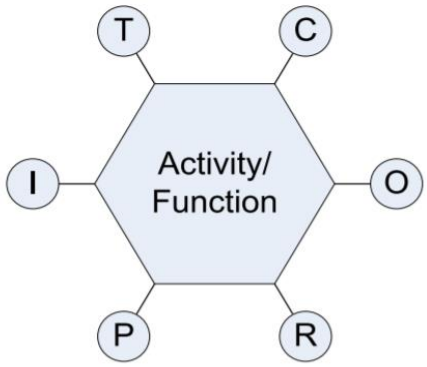

Fig. 2. FRAM model unit with the six basic parameters [8]

Table 1

Characteristics of FRAM functional units [15]

Parameter	Symbol	Description
Input	I	Incoming information, which is modified by the function to output. This constitutes a reference to previous functions. It triggers the function execution.
Output	O	Result of the function execution. Provides a reference to further functions. May represents the state change.
Time	T	Time required for processing by a functional unit.
Control	C	Limitations, methods and control procedures. They define how the function is monitored and controlled.
Preconditions	P	System conditions that are determined and must be satisfied before the execution of the function.
Resources	R	Resources that are required or used while processing a function.

2. FRAM MODELLING OF THE TRANSFER OF CONTROL OVER AIRCRAFT

2.1. Problem and methodology formulation

The problem selected for the exemplary analysis of FRAM model operativeness and correctness was the event of transferring control over the aircraft between the area control centre (ACC) and approach control (APC) units. This activity is difficult to analyse with the previously utilized methods, related to the Safety-I approach, mainly due to the complex interactions between the human, technological and organizational factors. Those are highly dependent on the functions involved at different stages of the process. Therefore, an approach that could analyse possible events and simulate the systems' limitations and uncertain states could prove highly beneficial for this particular problem.

Firstly, the activities in this process should be identified and implemented in the FRAM Model Visualizer (FMZ) software. In the case of the transfer of control over aircraft, those are selected on the basis of ICAO Doc 4444 [10]:

- Flight data processing system (FDPS) - flight data distribution within the system, updated in real time, related to events recognized by the flight monitoring subsystem,

- Radar data and flight plan - air traffic data, which allow the ATC units to monitor and plan.
- Air traffic monitoring - observation, scanning and inspection of the current situation in the airspace and providing aircraft with information and advice about their ATC clearances
- Air traffic planning - coordination in planning, organization and use of air traffic.
- Meteo data - meteorological analysis, reports and forecasts, related to existing or expected meteorological conditions, which are forwarded to support ATC decision-making.
- Coordination - between adjacent ATC units providing flight information service.
- TRANSFER function - authorization to passing control over the airplane to the receiving controller.
- ACCEPT function - obligation of passing the aircraft communication immediately.
- Transfer of communication - holds over the transfer of the control point or earlier if specified in the operational letter of agreement (LoA) between the adjacent ATC units.
- Transfer of control - performed between ATC units at the same time as the transfer of communication or just after.
- Communication means - voice communication system solutions, which permit the effective interconnection of various communication systems.

Having stated the elements of the problem and linked them with non-linear relations, the tool is able to indicate which of them form the basis of the system's resilience and protect it from unforeseen circumstances. Creating the FRAM model also allows us to greatly improve its ability to create durable and flexible processes.

The activity of the transfer of control over aircraft, along with the model created in the FMV, is discussed in the following chapters.

2.2. Procedures for the transfer of control over aircraft

When it is agreed that the adjacent ATC units have the same radar data, the process of transferring the aircraft takes place via the TRANSFER function. This process is computer-aided and used to eliminate verbal coordination and the manual input of the data into the system. It is initiated by the transferring controller. Using this function means:

- Sending the aircraft address
- Confirmation that control over the aircraft has been passed to the receiving controller
- An obligation to immediately transfer communication with the aircraft

Next, the receiving controller should use the ACCEPT function for the aircraft, which means:

- Accepting the conditions of release and transfer of control
- Requiring aircraft communication to be passed immediately

After using the ACCEPT function, the communication is sent by the transferring controller to the receiving one. The communication transfer and release of control take place, at the latest, at the transfer of control point, but no earlier than specified in the operational LoA between the adjacent ATS units.

Exchange of flight data is based on the assumption that the controllers are using the same database containing current flight plans in the FDPS module. This server receives, automatically analyses and processes, and then sends flight plan data to the controllers. Any change to the current flight plan requires correcting it in the system by the modifying unit. When the receiving authority has no access to the system database, the controller may require the transferring unit to pass the contents of the flight plan by telephone.

2.3. FRAM model for aircraft control transfer

The prepared FRAM model was created in the FMV tool. According to the instructions for the use of the FMV, crated by Hollnagel [3], the software allows us to graphically display information and provide useful features to check the completeness of the models.

Transfer of control of aircraft between ACC and APP units is carried out by means of electronic coordination. This eliminates the requirement for verbal coordination and the manual input of data into the system, as well as reduces the time, which is needed for transfer of control.

Traffic planning in the area of responsibility of the controller is based on monitoring the traffic situation by providing data to the system. These include up-to-date radar data and flight plans or meteorological data.

When the aircraft approaches the transfer of control point, the transferring controller initiates the TRANSFER function, which means the obligation to immediately transfer the communication of the aircraft and the confirmation of the release of control of the aircraft by the receiving a controller under the agreed conditions. Next, the receiver controller should use the ACCEPT TRANSFER function for the aircraft, which means the immediate transfer of the communication of the aircraft and the acceptance of the terms of the release of control.

Figure 3 presents the created model of the aircraft control transfer between ATC units.

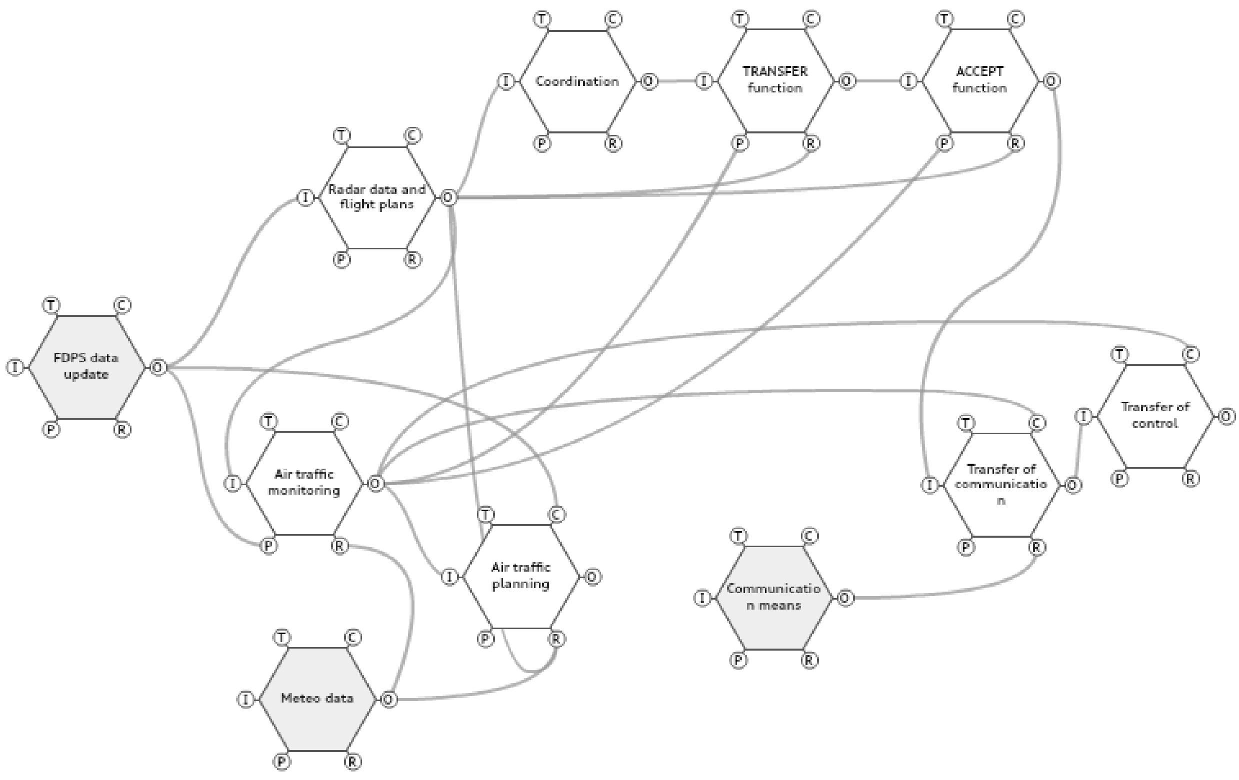

Fig. 3. FRAM model of transfer of control over the aircraft between ATC units

3. CONCLUSION

The FRAM, which complements the Safety-II approach, is an innovative method used in aviation, as well as medicine, nuclear power or maritime transport.

It is used to analyse daily activities in order to create models of how to perform particular tasks. This model can then be used for specific types of analysis in order to verify the feasibility of proposed solutions or interventions, to identify the causes of errors, possible threats or bottlenecks, and to understand how the activity is accomplished. It may be the basis of risk analysis or investigations into accidents that have already occurred or predictions of possible future events.

In the article, the FRAM method was used to examine a complex sociotechnical system, such as the ATC service, in order to determine complex interactions in the daily operation of the system. This FRAM model facilitates the monitoring and controlling of the variable performance of ATC work. It also describes how the individual functions of the system components are able to resonate and create hazards due to, for example, the lack of FDPS data updates, which, if undetected in time, can lead to accidents or serious incidents.

The presented model constitutes an example of a coordination scheme, limited to the basic activities performed by the ATC services, in order to show the general creation and operation rules for FRAM models. The elements of the process have been identified and assigned with a corresponding function type, dependent on either human, technological or organizational factors. Links between various functions have been implemented, based on the process of transferring control over aircraft, as well as the general rules of FRAM analysis. Finally, after supplying the software with the aforementioned data, it was capable of analysing the workflow and providing the means to conduct risk analysis, as well as preventing risk by corrective activities.

Based on the created model, it is possible to take further steps, such as function parameterization or functional unit input decomposition. It would allow for a more detailed model expansion, in order to supplement the processes of coordination and control transfer between the ATC services. The created model for the coordination and transfer of control over aircraft may be utilized to confirm or refine the operational instructions of the ATC services as well as perform their revision.

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