Decision support system HMI for the problem of four-dimensional navigation in civil aviation

E S Neretin, A S Budkov and A S Ivanov
Moscow Aviation Institute (National Research University), 4, Volokolamskeho shosse, Moscow, 125993, Russia
E-mail: e.s.neretin@mai.ru

Abstract. The work is devoted to the development of a human-machine interface (HMI) of the decision support system for the problem of four-dimensional navigation. As part of the work, the analysis of the functionality of modern flight management systems, which is designed to solve the problem of four-dimensional navigation, was carried out. The problems that arise during flights along the four-dimensional navigation routes are determined, and the insufficiency of the existing functionality of modern flight management systems for solving these problems is substantiated. The paper proposes the functionality of the decision support system as an addition to the functionality of the flight management systems, as well as the organization of the HMI of the decision support system, which provides display of the necessary information for the decision-making process by the crew.

1. Introduction
One of the key functions of 4-D navigation is the ability of the aircraft to arrive at a destination waypoint at a required time. In modern flight management systems, there is already exist a function that partially solves this problem. This function is called Time of Arrival Control (TOAC). The key parameter of this function is the required time of arrival (RTA).

During the flight, a situation is possible when the error in the time of arrival at a destination route point exceeds the permissible values [1]. In this situation, modern flight management systems will only generate an information message about the impossibility of arriving at RTA. In addition, in the event of bad weather conditions or conflict situations with other air traffic participants along the trajectory of an active route, any reaction from the flight management system is currently not provided.

In the context of the desire for global management of four-dimensional trajectories [2], where the world air navigation community of civil aviation is currently moving, such functionality will not be enough.

If the described problems arise, first of all, it is necessary to be able to provide a solution to the problem of finding the optimal four-dimensional route, information about which can be used to support the decision-making by the crew. But, at the same time, the constant growth of the onboard systems functionality leads to the need for the crew to analyze more information, which complicates the decision-making process in any emergency.

The constantly growing requirements for taking into account the human factor in the analysis of functional hazards suggest the need for a thorough study of the HMI of the entire cabin, and, in particular, the HMI of the display system [3].
Thus, information on the optimal four-dimensional route should be provided to the crew in the form of an intuitive HMI, which will provide convenient interaction between the crew and the system in the process of deciding on a further flight strategy in the event of any emergency.

2. Existing implementations
In modern civil aircraft equipped with a flight management system that supports the RTA function, the implementation of the display of information related to the RTA function, as a rule, looks like a separate page as part of the HMI of the flight management system. This page displays information about the status of the RTA task during the flight. In order to analyze the existing solutions, options for the implementation of RTA pages for the Airbus and Boeing aircraft families, as well as the promising domestic aircraft MS-21 [4] were considered.

As an example, figures 1 and 2 show the options for the implementation of the HMI page intended for the RTA task of the flight management systems of Airbus 380 [5] and Boeing 737 [6] aircrafts, respectively.

Figure 1. Airbus 380 RTA page.  
Figure 2. Boeing 737 RTA page.

As already mentioned, if the RTA restriction is violated during the flight, modern flight management systems, if it is impossible to select a speed profile that will compensate for this error, will only generate an information message for the crew with a text corresponding to the meaning. In order to further solve this problem in modern flight management system HMI it is possible to change RTA restriction, as well as change the route point to which this restriction is applicable.

3. Decision support system functions
In order to solve the described problems that may arise during the flight along four-dimensional routes, it is necessary not only to improve the HMI of flight management system, but also to modernize the existing functionality of the flight management system [7].

From the point of view of modernizing the existing functionality, the following additional functions are required:

- optimal four-dimensional route searching function;
- function of monitoring the status of flight availability according to the active flight plan.
The function of searching for the optimal four-dimensional route should search for a set of admissible four-dimensional trajectories in the range of specified speeds and flight altitudes, taking into account information about the wind situation, zones of difficult weather conditions and prohibited zones, as well as the aircraft performances. The result of the function is information about routes that are optimal for the necessary optimality criteria.

The monitoring function of the active flight plan should monitor the possibility of movement according to a given flight plan during its execution, taking into account information about weather conditions and airspace restrictions, as well as calculate the error between the estimated time of arrival (ETA) and RTA and form the status of the four-dimensional navigation task.

In [8], as a functional of the decision support system, a methodology of an optimal four-dimensional route searching is proposed, the result of which is the optimal routes according to the following route criteria:

- minimum time delay;
- minimum fuel consumption;
- minimum flight time;
- minimum fuel consumption/flight time.

The criterion of minimum time delay has the highest priority, since it is this criterion that determines the availability of a solution that satisfies the requirements of four-dimensional navigation [1]. A decision on this criterion does not always exist, therefore, if it is absent, a decision is not provided.

In order to find a solution for the criterion of minimum fuel consumption/flight time, the Cost Index (CI) parameter is used. It characterizes the weight of two criteria in relation to each other. The parameter is entered manually by the crew or determined by the airline's strategy. The parameter, as a rule, is defined by a value from 0 to 100. The extreme values of the parameter characterize the criteria for minimum fuel consumption and minimum flight time.

It is necessary to display the following information about them on the HMI for each of the four calculated routes, in order to be able to make a decision by the crew:

- ETA;
- calculated fuel consumption per route;
- route distance;
- flight altitude;
- flight speed.

The method proposed in [8] allows the calculation of routes optimal according to the relevant criteria for situations:

- if the flight along the active route is impossible due to the zone of difficult weather conditions or zones prohibited for flight;
- if in comparison with the active route, a route with more favorable characteristics is available.

In such situations, due to the possibility of assessing the available optimal routes and due to the new functionality of the decision support system and the modernization of the HMI for this functionality, the decision-making process by the crew is greatly simplified.

4. Decision support system HMI

Due to the fact that the proposed functionality of the decision support system is not limited only to the formation of information about the status of the RTA function, but involves solving the problem of finding an optimal four-dimensional route according to 4 different criteria and, in addition to this, continuously monitors the availability of traffic according to a given flight
plan in the process its implementation, the location of all this information on one page of the interface is not the most optimal solution. Also, when organizing an HMI, it is necessary to minimize the number of actions for the crew to gain access to the necessary information.

In view of the above, the graphical interface is designed as a pop-up window that can be integrated into existing flight management systems HMI. Calling such a window can be performed in one action with a special hot key on the display control panels, or by pressing the virtual button for calling the panel, which can be integrated anywhere in the HMI of the flight management system.

The interface ensures the interaction of the crew with the system to obtain the information necessary for making a decision, and also provides the crew with information about the appearance of problems during the flight along the four-dimensional route.

The HMI software of the decision support system is implemented in accordance with [9]. A general view of the decision support system HMI is shown in figure 3.

![Figure 3. General view of the decision support system HMI software.](image)

In order to simultaneously provide access to critical information on the status and parameters of the active route, as well as to minimize the number of actions by the crew to gain access to all the necessary information for making a decision on the RTA task, the HMI of the decision support system is divided into two zones of displayed data:

- active route information display area;
- area for displaying information pages of the graphical interface.

The active route information about the active route is always displayed. In order to inform the crew about the current flight status on the active route, it displays the following information:

- RTA task execution status;
- ETA;
- distance to the destination;
- estimated fuel consumption for the flight to the destination;
- flight altitude;
- flight speed.
The display area of information pages contains 3 pages:

- page for displaying the current flight status along the active route;
- page for changing or installing RTA;
- page for displaying information about optimal four-dimensional routes.

On the page displaying the current flight status along the active route, information is displayed in accordance with the monitoring algorithms of the active flight plan, namely, the status of the execution of the restriction on the specified arrival time and the availability of the flight along the trajectory of the active route. The view of the HMI software frame with information on the page displaying the current flight status along the active route is shown in figure 4.

![Figure 4. HMI software frame view with information on the page displaying the current flight status along the active route.](image)

On the page for changing or setting the RTA, the ability to enter the RTA value by the user, which is necessary to find the optimal route based on the criterion of minimum arrival delay, is implemented, as well as the ability to enter the identifier of the route point to which the RTA restriction will apply. The view of the HMI software frame with information on the page for changing or setting the RTA is shown in figure 5.

On the page displaying information about the optimal four-dimensional routes, it is possible to analyze the parameters of the optimal routes in comparison with the parameters of the active route to simplify the decision-making process. The information is located on separate tabs for each route separately in accordance with the accepted optimality criteria. In order to activate one of the 4 available routes, the user needs to click on the “Select” selector on one of the tabs that corresponds to the selected route. As an example of displaying information about one of the available optimal routes, figure 6 shows the view of the HMI software with information about the route that is optimal according to the criterion of minimum fuel consumption.

Due to the fact that, according to the criterion of minimum arrival delay, the solution to the problem of finding the optimal route does not always exist, in such situations a message is displayed on the corresponding tab on the unavailability of flight along the route with this criterion. The view of the HMI software frame with the message about the absence of a route according to the criterion of minimum time delay is shown in figure 7.
Thus, in the proposed organization of the decision support system HMI, the display of critical information on the status and parameters of the active route is provided, as well as the display of information obtained through the implementation of the decision support system functionality.

Also, due to the organization of the decision support system HMI in the form of a pop-up window with the ability to switch internal pages, the window size takes up part of the screen of the onboard indicator. But, despite the small size of the window, the decision-making process can be completed in at least two or three actions by the crew. At the first step, the crew either goes to the page for changing the RTA task limit, or to the page with information about the optimal routes.

At the second step, the crew either enters new RTA restriction or new destination point of the route, or selects the tab with the route of interest according to a certain criterion. For the
way of changing the restriction, this completes the procedure, and for the second way of solving the problem with the choice of another route, the third step is to select the route by pressing the “Select” button.

5. Conclusions
As a result of the analysis of the existing flight management systems HMI in terms of the 4-D navigation problem, their insufficient functionality was revealed in the context of the civil aviation’s aspiration for global control of four-dimensional trajectories. The problems that arise during the flight along the four-dimensional route are identified, and the existing solutions of the leading aircraft developers are analyzed.

For the proposed functionality of the decision support system, an HMI has been developed that can be integrated into existing flight management systems. The combination of the functional of the decision support system and its HMI provides an intuitive interaction between the crew and the system when it is necessary to make a decision caused by difficult weather conditions or other situations requiring rerouting of the active flight plan or changing the flight speed along the route.

References
[1] RTCA/DO-283B 2015 Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation USA, Washington, 16 December 2015 p 250
[2] ICAO Doc 9750-AN/963 2016 Global Air Navigation Plan 5th ed (Canada: Montreal) p 142
[3] Federal Aviation Administration The National Plan for Aviation Human Factors Washington, D.C.
[4] Neretin E S, Budkov A S, Ivanov A S and Ponomarev K A 2019 Research on modernization directions of the human-machine interface of flight management system for future civil aircrafts Int. Conf. “High-tech and Innovations in Research and Manufacturing (HIRM-2019)”—Journal of Physics: Conference Series 6 May 2019, Krasnoyarsk, Russian Federation vol 1353
[5] Airbus Group SE 2019 Airbus A350 Flight Crew Operating Manual
[6] The Boeing Company 2014 Boeing 737 Flight Crew Operating Manual
[7] Neretin E S, Budkov A S and Ivanov A S Optimal four-dimensional route searching methodology for civil aircrafts EAI IoTias 2020—6th EAI Int. Conf. on IoT as a Service. LNICST vol 346 pp 462–473
[8] Flight management systems on commercial aircraft—past, present and future (accessed: 2021-01-21) URL https://www.airbus.com/content/dam/corporate-topics/publications/fast/FAST42.pdf
[9] ARINC Specification 661-8 “Cockpit display system interfaces to user systems”, 20 September, 2020