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INFORMATIONAL SUPPORT OF AIR NAVIGATION SYSTEM HUMAN OPERATOR

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ABSTRACT

Conceptual models of decision support system for air traffic controller in flight emergencies and automated system of pre-flight information preparation with intelligent module for support the decision making about aircraft departure are presented and program realization of systems are shown. Algorithm of determining the optimal aerodrome for the forced landing of aircraft is provided.

ІНФОРМАЦІЙНА ПІДТРИМКА ЛЮДИНИ-ОПЕРАТОРА АЕРОНАВІГАЦІЙНОЇ СИСТЕМИ

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У статті представлено концептуальні моделі системи підтримки прийняття рішень авіадиспетчера в позаштатних польотних ситуаціях та автоматизованої системи підготовки передпольотної інформації з інтелектуальним модулем підтримки прийняття рішення на виліт, наведено програмну реалізацію систем, а також розроблено алгоритм визначення оптимального аеродрому для виконання вимушеної посадки повітряного корабля.

Ключові слова: *вимушена посадка, диспетчер з управління повітряним рухом, оптимальна альтернатива, передпольотна інформація, позаштатна ситуація, співробітник із забезпечення польотів / льотний диспетчер.*

Statement of purpose

Support of the safe functioning of Air Navigation System (ANS) is one of the most important scientific and technical problems. Statistical data show that human errors account for up to 80 % of all aviation accidents [1].

Latest demands of international aviation organizations directed towards the implementation of integrated approach for the improvement of aviation safety. One of the ways to increase safety is to support the pilot in emergency situations in due time [2]. This approach is based on characteristics (performance-based approach — PBA), principles of informed decision making to achieve the desired/required results and to use facts and data for decision-making [3]. The so called aeronautical decision-making is decision-making in a unique environment, namely aviation. It is a systematic approach to the mental process used by pilots to consistently determine the best course of action in response to a given set of circumstances. It is what a pilot intends to do, on the basic of latest information he has [4].

Decision Support Systems (DSS) may be defined as "interactive computer systems intended to support different types of activity during the decision making (DM) including poorly-structured and unstructured problems" [5—6].

Decision support systems contain common sets of components. These components include data related components, algorithm related components, user interface and display related components. The data related components are made of modules that ingest data, format data, store data, transfer data and archive data. The algorithm related components utilize diverse methods such as atmospheric models, rule based algorithms, fuzzy logic algorithms, statistical algorithms, algorithm of DM under uncertainty and risk, data mining algorithms.

Review of research results

Development of the automated systems in aviation is associated with anthropocentric approach and on the principles of human-oriented automation, required new approaches to solving the problems of man-machine interface [7]. One of the effective means of flight safety improvement is the inclusion of DSS to the automated systems of air traffic control (ATC) [8]. The problems of DSS's informational provision have been considered in the works of V.A. Tarasov, B.M. Gerasimov, V.M. Lokazyuk [5—6], I.B. Sirodzha [12], using intellectual DSS during ATC — V.N. Nedelko [10], I.N. Gluhih [11], K.K. Petrov [12]. The authors have obtained models of the DM by Air Navigation System's human-operator (H-O) and of the development of flight situations [13—15] that are used as a part of an air traffic controller's DSS in flight emergencies to assist in DM for choosing of the optimal alternative of action with minimal damage in the conditions of incomplete and uncertaint information and as a part of a flight dispatcher's DSS for assistance in DM regarding the aircraft (AC) departure.

Provision of informational support of DM by aircraft operator is possible in the conditions of data collection, processing and displaying of automation within a concept of perspective global CNS / ATM system (Communication, Navigation, Surveillance / Air Traffic Management), developed by International Civil Aviation Organization (ICAO) [16].

Purpose of work

The purposes of the article are:

- to introduce a concept of adaptive system for informational support of the DM by air traffic controller in flight emergencies, to get acquainted with the program realization of an air traffic controller's DSS;
- to present a conceptual model of an automated system of pre-flight information preparation with intelligent module for support of the decision making regarding aircraft departure, to get acquainted with its software implementation;
- to show the algorithm of determination of the optimal aerodrome for the emergency landing of the aircraft.

DSS of an air traffic controller in flight emergencies

Research [17] has shown the choice of the optimal variant of the flight completion in emergencies, which requires AC's forced landing, makes an operator analyze the significant amount of diverse information. For a comprehensive account of the factors that affect the DM by an air traffic controller, has been built to adaptive DSS, which allows take into account the dynamic characteristics of the state of the control object (AC) and of the external environment (ATC zone).

The main tasks of an air traffic controller's DSS in flight emergencies are [17]:

- data collection about the state of the control object (AC), external environment (ATC zone) and the individual qualities of the person, who makes the decision;
- creation of action strategy in flight emergency (continue flight to the destination (alternate) aerodrome or perform a forced landing);
- modeling of DM by H-O in flight emergency;
- prediction of the flight situation development during DM by H-O in flight emergency;
- construction of the AC's field of approachability in case of necessity of forced landing;
- evaluating the effectiveness of alternative decisions in flight emergency and formation of recommendations for determination of the optimal variant of flight completion.

The general concept of adaptive system for informational support of the DM by air traffic controller in flight emergency, which requires AC's forced landing, is presented in the form of a set of subsystems (Fig. 1). Structure of an air traffic controller's DSS in flight emergencies is shown in Fig. 2.

Functions of an air traffic controller's DSS in flight emergencies are expanded through information-analytical diagnostic complex for research of patterns of H-O's activity [18]. By using complex, air traffic controller can predict the flight situation development, based on the operational monitoring of the pilot's emotional state and determining the effect of social environment on him.

The specialized program complex "Prompt" [19] has been created, in order to provide informational support to an air navigation system's operator. This was done to enable him to make the decision concerning the selection of the optimum flight completion strategy in flight emergencies, which require a forced landing, in a timely manner.

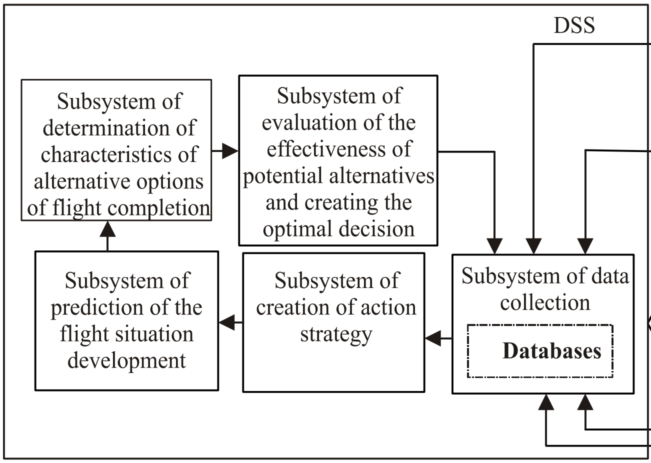

Fig. 1. A conceptual model of an air traffic controller's DSS in flight emergencies, which is adaptive to changes in the state of the controled object and of the external environment

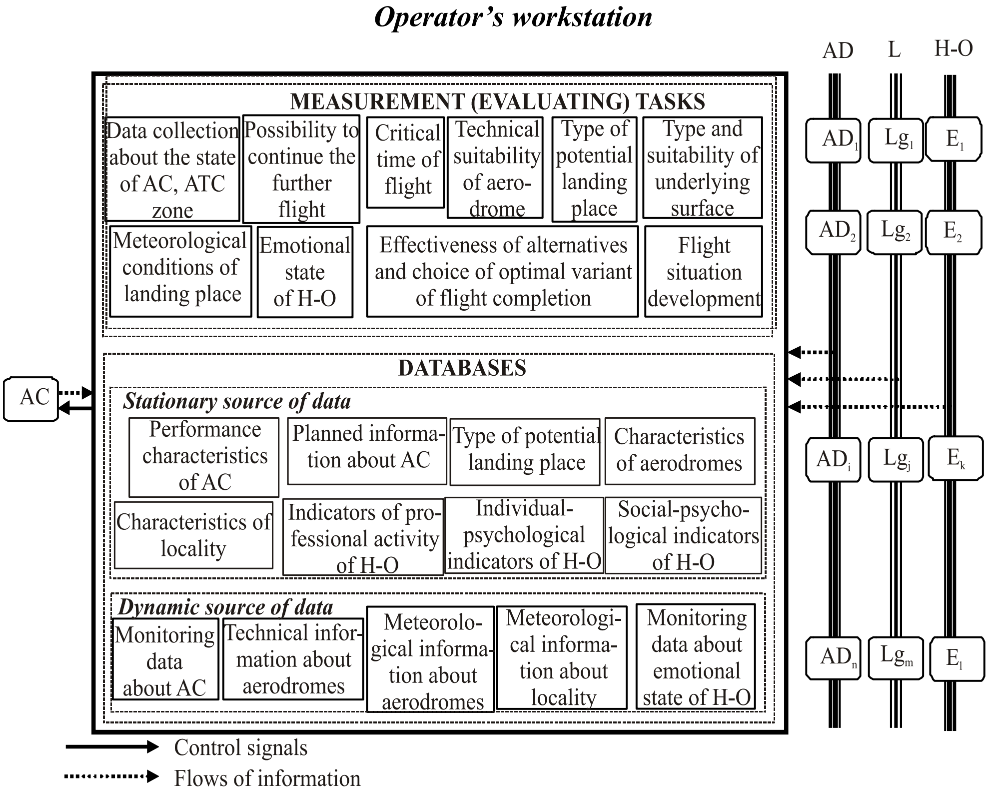

Fig. 2. The structure of DSS of an air traffic controller in flight emergency, which requires AC's forced landing: AD — aerodromes, L — locality, LG — landing grounds; E — emotional state of H-O

The program complex was created with the aid of the visual system for designing programs Delphi 5, which is based on the special version of the programming language Pascal — Object Pascal and supports the main principles of the object-oriented programming.

With the aid of the program "Prompt" the subsystems forming the strategies of actions, predicting the development of a situation, defining the characteristics of the alternative variants of the flight completion, evaluating the efficiency of the potential alternatives and building the optimum decision were realized.

The program "Prompt" enables handling of two non-standard situations — an engine failure and fire on board of an aircraft. When the system receives a message about the unusual situation origination, the additional panel for providing the recommendations concerning the possibility of the flight continuation or necessity to execute a forced landing appears on the operator's monitor. When a type of situation — engine failure — is to be handled the number of the engines which have failed is to be input; when the type — fire — is to be handled, the condition of the aircraft is to be input and the proper advice appears on the monitor (Fig. 3).

When the recommendation concerning the necessity to accomplish a forced landing received, the field of approachability for the aircraft is built on the monitor, also values of the potential loss required for selection of a definite flight completion alternative as well as the coordinates of the potential landing sites (azimuth, range) are presented on the monitor. The program envisages the formation of the field of approachability for two extreme cases — the regime of planning and regime of an immediate descent (Fig. 4, 5).

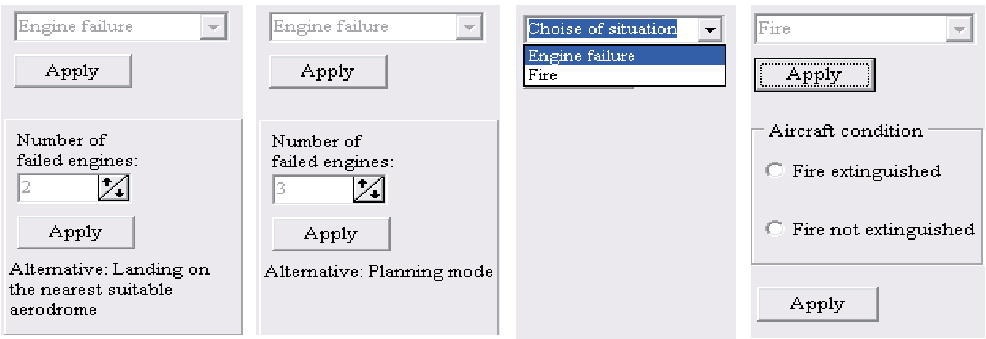

Fig. 3. Realization of the subsystem of forming the strategy of action

The program complex "Prompt" allows:

- giving the recommendations concerning the possibility of the further flight continuation or the necessity to accomplish a forced landing of the aircraft with the aid of the interface suitable for the user;
- defining the field of approachability of the aircraft in case when the necessity to make a forced landing arises;
- forming the evaluation of the alternative variants of the flight completion and define the optimum variant using the potential-loss minimization criterion.

DSS of a flight dispatcher

High-quality pre-flight preparation of an aircraft crew is an important stage of the flight. During pre-flight preparation the pilot must handle a large amount of diverse information and make decision about (not) departure [20]. In addition, the pre-flight preparation may take place under time pressure, so the solution of the pre-flight preparation tasks is advisable to entrust to the automated system of pre-flight information preparation (AS PIP) with intelligent module for support of the decision making about aircraft departure (Fig. 6, 7) [15].

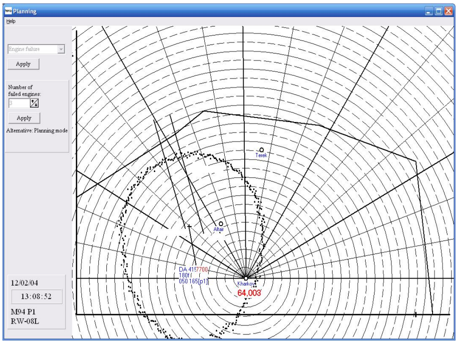

Fig. 4. The field of approachability and defined potential loss for a few variants of the flight completion in the event of the complete failure of the aircraft engines

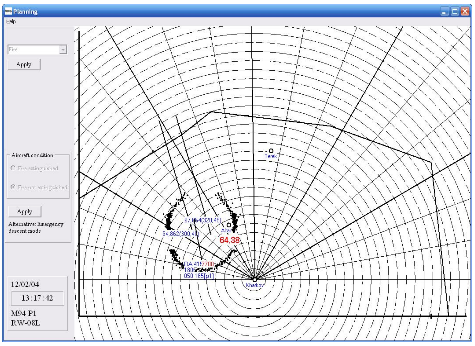

Fig. 5. The field of approachability and defined potential loss for a few variants of the flight completion in case of the fire on board the aircraft which was not extinguished

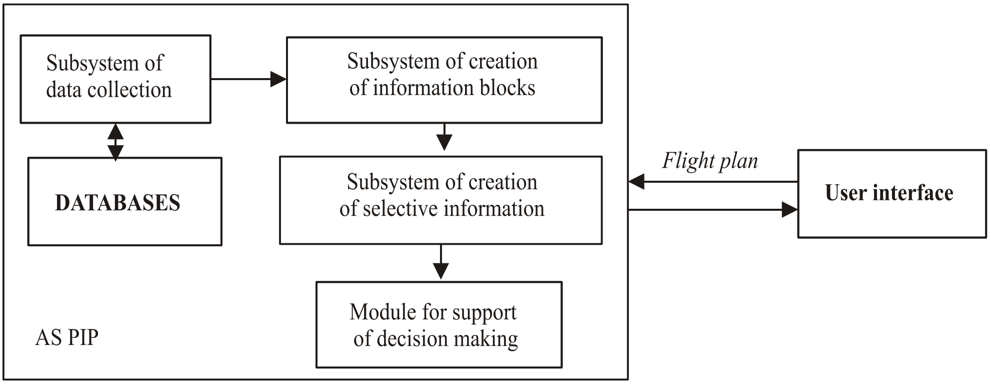

Fig. 6. Conceptual model of AS PIP

The result of pre-flight preparation is decision making by pilot regarding the aircraft departure / not departure. The main factors influencing the decision making are^ takeoff weight of AC and meteorological conditions at the aerodrome of departure, destination (alternate) aerodrome and enroute.

Based on the requirements that are set out in regulatory documents, module for support of the decision making about aircraft departure entrusted with the following main tasks:

- determination of compliance of actual takeoff weight of AC to permitted;
- determination of compliance of actual meteorological conditions at the aerodrome of departure to permitted;
- determination of the presence of hazardous weather phenomena enroute;
- determination of compliance of actual meteorological conditions at the destination (alternate) aerodrome to permitted.

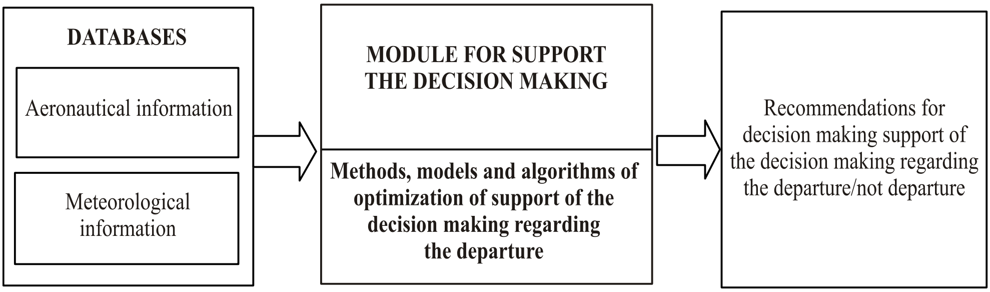

Fig. 7. The structure of intelligent module for support the decision making about aircraft departure

These data are input to the model, which generates recommendations for decision making regarding the aircraft departure. If any of the factors does not comply with the requirements, departure is prohibited. Compliance or non-compliance conditions for decision making about departure are represented in polar coordinates as a diagram "Spider-CWI" [21].

Another problem solved by the AC crew during pre-flight preparation is choise of the alternate aerodromes. According to the regulations, alternate aerodromes are chosen based on the following factors:

- minimum of the First Pilot;
- meteorological conditions at alternate aerodromes;
- amount of fuel on board;
- distance to the alternate aerodrome.

In flight emergencies for ensuring the flight safety and the cost-effectiveness of the flight, finding an optimal alternative for passengers, cargo and crew, in a flight dispatcher's DSS is used multifactorial model of choice of landing aerodrome, which takes into account more additional parameters: danger of the situation, type of the flight (regular, primary), technical characteristics of the AC, technical specifications of aerodromes (for example, condition of runways, navigational aids, lighting system), air navigation and airport charges, etc.

Algorithm of determination of the optimal landing aerodrome in flight emergencies:

1. Formation of the set of alternative decisions {A}:

$$\{A\} = \{A_{adest} \cup A_{adep} \cup \{A_{aalt}\}\} = \{A_1, A_2, \ldots A_i, \ldots, A_n\},$$

where A_{adest} — is an alternative decision to land at the destination aerodrome;
A_{adep} — is an alternative decision to return to the aerodrome of departure;
A_{aalt} — is a set of the alternate aerodromes.

2. Formation of the set of factors $\{\lambda\}$, influencing the choice of landing aerodrome in case of forced landings of the AC:

$$\{\lambda\} = \lambda_1, \lambda_2, ..., \lambda_j, ..., \lambda_m,$$

where λ_1 — is an availability of fuel on board;

λ_2 — is a remoteness of the aerodromes;

λ_3 — are the technical characteristics of runways of destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_4 — are the meteorological conditions at destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_5 — are the lighting systems at destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_6 — are the approach systems at destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_7 — are the navigational aids at destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_8 — are the characteristics of the apron, taxiways at destination aerodrome, aerodrome of departure, alternate aerodromes;

λ_9 — are the subjective factors (availability of hotels, easy transport for passengers, logistics requirements, air navigation and airport charges, etc.).

3. Formation of the set of possible results of DM under the influence of specified factors in flight emergencies, that were determined by the method of expert estimates by rating scales according to the regulations:

$$\{U\} = U_{11}, U_{12}, \ldots, U_{ij}, \ldots, U_{nm}.$$

4. Formation of the decision matrix $M = \|M_i\|$ (table 1).

Table 1. **Matrix of possible results of decisions in the task of choosing of the optimal landing aerodrome**

Alternative decisions		Factors influencing the decision making					
		λ_1	λ_2	…	λ_j	…	λ_m
A_1	A_{adest}	u_{11}	u_{12}	…	u_{1j}	…	u_{1n}
A_2	A_{adep}	u_{21}	u_{22}	…	u_{2j}	…	u_{2n}
…	…	…	…	…	…	…	…
A_i	A_{aalt}	u_{i1}	u_{i2}	…	u_{ij}	…	u_{in}
…	…	…	…	…	…	…	…
A_n	A_{aalt}	u_{m1}	u_{m2}	…	u_{mj}	…	u_{mn}

Choosing of the optimal aerodrome, in case of forced landing is carried out by the methods of decision making under uncertainty [22]. Selection of criterion of DM under uncertainty (Wald, Laplace, Hurwitz, Savage) is conducted according to the type of flight.

Wald criterion (minmax) is based on the principle of "conservative attitude", and is applied if it is necessary to find a guaranteed solution in case of primary flight:

$$A^* = \max_{A_i}\left\{\min_{\lambda_j} u_{ij}(A_i, \lambda_j)\right\}.$$

Laplace criterion is based on the principle of "insufficient reason" and applied is in case of regular flight:

$$A^* = \max_{A_i}\left\{\frac{1}{m}\sum_{j=1}^{n} u_{ij}(A_i,\lambda_j)\right\}.$$

Hurvytz criterion uses coefficient of a pessimism-optimism α ($0 \le \alpha \le 1$) and is applied in case of flight once in 2 weeks:

$$A^* = \max_{A_i}\left\{\begin{array}{l}\alpha \max\limits_{\lambda_j} u_{ij}(A_i,\lambda_j) + \\ + (1-\alpha)\min\limits_{\lambda_j} u_{ij}(A_i,\lambda_j)\end{array}\right\}.$$

The optimal solution for the Savage criterion can be found using matrix of "regret". In case of win the elements of the "regret" matrix $r_{ij}(A_i, \lambda_j)$ are defined as the difference between the maximum value u_{ij} in the row and other values in the row:

$$r_{ij}(A_i,\lambda_j) = \underset{A_i}{\Delta} = $$
$$= \max_{\lambda_k} u_{ij}(A_i,\lambda_j) - u_{ij}(A_i,\lambda_j).$$

Then, with the help of the "regret" matrix according to the minmax principle the minimum deviations are determined:

$$A^* = \min_{\lambda_j}\max_{A_i} r_{ij}(A_i,\lambda_j).$$

Thus the person, who makes a decision, expresses with the help of matrix $\left\|r_{ij}\right\|$ his "regret" if he can't make a best decision in the condition λ_j. Making this decision the person, who makes a decision, has a guarantee that in the worst conditions the obtained income would be not lower than the found income.

Conclusion

Concepts of an air traffic controller's DSS in flight emergencies and of a flight dispatcher's DSS have been presented, program realization of systems has been shown. DSS of an air traffic controller in flight emergencies gives to the aviation operator possibility to quantify evaluation of alternatives of the flight situation development and to operatively choose an action strategy with minimal potential damage in the conditions of incomplete and uncertainty information. DSS of a flight dispatcher provides fast search of the information and support of the aviation operator during DM regarding the the possibility of departure or regarding the the optimal aerodrome in case of forced landing of AC. It is reasonable to use an air traffic controller's DSS during the real ATC in flight emergencies, a flight dispatcher's DSS — in the automated system of pre-flight information preparation.

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ИНФОРМАЦИОННАЯ ПОДДЕРЖКА ЧЕЛОВЕКА-ОПЕРАТОРА АЭРОНАВИГАЦИОННОЙ СИСТЕМЫ

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В статье представлены концептуальные модели системы поддержки принятия решений авиадиспетчера во внештатных полетных ситуациях и автоматизированной системы подготовки предполетной информации с интеллектуальным модулем поддержки принятия решения на вылет, приведена программная реализация систем, а также разработан алгоритм определения оптимального аэродрома для выполнения вынужденной посадки воздушного корабля.

Ключевые слова: *внештатная ситуация, вынужденная посадка, диспетчер по управлению воздушным движением, оптимальная альтернатива, предполетная информация, сотрудник по обеспечению полетов / летный диспетчер.*