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UDC 004.8:656.7

HYBRID INTEGRATION OF EXPERT SYSTEMS INTO AVIATION LOGISTICS MANAGEMENT STRUCTURES

In this study authors considered the integration of expert systems into management of aviation logistics. The complexity of this integration is in the management structures and in the context of the operational complexity which is constantly increasing and the continuous supply of chain operations. It was determined that the existing systems and methods to make a decisions are not full sufficient with big data processing and do not taking into account the dynamic changes or does not fully smooth out the risk factors in aviation logistics. It was agreed that the traditional methods are not enough effective when the tasks are to process a big amount of data in conditions of dynamic changes. It was detected that the integration of expert systems which are able to simulate professional knowledge and operational expertise making a big impact on the decisions quality and reduces the human factor in critical operational time and provides adaptive and flexible planning. In this study authors are also analyze and compare several modern systems, such as NAVBLUE, Ramco Aviation Suite, Veronte Autopilot, ARTAS, FANS-1/A, TCAS II, RUN.S.A.F.E., SAREX, AIR Cargo handling System Assessment Model and Astrea UAV Integration Platform. The authors found that, regardless of the individual functional capabilities of each system, modern aviation expert systems are quite fragmented and do not have unified architectural approaches. This leads to the need to develop a hybrid integration model that will be focused on combining expert system cores with centralized logistics planning. In this article, the authors proposed new architectural and methodological approaches to building a modular, standardized architecture that unites distributed knowledge, synchronizes analytical processes, and provides unified integration into digital platforms such as ERP, MES, TMS. The practical meaning of this research is to find possible transformations of existing aviation logistics practices using unified hybrid decision support systems and in managing the design of future digital aviation infrastructures.

Keywords: aviation, air traffic, traffic management, resource planning, aviation logistics, expert systems, intelligent decision-making, digital logistics architecture, modular knowledge systems, flight operations management, forecasting.

Introduction

Considering global economic structure, it's impossible to not notice that aviation logistics is one of the important and complex parts of the transport infrastructure. It is a grate component that includes both flight planning, air traffic management, cargo handling, crew management, spare parts supply and resources allocation. Everything of this should work in constant environmental variability conditions (changes in weather conditions, various disruptions in the supply chain, different fluctuations in air transportation and other circumstances such as financial conflicts, strikes, cyberattacks, etc)[1]. Give these aspects into account to be effective in managing these processes systems need to be able to work in real time and being adaptive and support ability to make decisions in difficult conditions.

Reviewing the existing systems in aviation logistics, it's easy to notice that most of modern systems are very fragmented and focusing on solving problems within isolated subsystems [2, 3]. At the same time, we can observe the rapid growth of BigData which requires rapid analysis to form recommendations in real time.

As a result of described above, the expert systems usage shown the ability to separate the typical usecases, predict events development, experts' knowledge models, and recommendations formed under unpredictable conditions looks very profitable. Currently, the existing examples of the expert systems in aviation

practice already exist in next areas: technical air fleet conditions monitoring, highlighting the unexpected aircraft behaviour anomalies, estimation of route profits, scheduling and risk management. However, these systems are still being developed autonomously without considering the wide range of need in aviation logistics and infrastructure and do not count scalability or integration with other components [4].

Based on described above the principles, methods and models of expert systems hybrid integration into aviation logistics management structures looks as very needed in scope of intelligent air transport management new paradigm. Hovewer, practical implementation of hybrid integration of expert systems has a few challenges such as variety of knowledge data, complexity in expert experience formalization, need in unification of knowledge structure, interaction complexity in variety of systems, limited productivity in real time and cyber safety. As conclusion of all research there is a high need of developing new approaches in integration of expert systems into aviation logistics management systems. These new ways of building systems should consider dynamic changes in environment, growing safety requirements, modern aviation processes, precision and adaptive decision making.

The goal of this study is development of conceptual foundation and methological models to build the integration of expert systems into aviation logistics management structure with improvements of adaptability, decision-making accuracy, and the effective logistics structures under conditions of increasing operational complexity.

The object of this study is the expert systems integration into aviation logistics management structures in the time of increasing operational complexity and the need for sustainable supply chain operations.

Related works

In the last five years the focus in aviation logistics has been moved to usage the expert systems in logistics management structures. Complexity increasing in logistics processes, need to improve automation and adaptility, and decision making in multifactor contrains make that trend very popular in Scientifics [1-20]. The hybrid integration contains possibilities of expert systems with nowadays intelligent modules such as machine learning [3,4], ontological modeling [5,7], neaural network approaches and agent-based technologies [12-15] make the hybrid integration as key direction in the digital solution development for aviation logistics.

In recent years, various approaches can be distinguished in terms of the structure of building hybrid systems in aviation logistics. They include the development of adaptive resource planning systems, optimization of aviation spare parts delivery routes and forecasting delays and malfunctions based on historical data. There is also growing interest in connecting expert systems to open data sources (Open Aviation Data).

Particularly in study [1] the expert system based on probabalistics trees is proposed. This system is used to predict technical failures in Boeing and Airbas aircraft. Described system model of an expert system based on probabilistic decision trees is specifically used at forecasting the technical conditions of aircraft. The main goal of this system is to reduce the aircraft downtime by executing more accurately the diagnostics of system failures. Another similar solution is proposed in research [12], where hybrid expert system is integrated into flight safety logistics information system. In [16] authors higlhited the high system adaptability to changes in the supply structure but also determined need to improve integrations with other information flows. In the article [17], the authors considered in detail the use of multi-agent system with twins simulating logistics chains in real time. It was found out that such system reduces a lot of response time on changes in external factors such weather conditions or infrastructure overloads. Very interesting is article [9] from point of hybrid architecture view where authors consider the holonic management structure for urban air mobility using LLMs (large language model) in unpredictable situation dicesion making. In the paper [13] authors put the focus on reviewing and systematization the main challenges and problems of hybrid expert system integration into the aviation structure. They are focusing attention on the limitations such as difficulties in integration with existing ERP systems, and the lack of unified standards in data exchange protocols between system components and stuff training.

In article [14] authors considering the hybrid expert systems with Iot components to track the cargo movements in real-time conditions. The proposed model shows improvement of accuracy in the prediction of delivery time and allows us to fastly detect route deviations. The research proposed a hybrid architecture where combination of expert rules and machine learning methods are used for cargo routing.

In another newest research [2,5] authors tried to implement logistics support system in a cloud environment using hybrid expert logic and blockchain based transaction verification. Despite the authors' demonstration transparency and high security in logistics operations, they also highlighted a delay in transactions such as blockchain platform limitations, which might be an issue in real-time conditions. This investigation is important when used in multilevel analysis of decisions in high dynamics conditions. Also, another problem is lack of communication protocols between ERP systems and AI components.

Investigating research based on predictive logistics in ariports based on combinations between data analysis and expert modules [11] we can see that authors proposed the multilevel hybrid expert system model to optimize the logistics decisions in crisis situations. Also, it is worth paying attention for research described in articles [8,17], where authors focused on a hybrid expert systems integration into centralized logistics management at airports in emergency scenarios conditions. Authors of articles mentioned above demonstrate the system effectiveness in meantime highlights the low flexibility when transitioning to decentralized menegement models.

Summirizing all reviewed research we can confirm that the expert systems integration into aviation logistics structures got the evolution impulse due to the development of related technologies such as large language models, digital twins, blockchain and cloud computing. However, there are still a lot of challenges and issues regarding data exchange protocols, data model standardization, support of regulatory requirements and ensuring reliability under resource-constrained conditions. All these aspects require future research to develop comprehensive, scalable and adaptive management systems in aviation logistics of next generation.

In general, the analysis of literature shows a constant movement from the isolated use of expert systems to the creation of flexible, scalable hybrid architecture that contains combinations of logical inference with analytical possibilities of modern artificial intelligence. This transformation corresponds to the growing complexity of logistics processes in aviation and the need to be sure that their continuity, adaptability, and security in global logistics chain are fully considered.

Matherials and methods

The methodology of this research is based on the combination of system analysis principles, artificial intelligence, logistics modeling and architectural integration of software systems. The concept of hybrid integration is a basis and includes the combination of digital logistics based on a modular and service-oriented solution (Service-Oriented Architecture, SOA) with expert systems in aviation logistics [12, 15].

The research is based on the following principles:

– Hierarchical modeling of logistics process management;

– Modularity and standardization of expert knowledge;

– Hybridity – as a combination of deterministic and fuzzy methods (rule-based reasoning + fuzzy logic);

– Adaptability – the ability to automatically correct decisions when external conditions change;

– Interoperability – ensuring interaction with ERP, TMS, AIMS, and other industrial systems [18].

To define the structure of the hybrid model: Let us denote: $K = \{K_1, K_2, ..., K_n\}$: set of expert system kernels (knowledge models); $D_t = \{d_1^t, d_2^t, ..., d_m^t\}$: input data at a point in time (sensors, schedule, weather conditions, stocks); R: a set of rules for logical inference in expert systems. $A_t = f(K, D_t, R)$: set of analytical solutions at the moment t. Π_t: logistics plan at a given time t, which is formed on the basis of A_t. Then the generalized kernel of the expert system is given by outlining that this system is represented as a functional (1):

$$K_i: D_t \times R \to S_i^t \tag{1}$$

where: S_i^t – a partial decision or recommendation given K_i.

The aggregation mechanism (integration kernel) is given by the aggregation of solutions from all systems (2):

$$A_t = \bigcup_{i=1}^{n} \omega_i \cdot K_i(D_t, R) \tag{2}$$

where: $\omega_i \in [0,1]$ – weightning factors (measurements of reliability/relevants of the knowledge in expert system's K_i).

The logistics planning optimization model involving the plan formation Π_t, that minimizing the costs, risks, times of delivery and maximizing the reliability of logistics operations (3):

$$\min_{\Pi_t} [C(\Pi_t) + R(\Pi_t) - \alpha \cdot Q(\Pi_t)] \tag{3}$$

where: $C(\Pi_t)$: logistics plan cost function, $R(\Pi_t)$: risks measured by expert subsystems, $Q(\Pi_t)$: solution quality function (time, reliability, efficiency), α: quality priority coefficient.

The model includes monitoring systems for tracking the real state of airspace and automatic route adjustment for different emergencies.

Mathemetical justification

1. Root optimization. The model that formulates optimization problem can be presented using next formulated form (4):

$$min\ i\ mize\ Z = \sum_{i=1}^{n} C_i \cdot X_i \tag{4}$$

where: C_i – route costs i, X_i – routes number.

2. Correction factors: Usage of correction factors under impact of weather condition (15):

$$K_{total} = K_v \cdot K_h \cdot K_f \cdot K_t \cdot K_n \tag{5}$$

where each K used as specific factor that impact on the results. Management system development based on graph theory (6):

$$G = (V, E) \tag{6}$$

where V – nodes (airports, airway points), E – eges (routes).

Extended REGIONAL-INTEL mathematical model.

1. Optimization of routes.

For route optimization we will use linear programming problem that can be formulated using next formula (7):

$$min\ i\ mize\ Z = \sum_{i=1}^{n} C_i \cdot X_i \tag{7}$$

where Z – total costs, C_i –single route cost (fuel, time, etc), X_i – binar variable (1, in case route is selected/used, 0 - no).

2. Coefficients correction formation. Coeficients corrections is used for real time model adaptation and can be represented using next form (8):

$$K_{total} = K_v \cdot K_h \cdot K_f \cdot K_t \cdot K_n \qquad (8)$$

where K_v – speed coefficient, K_h - altitude coefficient, K_f fuel ratio, K_t time factor, K_n – loading factor.

3. Management system using Graph theory. Graphs that consist of airports (nodes) and routes (edges) (9):

$$G = (V, E) \qquad (9)$$

where V – nodes set, E - set of edges which represent routes between nodes. Costs of aircraft flight between nodes can be described in next view (10):

$$C_{ij} = d_{ij} + K_{weather} \qquad (10)$$

where C_{ij} – aircraft route costs from node i to node j, d_{ij} – distance between nodes, $K_{weather}$ – weather conditions corrections like heavy rain or show.

4. Fuel costs optimization. Fuel costs for aircraft route can be presented using next formula (11):

$$F = F_{base} \cdot \left(1 + K_f \cdot (T + R)\right) \qquad (11)$$

where F – costs of fuel, F_{base} – base fuel costs without any corrections, T – temperature (Celsius degrees), R – humidity (in %).

5. Decision Support System (DSS). Multicriteria optimization methods might be used for recommendations generation of DSS. All recommendations can be represented as following form (12):

$$V = \sum_{j=1}^{m} w_j \cdot R_j \qquad (12)$$

where V estimation of all overall alternatives, w_j – criterias weights, R_j – alternative estimate by the criteria j.

6. Dynamic conditions adaptation. To adapt systems under dynamic conditions, the adaptive management methods can be used. This adaptation can be represented as follows (13):

$$u(t) = K_p \cdot e(t) + K_i \cdot \int_0^t e(\tau)d\tau + K_d \cdot \frac{de(t)}{dt} \qquad (13)$$

where $u(t)$ – controlled action at specified time t, $e(t)$ – error or differences between expected and real value, K_p, K_i, K_d – proportional, integral and differential control coeficients.

Methods of analysis

Quantitive estimate: method of relative efficiency (14):

$$REI = \frac{Q_g}{Q_t} \cdot \frac{T_t}{T_g} \cdot \frac{R_t}{R_g} \qquad (14)$$

where Q_g – hyrid model decision quality, T_g – response time, R_g –incidence risk. Loss estimation model (15):

$$L = C_d \cdot D + C_r \cdot R + C_e \cdot E \qquad (15)$$

where C_d – cost of delays, D – duration, C_r – risks costs, R – probability, C_e – mistake costs, E – coefficient of mistakes.

For forecasting methods, the Bayesian network is a choice for risks estimation depending on conditions changes and LSTM model is used for adaptive forecasting of resource load changes.

**Usage results of hybrid expert system integration
into aviation logistics management structures**

Table 1 represents the results of technical system characteristics comparison in the aviation logisticas management systems.

Table 1 shows that the systems which are oriented on unmanaged aerial vehicles actively introducing the solutions based on Artificial Intelegence (AI) and autonomous solutions, to make these fully integrated with the air space regulated by dispatcher services. In this case it looks that the most promising platform for integration of unmanaged air vehicles is Astrea, which mostly focuses on safe introduction of UAVs into general airspace system and works in close cooperations with national regulation services.

At the same time, RUN.S.A.F.E and Ramco are the analytics solutions examples established on machine learning and forecasting. These platforms detect potential risks and provide instruments for decision making in real time. But successful usage of these platforms requires a high level of integration with internal processes of companies.

From the safety looks TCAS II stays crucial important systems, but this system is not enough flexible in front of adaptations to new types of airplanes. In meantime, SAREX has shown greater flexibility, covering as traditional airplanes as UAV's in rescue operations.

Table 1.

Results of technical system characteristics comparison in the aviation logisticas management systems

System	System type	Main function	Main module	Adaptivity	Integrability	Autonomy	AI/ML Integration	UAV Support	Integration with Other Systems
NAVBLUE	Platform	Flight planning	Partial	High	High	Medium	Yes	No	High (Airbus Skywise)
Ramco Aviation Suite	ERP	MRO	Embedded logic	Medium	High	High	Yes	No	High (ERP-level)
Veronte Autopilot	Autopilot	Autonomous control	High	High	Limited	High	Partial	Yes	Medium (for UAV systems)
ARTAS	ATM System	Radar data processing	None	Low	Medium	Medium	No	No	High
FANS-1/A	Communication	Message exchange	None	Low	Medium	Medium	No	No	High (with ATM systems)
TCAS II	Safety	Collision avoidance	Fixed logic	Low	Limited	High	No	No	Standard integration
RUN.S.A.F.E.	DSS	Runway overrun prevention	High	Medium	Low	Medium	Yes	No	High
SAREX	DSS / Expert System	Maintenance planning	High	High	High	Medium	No	Yes	Medium
Air Cargo Handling Model	Hybrid Model	Cargo systems assessment	High	High	Medium	Low	Partial	No	Medium
Astraea UAV Integration	Integration Platform	UAV management	High	High	Medium	High	Yes	Yes	High (with air traffic control systems)

At the same time, the Air Cargo Handle System Assesment Model looks like analytics element in hybrid logistics systems providing expert assessments of effectiveness in cargo handling.

In Table 2 there are results of decision makin time and critical mistakes analysis per 100 operations.

Table 2.

Results of decision makin time and critical mistakes analysis per 100 operations

System	Flight (min)	Load (min)	Supply (min)	GPS Failure (min)	Average Time (min)	Critical Errors (per 100 ops)
NAVBLUE	23	17	28	20	22.00	3
Ramco Aviation Suite	26	19	24	21	22.50	4
Veronte Autopilot	20	15	23	17	18.75	2
ARTAS	27	21	30	22	25.00	4
FANS-1/A	30	24	33	26	28.25	5
TCAS II	32	25	35	28	30.00	6
RUN.S.A.F.E.	24	18	29	20	22.75	3
SAREX	28	22	31	25	26.50	5
Air Cargo Handling System Model	25	19	27	22	23.25	4
Astraea UAV Integration	21	16	22	18	19.25	2
Hybrid Model (C)	18	14	22	17	17.75	1

This merged table clearly describes the connection between decision-making time in differents operational scenarios with critical mistakes per 100 operations for each system. Obviously, that hybrid model (C) demonstrates better productivity in decision-making process (approx. 17,75 min) and lowest count of critical errors (1), which means that system has bigger effectiveness and stability in aviation logistics.

On picture 1 there is a result of decision-making analysis.
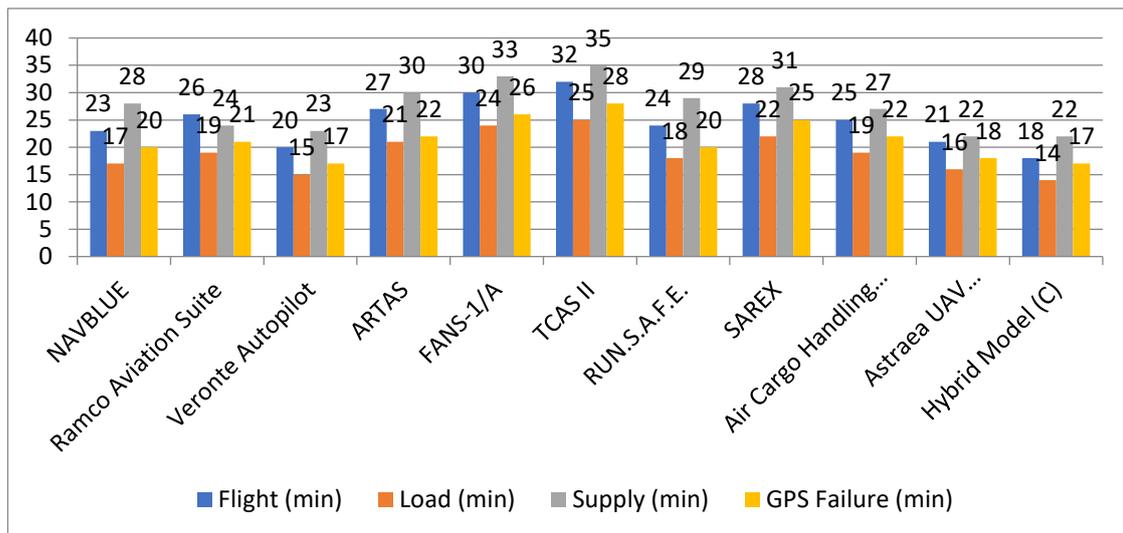
Pic. 1. Result of decision-making analysis

In this case, the analysis shows the need of implementation of hybrid approach for rising the efficiency and stability of logistics systems in aviation.

Discussion of the results

The tendency to implement hybrid logistic systems in aviation has already got a clear technological form that is outside of the box of improvements in simple isolated solutions. Integration is highly critical important as this allows us to combine strictly defined expert algorithms with flexible machine learning models. This feature is especially important for effective functioning of global aviation nodes.

In this context the model of integration and management system hierarchy is suggested on regional level. The model is calling REGIONAL-INTEL (Regional Intelectual Management System). The main components of this system include environmental data, collecting and analysis of information about weather in real-time. Creating an integrated Data Base that centralized the information about aircraft, routes, weather conditions and economic values includes data from different sources (Meteo services, aeroports, aviation companies). The optimization algorithms are used for optimal routes calculation, then machine learning methods used for delay predictions and route corrections. Hierarchy structure of management covers a local, regional and national level, supporting cooperation between all these levels to make reactions faster in changed conditions. And finally, the system of decisions support is developed as intellectual platform with cooperation ability with operators and pilots for route correction in time [16].

The main sense of usage hybrid approach is in expert knowledgebase merge with machine learning adaptive algorithms, that supply system ability for self-learning, unpredictable situations adaptation, fast decision-making and autonomic process management. This allows us to excute not only planned maintenance but also adapt the technical maintenance schedule to predict overloads and actual environment conditions [10]. As good example of hybrid integration is the platform RUN.S.A.F.E., that combine static risk profiles with dynamic data analysis includes the crew behaviour or overloads on some route nodes. Also, as good example of usage are the platforms of unmanaged air vehicles integration are Veronte AutoPilot and Astera UAV Integration Platform, which are the base for hybrid management of unmanged air vehicle systems in logistics network.

The hybrid systems integration into global menegement structures of aviation logistics require the quaranty the compatibility with expert or intellectual modules. From tis point of view the NAVBLUE shows the effective integration of routing systems with analytical forecasting modules, that allows logistics optimization considering weather conditions, cargo types and aircraft schedules. Also, it's necessary to claim that ARTAS and FANS-1/A also are very important as infrastructures components in hybrid systems and providing the high-quality communication channels between arcraft and ground management departments.

Meantime, the Air Cargo Handling System is used as analytical component on hybrid logistics systems, providing the expert effectiveness estimations in cargo handling which might be used in the future as data for self-learning management systems.

REGIONAL-INTEL model proposes new level of integration, adaptivity and complexity in regional level of management in aviation traffic and resolving the problems which were not considered in others existing systems (absence of multicriteria solutions, limited data dynamics). These advantages make implementation of this system very promised from modern aviation infrastructure side by improvements of safety and make management more effective. Comparison of REGIONAL-INTEL models with other existing management systems in aviation traffic show special advantages and limitations in such aspects as multicritria approach, data dynamics, optimizations methods, hierarchy structure, monitor and warnings. As results, REGIONAL-INTEL demonstrates these significants

advantages in management of aviation logistics due to adaptivity, modern optimization methods usage and multicriteria approach integration that make this system unique.

Description of algoritms by mathematical formulas providing the structured approach to build the more integrated and hierarchical regional system management of aviation logistics. Usage of precision mathematical formulas makes each stage more structured and formalized, and promoting the future software implementation and provides precision in aviation traffic managements.

Thus, the extended block model for the integration and hierarchy of the regional control system considers such important aspects as forecasting and feedback, that significantly increase the effectiveness and adaptability. This allows us to resolve better modern challenges in aviation logistics area, contributing to increasing safety and making effective decisions in management systems of aviation logistics. As was mentioned above, the integration of management system hierarchy on the regional level into multicriteria analysis information technologies allows us to build routes for aircraft considering all possible criterias and constraints. The solution requires comprehensive mathematical modeling and integration with modern informational systems to support effective decon-making.

Conclusions

This maked study confirms thad hybrid integration of expert systems into aviation management logistics structures increasing operational effectiveness, accuracy of decision-making and adaptability of the system in changed dynamic conditions. Comperison analysis shows that the proposed hybrid model (C) demonstrated better performance, achiving the minimum of average time for decision-making, the lowest value of mistakes coefficient per 100 operations, the fastest reaction time on changed conditions and the highest Relative Effectivenes Index (REI) value. The REGIONAL-INTEL architecture that includes adaptive algorithms, data union in real time conditions and hierarchy management structure increase the coordinations and forecasting on regional level. Combaining the logic based on the rules, AI modules, and optimization methods such as genetic algorithms and TOPSIS/AHP methods, model provide the multicriteria approach in building routes, minimizing the fuel costs, improving safety and adapting to change in environment conditions. This study provides strict mathematical and algorithms base for implementation of intelligent aviation logistics system fo next-generation and make the movement to scalable, interoperable and self-learnig hybrid infrastructure within digital aviation ecosystems more reasonable.

The practical meaning of this research is in the transformation potential of existed approaches in aviation logistics based on the unified hybrid systems of decisions support and in management of digital aviation infrastructure future development.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS
Conceptualization O.S.; methodology N.L.; validation N.L.; formal analysis, O.S.; investigation, O.S.; data curation N.L.; writing-original draft preparation, O.S.; writing-review and editing, O.S.; visualization, O.S.; project administration, O.S.; software O.S.; resources O.S.; supervision N.L.

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ГІБРИДНА ІНТЕГРАЦІЯ ЕКСПЕРТНИХ СИСТЕМ У СТРУКТУРИ УПРАВЛІННЯ АВІАЦІЙНОЮ ЛОГІСТИКОЮ

Об'єктом цього дослідження є інтеграція експертних систем у структури управління авіаційною логістикою в умовах зростаючої операційної складності та потреби в стійкій роботі ланцюга поставок. Встановлено, що традиційні методи прийняття рішень недостатні для обробки великих обсягів даних, врахування динамічних змін навколишнього середовища та пом'якшення різноманітних факторів ризику в авіаційній логістиці. Доведено, що інтеграція експертних систем, здатних моделювати професійні знання та операційну експертизу, підвищує якість рішень, зменшує людські помилки в критичних операціях та забезпечує адаптивне, гнучке планування. У дослідженні аналізується та порівнюється кілька сучасних систем, таких як NAVBLUE, Ramco Aviation Suite, Veronte Autopilot, ARTAS, FANS-1/A, TCAS II, RUN.S.A.F.E., SAREX, Air Cargo Handling System Assessment Model та Astraea UAV Integration Platform. Було визначено, що, незважаючи на свої індивідуальні функціональні можливості, сучасні авіаційні експертні системи часто фрагментовані та не мають єдиних архітектур інтеграції. Обґрунтовано необхідність розробки гібридної моделі інтеграції, зосередженої на поєднанні ядер експертних систем із централізованим плануванням логістики. Запропоновано концептуальну та методологічну основу для модульної, стандартизованої архітектури, яка об'єднує розподілені знання, синхронізує аналітичні процеси та забезпечує безперешкодну інтеграцію з цифровими платформами, такими як ERP, MES та TMS. Пріоритет надається розробці модульних експертних компонентів, які адаптуються до операційної мінливості та масштабуються в різних авіаційних структурах. Практичне значення дослідження полягає в його потенціалі для трансформації існуючих практик авіаційної логістики за допомогою уніфікованих гібридних систем підтримки рішень та в управлінні проектуванням майбутніх цифрових авіаційних інфраструктур.

Ключові слова: авіація, повітряний рух, управління рухом, планування ресурсів, авіаційна логістика, експертні системи, інтелектуальне прийняття рішень, архітектура цифрової логістики, модульні системи знань, управління польотними операціями, прогнозування.