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Enhancing the Ability of Flight Safety Risk Management with the Empowerment of Digital&Intelligent Technology

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Abstract. Aimed at these disadvantages of training method, accident investigation and fault regression among flight safety management, it put forward some specific methods in terms of Digital&intelligent application research and design. From the angle of flight safety management, it carried out application system analysis of Digital &Intelligent technology, such as artificial intelligence, big data and cloud computing. It built systematic flight safety risk management by requirement frame design, digital&intelligent technology application strategy, ability enhancing design and typical application scene design, thus achieved the goal enhancing training effect, accident estimation quality and fault regression effect.

Keywords: Flight safety; Digital&Intelligent technology; Risk management; Artificial intelligence

1 Introduction

Since 2019, digital intelligence technologies such as artificial intelligence (AI), large models, big data, and cloud computing have experienced rapid development, leading to successive waves of AI advancement [1]. Currently, the technology of large models is becoming increasingly mature and is demonstrating a strong momentum for widespread application across various vertical industries [2,3]. In the past two years, Western countries—particularly the United States—have significantly increased their investments in AI applications across fields such as cybersecurity, image processing, facial recognition, and drone technology. Reports indicate that in 2022 alone, the U.S. Department of Defense allocated nearly $700 million to initiatives within the realm of AI. In the specialized field of flight safety management, the application of intelligent digital technologies is largely in its nascent stages. Notably, AI has seen some exploratory research in trend analysis and fault diagnosis concerning aircraft and engine parameters [4]. The implementation of big data platform technology within flight safety management has commenced engineering development and deployment; this approach leverages autonomous learning, neural networks, and knowledge repositories to enhance data analysis capabilities [5]. Additionally, mobile application technologies have begun preliminary

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engineering applications for executing data reporting, situational display, and information interaction during flight missions [6].

The large model technology epitomized by ChatGPT represents a significant milestone towards artificial general intelligence (AGI). It signifies an important trend in the future development of AI technology and offers a new impetus for applications in the field of military intelligence [7-8]. In the field of civil aviation safety, big data technology is used to explore the digital transformation of flight safety management practices. By employing big data and AI technologies, it is possible to monitor the entire flight operation process, accurately locate non-standard operational behaviors, and identify potential risks [9]. In terms of aviation safety prediction, a new prediction method based on an improved long short-term memory model has been developed, which reduces prediction errors through AI algorithms [10]. The application prospects of AGI in the field of flight safety are broad, and it can play an important role in pilot training, decision-making consulting suggestions, and data intelligence analysis [11].

Given the rapid development of digital intelligence technologies, a generational advantage has gradually emerged within existing technological systems. To address the long-standing issues of low training efficiency and frequent malfunctions during flight missions, it is essential to incorporate advanced technologies such as AI, big data, large-scale models, cloud computing, and digital twins. By transforming and upgrading the existing flight safety management system, one can achieve an enhancement in flight safety risk management through the replacement of technical means.

2 The Application Design of Intelligent Digital Technologies in the Flight Safety System

(1) Overall demand design

The application of digital intelligence technology follows an upgrade path characterized by business-driven initiatives, capability enhancement, system transformation, and data mining. It accurately identifies the key pain points experienced by users in their business activities. An evaluation of existing and under-construction functional systems is conducted using new technological methods such as AI, big data, mobile platforms, and digital twins. This process involves specific approaches, including adjustments to system architecture, modifications to functional modules, and optimization of operational logic, to achieve the upgrade and construction of digital intelligence technology applications. Figure 1 below presents the overall demand framework for the application of digital intelligence technology.

The business and capability domains, from a top-level design perspective, provide optimization requirements and capability enhancement needs for the operational activities of aviation safety management agencies, flight implementation entities, and industrial sectors. The system domain outlines the typical business application support systems that have already been deployed. The intelligent digital domain presents the functional systems that require digital intelligence upgrades, with a focus on optimizing application system construction.

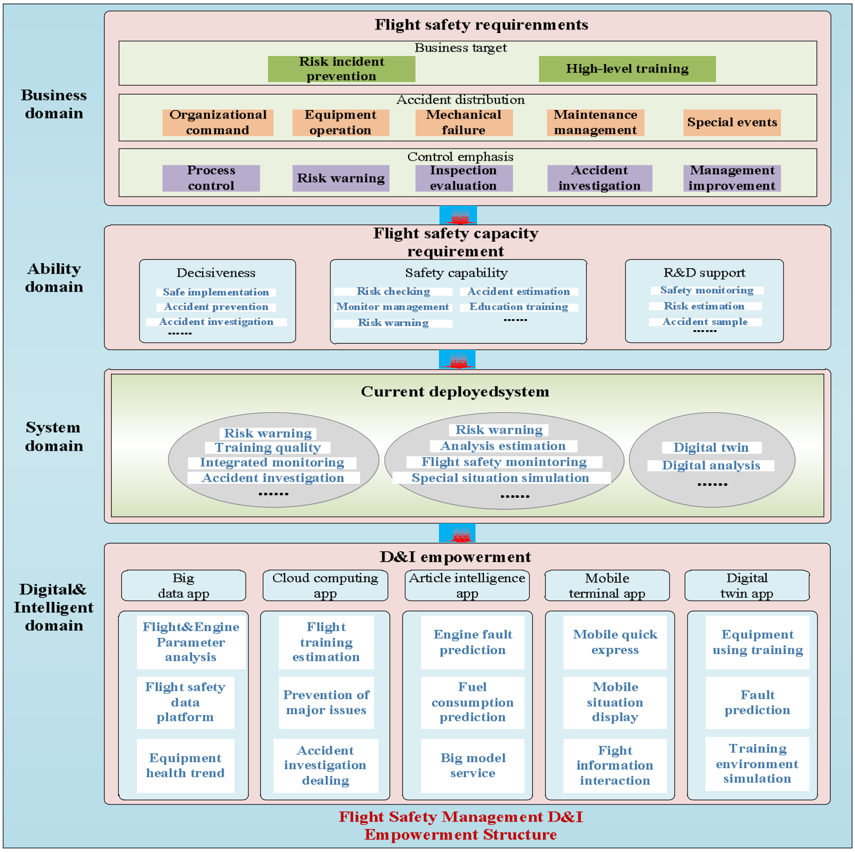

Fig. 1. Overall requirements for flight safety management

(2) Intelligent digital application design

Based on the distribution status of application systems already deployed within the flight safety management cybersecurity framework, and considering new security requirements, new equipment deployments, and the gradual readiness for the promotion and application of emerging technologies, we will develop an application plan for intelligent technologies such as AI, big data, cloud computing, mobile applications, and digital twins. We will decompose the system deployment and intelligentization needs from two perspectives—business departments and phases of flight missions. Table 1 presents our decomposition concept.

In the business domain of flight safety management, there are three categories of entities involved: management (government agencies), training (military units), and equipment (industry). The task phase consists of three stages: pre-training, during training, and post-training. Flight mission implementation activities are organized chronologically through these stages. By categorizing and decomposing the activities along these two dimensions, it is possible to accurately pinpoint the business activity and task phase of any aviation safety management information system. This approach offers guidance for analyzing and evaluating the applications of intelligent digital technology.

Table 1. Intelligent digital application design

Business Field	Task Phase	Pre training	Training in progress	After training
Management (department)	Typical scene	Big model assisting; Safety service	Safety risk warning	Accident investigation analysis
	Current system	Big model intelligent policy assisting; Flight safety system	Warning system; Situation display system	Playback system; Statistics system
	Satisfaction	Partically satisfied	Partically satisfied	Partically satisfied
	D&I applicaiton	Large language mode; Big data; Cloud computing	Big data; Mobile application	Big data; Article intelligence; Mobile application
	Ability promotion	Policy ability; Warning ability	Prediction/Warning ability	Accident dealing ability
Training (team)	Typical scene	Safety prediction; Pilot risk profile; Equipment selection	Mobile express; Bird collision avoidance; Minimum altitude flight	Training quality estimation; Flight data analysis; Engine parameter analysis
	Current system	The ruled prediction system	systems with lack of automation measures	Data statistics system; Estimation system
	Satisfaction	Seriously unsatisfied	Seriously unsatisfied	Partically satisfied
	D&I applicaiton	Big data; Article intelligence	Mobile application; Big data; Cloud computing	Big data; Article intelligence; Large language mode
	Ability promotion	Prediction ability	Quickly response ability; Special situation dealing ability	Estimation ability
Equipment (industry)	Typical scene	Equipment using training; Repairing training; Simulation practice	Attending training	Data analysis improvement; Safety design improvement;
	Current system	Training system; Simulation system; Twin training environment	Situation display system	Statistics system; Simulation estimation system
	Satisfaction	Partically satisfied	—	Seriously unsatisfied
	D&I applicaiton	Large language mode; Digital twin	—	Digital twim; Big data; Article intelligence
	Ability promotion	Practice and Operation ability	—	Equipment estimation ability

For management entities (government agencies), there are established guidelines for decision-making, predictive warnings, and organizational accident investigations at each stage of training: before, during, and after training. To support these activities, information systems and commonly used data statistical analysis methods have been implemented. However, the potential of advanced technologies, such as large model applications, mobile applications, and AI models, has yet to be fully leveraged to enhance overall management levels and capabilities.

For military training, operational activities and typical scenarios are numerous, constituting the main part of flight safety management. Currently, a large number of application systems have been developed, including flight monitoring, predictive warnings, training assessment, aircraft status evaluation, and data management. However, in scenarios such as mobile rapid reporting, emergency response handling, flight profiling, and low-altitude night training, more advanced digital intelligence technology applications are needed to achieve the deployment and operation of technical systems that support these operational activities.

For equipment (industry), training exercises and equipment optimization activities are primarily conducted pre-training and post-training. Technologies such as digital twins and AI models enhance the effectiveness of these drills and provide decision-making recommendations for equipment optimization.

3 Design of Intelligent Digital Empowerment Scenarios for Flight Safety Risk Management

From the perspectives of management, training, and equipment, we provide an analysis of risk management in some typical scenarios. From a management standpoint, typical scenarios include the use of large models to assist in decision-making and comprehensive monitoring and assessment of aircraft safety status. In terms of training, representative scenarios encompass pilot risk profiling, emergency response handling, mobile application development, fuel consumption data forecasting, low-altitude flight operations, scene monitoring and guidance scheduling, as well as flight parameter data analysis and diagnostics. Regarding equipment, notable scenarios involve digital twin training environments and data analysis evaluations.

(1) Decision-making assisted by large models

By applying large model systems, functionalities such as human-computer interaction, knowledge retrieval, and associative analysis are developed to facilitate the interaction between critical data and decision-making suggestions provided by large models for flight training personnel. This approach aids various roles in making informed decisions comprehensively. With the application of large model technology, the dialogue management module functions as the 'brain' within the dialogue system. An effective design of this module is crucial for achieving favorable dialogue outcomes. By leveraging this digital intelligence technology, users gain access to efficient data acquisition and high-quality safety consultation advice, thereby enhancing both their decision-making efficiency and accuracy.

(2) Comprehensive monitoring and assessment of aircraft safety status

On the basis of existing data obtained from aircraft and engine trend monitoring systems, this study integrates various data resources, including flight parameters, fluid monitoring, non-destructive testing, and external field command and control. By employing big data analysis and cloud computing technologies, we conduct multi-source data fusion analysis and processing to achieve comprehensive monitoring and health assessment. Through comprehensive monitoring and assessment of aircraft safety status, we conduct an integrated analysis and trend evaluation of various multi-source heterogeneous data. This process involves analyzing the correlation impacts of abnormal data, thereby enhancing diagnostic capabilities. Ultimately, we aim to provide a thorough evaluation of the health status and airworthiness of the aircraft. With this functionality, equipment management departments are able to conduct comprehensive assessments and select aircraft that exhibit optimal conditions and align with airworthiness performance standards.

(3) Pilot risk profile

The Pilot Risk Portrait System employs data analysis, mining, and presentation techniques to comprehensively enhance the technical means and capabilities of risk assessment at the operational level of flight. This approach aims to reduce the likelihood of human factor-related risks. Various departments and roles involved in flight safety management can leverage the pilot portrait system to comprehensively review data from each segment of a flight. This system emphasizes identifying and controlling core risks associated with flight operations. Additionally, these entities can systematically organize and filter data on a regular basis to enhance the accuracy of measures taken to ensure flight safety. The data derived from the Pilot Risk Portrait System can provide a foundational basis for assessing flight training, thereby establishing a comprehensive data framework for the full lifecycle management of pilots.

(4) Emergency response

The current methods for cultivating emergency response capabilities are lacking. While regular simulation training for emergency responses is conducted, it predominantly relies on hypothetical scenarios, such as a specific aircraft facing a particular emergency situation, and then engages in virtual training based on these scenarios. However, the dynamics of aerial situations can change rapidly, and even for similar types of emergencies, response strategies can differ significantly based on various factors such as aircraft type, airport environment, seasonal variations, and meteorological conditions. It is also crucial to make flexible adjustments that consider the pilot's experience and skill level. Due to its inherent complexity and high risk, enhancing emergency response capabilities through conventional theoretical training and hypothetical exercises is challenging. By leveraging digitalization methods such as virtual reality and digital twins, it is possible to conduct comprehensive scenario simulations and full-process drills. Additionally, implementing highly targeted training for specific scenarios—such as high-density operations and busy phases, complex interrelated emergencies, and incidents occurring in intricate meteorological conditions—can facilitate a greater level of proficiency and ease in managing these situations.

(5) Mobile application for flight missions

By promoting the use of mobile applications, the efficiency of data transmission and the convenience of visualizing data can be significantly enhanced in various areas, including flight safety information reporting, flight safety communication, flight safety education supervision, flight safety risk management, and the monitoring of flight training safety. The widespread deployment of mobile devices facilitates the collection, transmission, and display of data in flight training. This advancement accelerates data acquisition, enhances processing efficiency, and simplifies data presentation, thereby enabling real-time monitoring of training conditions. The application of mobile devices empowers flight training participants to improve their capabilities in data acquisition, data analysis, command adjustment, and emergency handling.

(6) Prediction of fuel consumption data

The accurate estimation of an aircraft's fuel consumption is essential for effective flight radius planning, remaining flight time assessment, and other critical factors. This information aids planners and pilots in making informed decisions. Currently, the existing technical methods for predicting fuel consumption are limited in scope, and the accuracy of these predictions is relatively outdated. There is an urgent need to expand advanced technological approaches to enhance predictive capabilities. By incorporating machine learning model analysis techniques, a comprehensive correlation analysis can be performed on the various factors influencing fuel consumption, thereby improving the accuracy of data predictions. With advancements in fuel consumption prediction capabilities, mission planners are now able to more accurately evaluate the maximum flight radius of aircraft. Consequently, pilots can effectively assess their remaining flight time and determine the farthest position they can reach.

(7) Ultra-low altitude flight

Ultra-low altitude flight primarily refers to operations conducted at altitudes of less than 100 meters above ground level. Due to the inherent complexities of the low-altitude environment and the frequent occurrence of unpredictable conditions, ultra-low altitude flight missions are associated with significant safety risks and challenges. In addition to the necessity for pilots to possess exceptional flight experience and skills, it is imperative to strategically plan ultra-low altitude routes. This planning should aim to minimize encounters with random obstacles such as flocks of birds, dark clouds, and rainfall whenever possible. By doing so, we can achieve a clear airspace effect and create favorable conditions for effective flight safety management. By incorporating AI methodologies, specifically through the application of machine learning classification techniques and generative models, and by leveraging training based on data samples, it is possible to obtain higher-quality short-term predictive data. This advancement provides a robust data foundation for route planning and pilot operations. Through these applications, AI can assist command personnel in formulating more rational ultra-low altitude flight route plans and making more precise immediate adjustments. Additionally, it aids pilots in predicting and reasonably avoiding obstacles.

(8) Scene monitoring and guidance scheduling

During the aircraft landing phase, both ground control personnel and pilots must continuously monitor the prevailing landing conditions to ensure the safe and orderly guidance of the aircraft towards the designated target track area. By integrating radar detection with computer vision through the technology of radar-vision fusion, a unified processing link is established. This approach leverages AI to achieve the seamless integration of image signals and radar signals, thereby enabling the direct acquisition of high-quality situational distributions and data information regarding various ground obstacles. For ground guidance dispatchers and pilots, the acquisition of more reliable and direct information regarding ground situations, along with enhanced display effects, provides a more dependable basis for operational handling. Consequently, the guidance and decision-making processes during landing are clearer.

(9) Analysis of flight data and prediction of faults

Aircraft fuselage safety is one of the targets of flight safety management. For the rotor components of aviation engines, it is essential to closely monitor flight operation parameters and component wear, track and analyze potential faults, predict trends, and promptly advise maintenance personnel on the extraction of spare parts and replacement of components. By employing deep learning techniques, a comprehensive excavation of data features and their interrelations is achieved. This process facilitates the identification of profound performance evolution and the probability of fault occurrence, thereby technically enhancing the ability of fault diagnosis and prediction. On the basis of improving diagnostic and predictive capabilities, maintenance personnel can promptly assess the health status of relevant components and make decisions regarding their replacement.

(10) Digital twin training environment

Currently, flight training for command personnel, ground crew, pilots, and other relevant staff is conducted through a combination of offline training sessions, computer-based study materials, simulation system exercises, and practical drills. Among these, practical drills are often costly and require careful planning and control. There is an urgent need to acquire additional training skills and knowledge before engaging in actual flight training. Digital twin training, a model-based systems engineering approach, significantly enhances the refinement of environmental and operational models, providing a training environment with exceptionally high levels of simulation fidelity that closely resemble real-world conditions. By strategically planning the model granularity of various systems based on the environmental and operational impact levels associated with flight missions, it becomes possible to achieve optimal training objectives.

4 Conclusion

In the context of the rapid advancement of digital and intelligent technologies, this study aims to enhance capabilities in flight safety risk management by investigating the demand system for flight safety through the lens of empowerment provided by these technologies, including big data and AI. Furthermore, it analyzes and outlines typical applications, as well as specific advantages of digital and intelligent technologies in the realm of flight safety management. Finally, this study thoroughly examines the application pathways and methodologies for digital and intelligent technologies in key scenarios related to specific flight safety activities. Through this research, it offers a comprehensive methodology for integrating digital and intelligent technologies into flight safety risk management.

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