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Article

Qualification Management and Training System Construction for Low-Altitude Flight Operators: A Perspective of Industry

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ABSTRACT
With the rapid development of the low-altitude economy, low-altitude flight operations have been widely applied in logistics, agriculture, emergency rescue and other fields. However, the lack of standardized qualification management systems and scientific training systems for low-altitude flight operators has become a key bottleneck restricting the healthy development of the low-altitude economy. This study takes industry standardization as the core perspective, systematically explores the construction path of qualification management and training system for low-altitude flight operators. Through comparative analysis of qualification management policies and training practices in China, the United States, South Korea and Italy, this paper identifies the key problems existing in the current operator management and training system. On this basis, the paper constructs a multi-level qualification classification system for low-altitude flight operators and designs a modular training system based on competency model. Research results show that the standardized qualification management and scientific training system can effectively improve the professional quality and safety operation level of low-altitude flight operators, and provide institutional guarantee for the high-quality development of the low-altitude economy. This study enriches the research on the standardization of the low-altitude economy industry and provides practical guidance for government departments to formulate operator management policies and training standards.

Keywords: Low-Altitude Flight Operator; Qualification Management; Training System; Industry Standardization; Competency Model; Safety Operation

1. Introduction

1.1 Research Background

In recent years, driven by technological innovation and policy support, the low-altitude economy has entered a stage of rapid development worldwide, becoming a new growth point for the global economy . Low-altitude flight operations, as the core carrier of the low-altitude economy, involve a variety of scenarios such as urban logistics distribution, agricultural plant protection, power inspection, emergency rescue and aerial photography . The wide application of these operations has effectively promoted the transformation and upgrading of related industries and improved the efficiency of social services. However, the safety risks brought by low-altitude flight operations have also attracted widespread attention. According to the statistics of the International Civil Aviation Organization (ICAO), more than 60% of low-altitude flight accidents are related to human factors, among which the lack of professional quality and standardized operation skills of flight operators are the main causes .

The professional quality and operation level of low-altitude flight operators directly determine the safety and efficiency of low-altitude flight operations. At present, the low-altitude flight operator team in most countries has the problems of uneven professional quality, unclear qualification classification and non-standard training. On the one hand, the qualification management system for low-altitude flight operators is not perfect. There is no unified qualification classification standard and access threshold, resulting in mixed operators and difficulty in effective supervision . On the other hand, the training system for low-altitude flight operators is unscientific. The training content is outdated, the training methods are single, and the training effect is difficult to guarantee. Most training focuses on theoretical knowledge and simple operation skills, ignoring the training of emergency disposal capabilities and practical operation experience .

In response to these problems, major economies around the world have begun to strengthen the construction of qualification management and training systems for low-altitude flight operators. China has issued the „Regulations on the Administration of Civil Unmanned Aerial Vehicle Flight Activities“ and other policies, clarifying the qualification requirements for low-altitude flight operators, and promoting the standardized development of operator management . The United States has established a relatively complete qualification certification system for low-altitude flight operators through the Federal Aviation Administration (FAA), and has formulated targeted training standards for different types of low-altitude flight operations . South Korea and Italy have also introduced relevant policies and measures to strengthen the training and management of low-altitude flight operators and improve the safety level of low-altitude flight operations . However, there are still some gaps in the construction of qualification management and training systems for low-altitude flight operators in various countries, such as inconsistent qualification standards, disconnection between training content and actual operation needs, and lack of effective evaluation mechanisms for training effects .

Against the background of the accelerating development of the low-altitude economy, exploring the construction path of standardized qualification management and scientific training system for low-altitude flight operators is of great theoretical and practical significance for improving the safety level of low-altitude flight operations, promoting the healthy development of the low-altitude economy and ensuring the orderly use of low-altitude airspace .

1.2 Research Objectives and Significance

The main objectives of this study are: (1) to systematically sort out the connotation and characteristics of qualification management and training system for low-altitude flight operators under the background of industry standardization, and clarify the core elements and operation mechanism of the system; (2) to compare and analyze the current situation of qualification management and training system for low-altitude flight operators in major economies, and identify the key problems and root causes existing in the current system; (3) to construct a multi-level qualification classification system for low-altitude flight operators based on the characteristics of different low-altitude flight scenarios, and design a modular training system based on competency model; (4) to put forward targeted policy suggestions and implementation paths for improving the qualification management and training system for low-altitude flight operators.

The theoretical significance of this study lies in: first, it enriches the research system of low-altitude economy industry standardization, and deepens the understanding of the internal logic and construction rules of qualification management and training system for low-altitude flight operators; second, it constructs a multi-level qualification classification system and a modular training system based on competency model, which provides a new theoretical framework for the research on operator management in the low-altitude

economy field. The practical significance is reflected in: first, it can provide decision-making references for government departments to formulate and improve low-altitude flight operator qualification management policies, training standards and supervision measures; second, it can guide training institutions to carry out scientific and standardized training work, improve the professional quality and safety operation level of low-altitude flight operators; third, it helps to standardize the order of low-altitude flight operations, reduce flight safety risks, and promote the high-quality development of the low-altitude economy.

1.3 Research Methodology and Structure

This study adopts a combination of literature review, comparative analysis, expert interview and logical deduction methods. First, through a systematic review of domestic and foreign literature on low-altitude flight operator management, qualification certification, training system and industry standardization, this paper sorts out the research progress and existing deficiencies in related fields, and lays a theoretical foundation for the research. Second, through comparative analysis, this paper compares and analyzes the qualification management policies, training systems and supervision mechanisms of low-altitude flight operators in China, the United States, South Korea and Italy, and summarizes the advanced experience and existing problems of different countries. Third, through expert interviews, this paper consults experts in the fields of civil aviation management, low-altitude flight operation, vocational training and other fields, and collects opinions and suggestions on the construction of qualification management and training system for low-altitude flight operators. Finally, based on the above research, this paper uses logical deduction to construct the qualification classification system and training system for low-altitude flight operators, and puts forward corresponding policy suggestions.

The structure of this paper is arranged as follows: the first part is the introduction, which elaborates on the research background, objectives, significance, methodology and structure. The second part is the literature review and theoretical basis, which sorts out the related literature and expounds the theoretical basis of the research. The third part analyzes the current situation and problems of qualification management and training system for low-altitude flight operators in major economies. The fourth part explores the core elements and construction principles of qualification management and training system for low-altitude flight operators. The fifth part constructs the multi-level qualification classification system and modular training system for low-altitude flight operators. The sixth part puts forward the policy suggestions and implementation paths for improving the qualification management and training system for low-altitude flight operators. The seventh part is the conclusion and prospect.

2. Literature Review and Theoretical Basis

2.1 Research Progress on Low-Altitude Flight Operator Management

Domestic and foreign scholars have carried out a lot of research on low-altitude flight operator management, mainly focusing on qualification certification, safety management and supervision mechanism. In terms of qualification certification, scholars have focused on the setting of qualification standards and the design of certification processes. For example, some scholars have studied the qualification requirements for low-altitude UAV operators, and proposed that the qualification certification should consider factors such as theoretical knowledge, operation skills, emergency disposal capabilities and professional ethics . Others have studied the certification process of low-altitude flight operators, and put forward suggestions for optimizing the certification process to improve the efficiency and standardization of certification . In

terms of safety management, relevant studies have focused on the identification of human factors in low-altitude flight accidents and the formulation of safety management measures. Some scholars have analyzed the influence of operator‘s psychological quality, operation habits and professional skills on flight safety, and put forward targeted safety management measures . Others have studied the construction of safety management systems for low-altitude flight operators, and proposed to establish a full-process safety management mechanism covering pre-training, in-operation and post-evaluation .

In terms of supervision mechanism, scholars have focused on the construction of multi-party collaborative supervision systems and the application of intelligent supervision technologies. Some studies have proposed to establish a supervision mechanism involving government departments, industry associations, training institutions and operation enterprises to realize the full-chain supervision of low-altitude flight operators . Others have studied the application of IoT, big data and other technologies in the supervision of low-altitude flight operators, realizing the real-time monitoring of operator‘s operation status and the early warning of safety risks . However, the existing research still has some deficiencies: first, most studies focus on a single link of operator management, such as qualification certification or safety management, and lack a systematic research on the overall system of qualification management and training; second, the research on the classification of low-altitude flight operator qualifications is not in-depth enough, and there is a lack of classification standards based on the characteristics of different flight scenarios; third, the research on training systems is mostly focused on the improvement of training content and methods, and lacks the construction of training systems based on competency models.

2.2 Research Progress on Vocational Training System

Vocational training system is an important part of operator management, and scholars have carried out a lot of research on vocational training system in various fields. In terms of training system design, relevant studies have focused on the construction of modular training systems and the application of competency models. For example, some scholars have constructed a modular training system for technical workers based on the characteristics of different job positions, which can improve the pertinence and effectiveness of training . Others have studied the application of competency models in vocational training, and proposed to design training content and training methods based on the competency requirements of job positions, so as to improve the matching degree between training and job needs . In terms of training effect evaluation, scholars have focused on the construction of multi-dimensional evaluation indexes and the application of scientific evaluation methods. Some studies have established a training effect evaluation index system including theoretical knowledge, practical skills, work performance and other dimensions, and used fuzzy comprehensive evaluation method to evaluate the training effect . Others have studied the application of big data technology in training effect evaluation, realizing the dynamic tracking and quantitative evaluation of training effect .

However, the existing research on vocational training systems is mostly concentrated in traditional industries such as manufacturing and construction, and there is a lack of targeted research on the training system of low-altitude flight operators. The low-altitude flight operation has the characteristics of strong professionalism, high safety requirements and diverse application scenarios, which requires a more scientific and targeted training system. Therefore, it is necessary to combine the characteristics of low-altitude flight operations to carry out in-depth research on the construction of training systems for low-altitude flight operators.

2.3 Theoretical Basis

2.3.1 Industry Standardization Theory

Industry standardization theory refers to the process of formulating and implementing unified standards for various links in the industry to achieve the goals of improving industry efficiency, ensuring product quality and reducing safety risks . The core content of industry standardization theory includes standard formulation, standard implementation and standard supervision. In the construction of qualification management and training system for low-altitude flight operators, industry standardization theory can provide a theoretical basis for formulating unified qualification classification standards, training standards and evaluation standards. By standardizing the whole process of operator qualification management and training, the professional quality and operation level of operators can be improved, and the healthy development of the low-altitude economy industry can be promoted.

2.3.2 Competency Model Theory

Competency model theory refers to the sum of knowledge, skills, abilities, qualities and other factors required by individuals to complete specific job tasks . The competency model usually includes core competencies, professional competencies and job-specific competencies. In the construction of training systems for low-altitude flight operators, competency model theory can be used to clarify the competency requirements of different types of low-altitude flight operators, and design targeted training content and training methods based on these requirements. By improving the competency of operators, the safety and efficiency of low-altitude flight operations can be improved.

2.3.3 Human Factor Engineering Theory

Human factor engineering theory studies the interaction between humans and machines, environments and organizations, and focuses on optimizing the design of human-machine systems to improve work efficiency and safety . In the management of low-altitude flight operators, human factor engineering theory can be used to analyze the influence of operator‘s physiological characteristics, psychological quality and operation environment on flight safety. By optimizing the training content and operation environment, the influence of human factors on flight safety can be reduced, and the safety level of low-altitude flight operations can be improved.

3. Current Situation and Problems of Qualification Management and Training System for Low-Altitude Flight Operators in Major Economies

3.1 Current Situation of Development in Major Economies

3.1.1 China

China has attached great importance to the management of low-altitude flight operators in recent years, and has introduced a series of policies to standardize the qualification management and training of operators. The Civil Aviation Administration of China has issued the „Regulations on the Administration of Civil Unmanned Aerial Vehicle Flight Activities“ and „Standards for the Training of Civil Unmanned Aerial Vehicle Operators“, which clarify the qualification classification standards and training requirements for low-altitude flight operators . At present, China‘s low-altitude flight operator qualifications are mainly divided into two categories: pilot qualifications for civil UAVs and professional operation qualifications. The pilot qualifications for civil UAVs are divided into different levels according to the weight and flight

altitude of UAVs, and the professional operation qualifications are divided according to the type of operation scenarios .

In terms of training, China has formed a training system composed of professional training institutions, colleges and universities and enterprises. A number of professional training institutions have been established across the country, providing training services for low-altitude flight operators. Colleges and universities have also set up relevant majors to cultivate professional low-altitude flight operation talents. Enterprises have carried out internal training according to their own operation needs to improve the professional skills of their employees . In terms of supervision, the government has established a supervision mechanism led by the Civil Aviation Administration of China, with the participation of local civil aviation management departments and public security departments, to carry out supervision and inspection on the qualification and operation of low-altitude flight operators.

3.1.2 United States

The United States has a relatively complete qualification management and training system for low-altitude flight operators, which is mainly managed by the Federal Aviation Administration (FAA). The FAA has formulated detailed qualification certification standards and training requirements for low-altitude flight operators, and divides low-altitude flight operator qualifications into Part 107 Remote Pilot Certificate and Part 61 Pilot Certificate according to the type of flight operations . The Part 107 Remote Pilot Certificate is applicable to commercial UAV operators, and the Part 61 Pilot Certificate is applicable to low-altitude manned flight operators. The qualification certification process in the United States is strict, including theoretical examination, practical operation assessment and background investigation .

In terms of training, the United States has formed a market-oriented training system, with a large number of professional training institutions providing personalized training services for operators. The training content covers theoretical knowledge, practical operation, emergency disposal and other aspects, and the training methods are diverse, including online courses, offline practical training and simulation training . In terms of supervision, the FAA has established a strict supervision mechanism, using technologies such as GPS positioning and real-time video monitoring to carry out real-time supervision of operator‘s operation status. At the same time, the FAA has formulated severe punishment measures for illegal operations to ensure the standardized operation of operators.

3.1.3 South Korea

South Korea attaches great importance to the development of the low-altitude economy and has introduced a series of policies to strengthen the management of low-altitude flight operators. The Ministry of Land, Infrastructure and Transport of South Korea is responsible for the qualification management and training of low-altitude flight operators, and has formulated unified qualification certification standards and training guidelines . The low-altitude flight operator qualifications in South Korea are divided into UAV operator qualifications and low-altitude manned flight operator qualifications, and the UAV operator qualifications are further divided into different levels according to the weight and application scenario of UAVs.

In terms of training, South Korea has strengthened the cooperation between government and enterprises, and encouraged enterprises to participate in the construction of training systems. The government has formulated preferential policies to support training institutions to carry out training work, and the training content is closely combined with the actual needs of the industry . In terms of supervision, South Korea has established a multi-party collaborative supervision mechanism involving government

departments, industry associations and enterprises, and has introduced intelligent supervision technologies to realize the full-chain supervision of low-altitude flight operators.

3.1.4 Italy

Italy has carried out in-depth research and practice on the management of low-altitude flight operators, and the Italian Civil Aviation Authority (ENAC) is responsible for the qualification management and training of low-altitude flight operators. ENAC has formulated detailed qualification certification standards and training requirements, and divides low-altitude flight operator qualifications into different categories according to the type of flight operations and the weight of aircraft . The qualification certification in Italy pays attention to the practical operation ability of operators, and the assessment content includes not only theoretical knowledge, but also practical operation skills and emergency disposal ability.

In terms of training, Italy has formed a training system combining theoretical teaching and practical training, and has introduced advanced simulation training equipment to improve the training effect. The training institutions have established close cooperative relations with operation enterprises to ensure that the training content is consistent with the actual operation needs . In terms of supervision, ENAC has established a strict supervision system, carried out regular inspection on the qualification and operation of operators, and severely punished illegal operations.

3.2 Main Problems Existing in Qualification Management and Training System

3.2.1 Unclear Qualification Classification Standards

At present, the qualification classification standards for low-altitude flight operators in most countries are not clear. First, the classification basis is not scientific. Most countries classify operator qualifications based on the weight and flight altitude of aircraft, ignoring the differences in competency requirements of operators in different flight scenarios . For example, the competency requirements of UAV operators engaged in agricultural plant protection are quite different from those engaged in urban logistics distribution, but the current qualification classification standards do not reflect these differences. Second, the classification level is too simple. The current qualification classification levels are mostly 2-3 levels, which cannot meet the needs of refined management of operators in different flight scenarios . Third, the connection between qualification classification and job needs is not close. The qualification standards do not fully consider the actual job requirements of operators, resulting in a low matching degree between qualified operators and job positions.

3.2.2 Unscientific Training System

The training system for low-altitude flight operators in most countries is unscientific, which affects the training effect. First, the training content is outdated and single. Most training content focuses on basic theoretical knowledge and simple operation skills, ignoring the training of emergency disposal capabilities, practical operation experience and professional ethics . For example, in the training of urban logistics UAV operators, the training on how to deal with flight conflicts and bad weather is insufficient. Second, the training methods are backward. Most training still adopts the traditional „theoretical teaching + simple practical operation“ mode, and the application of advanced technologies such as simulation training and online interactive training is insufficient . This leads to the poor practical operation ability of operators after training. Third, the training objectives are not clear. The training objectives do not closely focus on the competency requirements of operators, resulting in the disconnection between training and job needs.

3.2.3 Imperfect Qualification Evaluation and Supervision Mechanisms

The qualification evaluation and supervision mechanisms for low-altitude flight operators are not perfect, which affects the standardization of operator management. First, the qualification evaluation method is backward. Most countries still adopt the traditional paper-and-pencil examination and on-site assessment methods, which cannot accurately evaluate the comprehensive quality and practical operation ability of operators . Second, the re-evaluation mechanism is not perfect. There is no clear regulation on the validity period of qualifications and the re-evaluation cycle, resulting in some operators' professional skills failing to keep up with the development of technology, which brings potential safety risks. Third, the supervision mechanism is not in place. The supervision scope is narrow, and the supervision of the whole process of operator training, operation and re-evaluation is not realized. At the same time, the application of intelligent supervision technologies is insufficient, resulting in low supervision efficiency and difficulty in timely discovery of illegal operations .

3.2.4 Lack of Unified Industry Standards and Collaborative Mechanisms

The lack of unified industry standards and collaborative mechanisms restricts the healthy development of the qualification management and training system for low-altitude flight operators. First, there is no unified international industry standard. The qualification management and training standards of different countries are quite different, which brings difficulties to the cross-border operation of low-altitude flight operators . Second, the collaborative mechanism between government departments, industry associations, training institutions and operation enterprises is not perfect. There is a lack of effective communication and cooperation between all parties, resulting in the disconnection between policy formulation, training implementation and operation practice . Third, the information sharing mechanism is not perfect. The information on operator qualification, training and operation is scattered in different departments and enterprises, which cannot be effectively shared, affecting the efficiency of management and supervision.

3.2.5 Insufficient Investment in Training Resources and Talent Team Construction

The investment in training resources and talent team construction for low-altitude flight operators is insufficient, which restricts the improvement of training quality. First, the investment in training equipment is insufficient. Most training institutions are lack of advanced simulation training equipment, which affects the training effect of practical operation skills . Second, the construction of the training teacher team is backward. The training teachers are mostly from the civil aviation field, lacking practical experience in low-altitude flight operations, and the teaching level is uneven . Third, the investment in scientific research on training is insufficient. There is a lack of in-depth research on the training content, training methods and training effect evaluation of low-altitude flight operators, which cannot provide theoretical support for the improvement of the training system.

4. Core Elements and Construction Principles of Qualification Management and Training System for Low-Altitude Flight Operators

4.1 Core Elements

4.1.1 Qualification Classification System

The qualification classification system is the core of the qualification management system for low-altitude flight operators, which includes classification basis, classification levels and qualification standards. The classification basis should be based on the characteristics of low-altitude flight scenarios and the

competency requirements of operators, and comprehensively consider factors such as flight equipment type, flight altitude, flight range and operation risk . The classification levels should be refined according to the difficulty of operation and the level of risk, so as to meet the needs of refined management. The qualification standards should clearly define the requirements of theoretical knowledge, practical skills, emergency disposal capabilities and professional ethics for operators of different levels and types.

4.1.2 Training System

The training system includes training objectives, training content, training methods and training effect evaluation. The training objectives should be based on the competency requirements of operators, and clarify the knowledge, skills and qualities that operators need to master . The training content should be modularized and designed according to the characteristics of different qualification levels and flight scenarios, including basic theoretical modules, professional skill modules and comprehensive quality modules. The training methods should be diversified, combining online theoretical teaching, offline practical training, simulation training and on-the-job training. The training effect evaluation should establish a multi-dimensional evaluation index system, including theoretical knowledge assessment, practical operation assessment, work performance evaluation and safety record evaluation.

4.1.3 Evaluation and Supervision Mechanism

The evaluation and supervision mechanism includes qualification evaluation, re-evaluation and daily supervision. The qualification evaluation should adopt a combination of theoretical examination, practical operation assessment and psychological evaluation to comprehensively evaluate the comprehensive quality of operators . The re-evaluation should clearly define the validity period of qualifications and the re-evaluation cycle, and update the qualification standards in a timely manner according to the development of technology and industry. The daily supervision should adopt a combination of traditional supervision methods and intelligent supervision technologies to realize the full-process supervision of operator‘s training, operation and re-evaluation.

4.1.4 Collaborative Management Mechanism

The collaborative management mechanism includes the collaborative mechanisms between government departments, industry associations, training institutions and operation enterprises. Government departments are responsible for formulating policies and standards, and carrying out supervision and management; industry associations are responsible for organizing the formulation of industry self-discipline standards, and carrying out industry statistics and information release; training institutions are responsible for carrying out standardized training work, and improving the professional quality of operators; operation enterprises are responsible for putting forward training needs, and organizing on-the-job training for employees . All parties should strengthen communication and cooperation, realize the sharing of resources and information, and form a joint force for the construction and operation of the system.

4.2 Construction Principles

4.2.1 Industry Standardization Principle

The construction of qualification management and training system for low-altitude flight operators should adhere to the principle of industry standardization. It is necessary to formulate unified qualification classification standards, training standards, evaluation standards and supervision standards to ensure the standardization and uniformity of the whole process of operator management and training . At the same

time, it is necessary to actively participate in the formulation of international industry standards, promote the internationalization of domestic standards, and facilitate the cross-border operation of operators.

4.2.2 Competency-Oriented Principle

The construction of the system should adhere to the competency-oriented principle, and take the improvement of operator‘s competency as the core goal. The qualification classification, training content and training methods should be designed based on the competency requirements of different flight scenarios and job positions . It is necessary to strengthen the training of operator‘s practical operation skills and emergency disposal capabilities, and improve the matching degree between operator‘s competency and job needs.

4.2.3 Practicality and Applicability Principle

The construction of the system should adhere to the principle of practicality and applicability, and closely combine with the actual needs of low-altitude flight operations. The training content should be closely related to the actual operation scenarios, and the training methods should be in line with the characteristics of operator‘s learning and cognitive laws . It is necessary to avoid the formalization of training and ensure that the training effect can be effectively transformed into the actual operation ability of operators.

4.2.4 Dynamic Adjustment Principle

The construction of the system should adhere to the principle of dynamic adjustment. With the development of low-altitude economy technology and the expansion of application scenarios, the competency requirements of low-altitude flight operators are constantly changing. Therefore, it is necessary to regularly update the qualification classification standards, training content and evaluation standards to ensure that the system can adapt to the development needs of the industry . It is necessary to establish a feedback mechanism to collect the opinions and suggestions of all parties in a timely manner, and adjust and improve the system according to the feedback results.

4.2.5 Multi-Party Collaborative Principle

The construction of the system should adhere to the multi-party collaborative principle. It is necessary to give full play to the roles of government departments, industry associations, training institutions and operation enterprises, strengthen communication and cooperation between all parties, and form a joint force for the construction and operation of the system . It is necessary to establish an information sharing mechanism to realize the sharing of operator‘s qualification, training and operation information, and improve the efficiency of management and supervision.

5. Construction of Qualification Classification System and Training System for Low-Altitude Flight Operators

5.1 Construction of Multi-Level Qualification Classification System for Low-Altitude Flight Operators

5.1.1 Classification Basis and Level Setting

Based on the characteristics of low-altitude flight scenarios and the competency requirements of operators, this study divides the qualifications of low-altitude flight operators into four categories: general operation qualification, professional operation qualification, special operation qualification

and management operation qualification. Each category is further divided into three levels: primary, intermediate and advanced. The specific classification basis and level setting are as follows: (1) General operation qualification: applicable to low-risk low-altitude flight operations such as aerial photography and entertainment. The classification is based on the weight of the aircraft and the flight altitude. Primary operators can operate small aircraft with a weight of less than 2kg and a flight altitude of less than 120 meters; intermediate operators can operate medium-sized aircraft with a weight of 2-15kg and a flight altitude of 120-500 meters; advanced operators can operate large aircraft with a weight of 15-150kg and a flight altitude of 500-1000 meters. (2) Professional operation qualification: applicable to professional low-altitude flight operations such as agricultural plant protection, power inspection and urban logistics. The classification is based on the type of operation scenario and the difficulty of operation. Primary operators can engage in simple professional operation scenarios; intermediate operators can engage in general professional operation scenarios; advanced operators can engage in complex professional operation scenarios. (3) Special operation qualification: applicable to high-risk low-altitude flight operations such as emergency rescue, fire fighting and aerial survey. The classification is based on the risk level of the operation and the emergency disposal requirements. Primary operators can assist in special operation scenarios; intermediate operators can independently engage in general special operation scenarios; advanced operators can independently engage in high-risk special operation scenarios. (4) Management operation qualification: applicable to the management of low-altitude flight operations such as fleet management and airspace coordination. The classification is based on the scope of management and the level of management responsibilities. Primary operators can engage in basic operation management work; intermediate operators can engage in general operation management work; advanced operators can engage in senior operation management work.

5.1.2 Qualification Standards

The qualification standards for low-altitude flight operators include four aspects: theoretical knowledge, practical skills, emergency disposal capabilities and professional ethics. (1) Theoretical knowledge: including airspace management regulations, flight principles, meteorological knowledge, equipment maintenance knowledge and safety management knowledge. The requirements for theoretical knowledge increase with the improvement of qualification level. (2) Practical skills: including aircraft operation skills, route planning skills, cargo loading and unloading skills (for logistics operations) and equipment debugging skills. The requirements for practical skills are different according to the type of qualification. For example, professional operation qualification requires operators to master professional operation skills corresponding to the operation scenario. (3) Emergency disposal capabilities: including the ability to deal with aircraft failure, bad weather, flight conflicts and other emergency situations. The requirements for emergency disposal capabilities increase with the improvement of qualification level, especially for special operation qualification operators, who need to have strong emergency disposal capabilities. (4) Professional ethics: including abiding by laws and regulations, respecting the rights and interests of others, and ensuring flight safety. All operators must meet the basic requirements of professional ethics.

5.1.3 Qualification Certification Process

The qualification certification process for low-altitude flight operators includes four links: application, pre-examination, assessment and certification. (1) Application: Operators submit qualification application materials to the designated certification authority, including personal identity materials, educational

background materials and training certificates. (2) Pre-examination: The certification authority conducts pre-examination of the application materials to check whether the applicant meets the basic conditions for qualification application. (3) Assessment: The assessment includes theoretical examination, practical operation assessment and psychological evaluation. The theoretical examination adopts online computer-based examination; the practical operation assessment adopts on-site operation and simulation operation methods; the psychological evaluation adopts psychological test and interview methods. (4) Certification: For applicants who pass the assessment, the certification authority issues corresponding qualification certificates; for applicants who fail the assessment, they can apply for re-assessment after supplementary training.

5.2 Construction of Modular Training System for Low-Altitude Flight Operators Based on Competency Model

5.2.1 Construction of Competency Model

Based on the competency model theory, this study constructs a competency model for low-altitude flight operators, which includes three levels: core competencies, professional competencies and job-specific competencies. (1) Core competencies: including safety awareness, sense of responsibility, learning ability and communication ability. These competencies are required for all low-altitude flight operators. (2) Professional competencies: including theoretical knowledge, practical operation skills, emergency disposal capabilities and equipment maintenance capabilities. These competencies are required for professional and special operation qualification operators. (3) Job-specific competencies: including the professional skills corresponding to specific operation scenarios, such as agricultural plant protection skills for agricultural plant protection operators, logistics distribution skills for urban logistics operators, and emergency rescue skills for emergency rescue operators.

5.2.2 Design of Modular Training Content

Based on the competency model, this study designs a modular training content system, which includes four modules: basic theoretical module, core competency module, professional skill module and job-specific skill module. (1) Basic theoretical module: including airspace management regulations, flight principles, meteorological knowledge, equipment maintenance knowledge and safety management knowledge. This module is a basic module for all operators. (2) Core competency module: including safety awareness training, sense of responsibility training, learning ability training and communication ability training. This module is designed to improve the core competencies of operators. (3) Professional skill module: including practical operation skills training, emergency disposal capabilities training and equipment maintenance capabilities training. This module is mainly for professional and special operation qualification operators. (4) Job-specific skill module: including the professional skills training corresponding to specific operation scenarios. For example, the agricultural plant protection module includes training on pesticide spraying technology and crop identification; the urban logistics module includes training on route planning and cargo loading and unloading.

5.2.3 Selection of Training Methods

To improve the training effect, this study adopts a diversified training method system, including online theoretical teaching, offline practical training, simulation training and on-the-job training. (1) Online theoretical teaching: Using online learning platforms to provide flexible and convenient theoretical knowledge learning services for operators, including video courses, online exercises and online

examinations. (2) Offline practical training: Carrying out on-site practical operation training in professional training bases, with professional teachers guiding operators to master practical operation skills. (3) Simulation training: Using advanced simulation training equipment to simulate various flight scenarios and emergency situations, allowing operators to conduct repeated training to improve their emergency disposal capabilities and practical operation skills. (4) On-the-job training: Organizing on-the-job training by operation enterprises, combining the actual operation tasks of enterprises to carry out targeted training, and improving the matching degree between training and job needs.

5.2.4 Construction of Training Effect Evaluation System

This study constructs a multi-dimensional training effect evaluation system, which includes four evaluation dimensions: theoretical knowledge, practical skills, work performance and safety record. (1) Theoretical knowledge evaluation: Adopting online computer-based examination to evaluate the mastery of theoretical knowledge by operators. (2) Practical skills evaluation: Adopting on-site operation and simulation operation methods to evaluate the practical operation skills and emergency disposal capabilities of operators. (3) Work performance evaluation: Evaluating the work performance of operators by operation enterprises, including operation efficiency, task completion quality and service satisfaction. (4) Safety record evaluation: Recording the safety operation status of operators, including the number of safety accidents, violations and other indicators. The evaluation results are used as an important basis for operator‘s qualification re-evaluation and job promotion.

6. Policy Suggestions and Implementation Paths for Improving the Qualification Management and Training System for Low-Altitude Flight Operators

6.1 Policy Suggestions

6.1.1 Improve the Qualification Management System and Formulate Unified Industry Standards

The government should take the lead in formulating a unified qualification classification standard for low-altitude flight operators, clarifying the classification basis, classification levels and qualification standards. It is necessary to combine the characteristics of different low-altitude flight scenarios to refine the qualification classification and improve the matching degree between qualification and job needs . At the same time, it is necessary to formulate unified training standards, evaluation standards and supervision standards to ensure the standardization and uniformity of the whole process of operator management and training. It is necessary to actively participate in the formulation of international industry standards, promote the mutual recognition of domestic and foreign qualifications, and facilitate the cross-border operation of operators.

6.1.2 Strengthen the Construction of Training Resources and Improve the Training Quality

The government should increase investment in training resources, support training institutions to purchase advanced simulation training equipment and build professional training bases. It is necessary to strengthen the construction of the training teacher team, establish a training teacher certification system, and improve the professional quality and teaching level of training teachers . It is necessary to encourage colleges and universities to set up relevant majors to cultivate professional low-altitude flight operation talents, and strengthen the cooperation between colleges and universities and enterprises to realize the

integration of production and education. It is necessary to increase investment in scientific research on training, support research institutions to carry out in-depth research on training content, training methods and training effect evaluation, and provide theoretical support for the improvement of the training system.

6.1.3 Improve the Evaluation and Supervision Mechanism and Strengthen the Full-Process Supervision

The government should improve the qualification evaluation mechanism, adopt a combination of theoretical examination, practical operation assessment and psychological evaluation to comprehensively evaluate the comprehensive quality of operators. It is necessary to establish a sound re-evaluation mechanism, clarify the validity period of qualifications and the re-evaluation cycle, and update the qualification standards in a timely manner according to the development of technology and industry . It is necessary to strengthen the application of intelligent supervision technologies, such as IoT, big data and AI, to realize the real-time monitoring of operator‘s operation status and the early warning of safety risks. It is necessary to establish a multi-party collaborative supervision mechanism involving government departments, industry associations, training institutions and operation enterprises to realize the full-chain supervision of operator‘s training, operation and re-evaluation.

6.1.4 Establish a Collaborative Management Mechanism and Promote Information Sharing

The government should establish a collaborative management mechanism involving government departments, industry associations, training institutions and operation enterprises, and clarify the responsibilities and division of labor of all parties. It is necessary to strengthen communication and cooperation between all parties, hold regular coordination meetings to study and solve the problems existing in the construction and operation of the system . It is necessary to establish an information sharing platform for low-altitude flight operators, integrating operator‘s qualification, training, operation and supervision information to realize the sharing of information between all parties. It is necessary to promote the digital management of operator‘s information, improve the efficiency of management and supervision.

6.1.5 Strengthen Policy Support and Guide Industry Healthy Development

The government should formulate preferential policies to support the development of training institutions and operation enterprises, such as financial subsidies, tax preferences and land support. It is necessary to encourage social capital to participate in the construction of the qualification management and training system for low-altitude flight operators, and form a diversified investment pattern . It is necessary to strengthen the publicity and popularization of policies and standards, improve the awareness of operators, training institutions and operation enterprises on the importance of qualification management and training. It is necessary to carry out pilot demonstrations of qualification management and training systems in key regions and key industries, and promote the experience of pilot demonstrations to the whole country.

6.2 Implementation Paths

6.2.1 Short-Term Implementation Path (1-2 Years)

In the short term, the main tasks are: (1) Formulate and issue unified qualification classification standards, training standards and evaluation standards for low-altitude flight operators. (2) Carry out the rectification of existing training institutions and qualification certification authorities to improve the standardization of training and certification work. (3) Build a preliminary information sharing platform for low-altitude flight operators, realizing the sharing of basic information such as operator‘s qualification and

training. (4) Carry out pilot demonstrations of modular training systems in key regions and key industries, and summarize pilot experience.

6.2.2 Medium-Term Implementation Path (3-5 Years)

In the medium term, the main tasks are: (1) Improve the qualification management and training system, and promote the full implementation of unified standards. (2) Strengthen the construction of training resources, build a number of professional training bases and improve the training teacher team. (3) Popularize the application of intelligent supervision technologies, realize the full-process supervision of operator‘s operation. (4) Improve the information sharing platform, realize the integration of operator‘s qualification, training, operation and supervision information. (5) Promote the mutual recognition of domestic and foreign qualifications, and participate in the formulation of international industry standards.

6.2.3 Long-Term Implementation Path (5-10 Years)

In the long term, the main tasks are: (1) Form a mature and perfect qualification management and training system for low-altitude flight operators, which is in line with the development needs of the low-altitude economy. (2) Build a high-quality professional low-altitude flight operator team to meet the needs of the development of the low-altitude economy. (3) Realize the internationalization of the qualification management and training system, and enhance the international influence of China‘s low-altitude economy industry. (4) Promote the healthy and sustainable development of the low-altitude economy, and make it an important pillar of the national economy.

7. Conclusion and Prospect

7.1 Research Conclusions

This study takes industry standardization as the core perspective, systematically studies the construction of qualification management and training system for low-altitude flight operators, and draws the following conclusions: First, the qualification management and training system for low-altitude flight operators is an important guarantee for the healthy development of the low-altitude economy, but at present, there are still problems such as unclear qualification classification standards, unscientific training systems, imperfect evaluation and supervision mechanisms, lack of unified industry standards and insufficient investment in training resources in major economies. Second, the core elements of the qualification management and training system for low-altitude flight operators include qualification classification system, training system, evaluation and supervision mechanism and collaborative management mechanism, and the construction of the system should adhere to the principles of industry standardization, competency orientation, practicality and applicability, dynamic adjustment and multi-party collaboration. Third, the multi-level qualification classification system constructed in this study, which is divided into four categories and three levels based on the characteristics of flight scenarios and competency requirements, can realize the refined management of operators. The modular training system based on competency model, which includes four modules and adopts diversified training methods, can improve the pertinence and effectiveness of training. Fourth, the policy suggestions put forward in this study, such as improving the qualification management system, strengthening the construction of training resources, improving the evaluation and supervision mechanism, establishing a collaborative management mechanism and strengthening policy support, can provide practical guidance for the construction and improvement of the qualification management and training system for low-altitude flight operators.

7.2 Research Prospect

In the future, the research can be carried out in the following aspects: First, carry out in-depth research on the qualification management and training system for low-altitude flight operators in specific fields, such as emergency rescue, agricultural plant protection and urban logistics, to improve the pertinence of the system. Second, strengthen the research on the application of emerging technologies such as AI, virtual reality (VR) and augmented reality (AR) in the training of low-altitude flight operators, and explore more efficient and scientific training methods. Third, carry out comparative research on the qualification management and training systems of low-altitude flight operators in more countries, and learn from advanced international experience to promote the internationalization of China's system. Fourth, carry out empirical research on the constructed qualification classification system and training system, and verify the effectiveness and feasibility of the system through practical application.

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