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Multi-attribute evaluation of air traffic safety control based on hesitant fuzzy judgments

Xinyu Du[1], Qi Zhang[1], Li Zou[2], *

[1] Business School, Sichuan University, Chengdu 610064, China
[2] Regional Control Office of Southwest Air Traffic Control Bureau, Civil Aviation Administration of China, Chengdu 610064, China

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Abstract. With the continuous improvement of China's national economy, more and more passengers are choosing fast and convenient air transportation. At the same time, the country has successively introduced a series of favorable policies on civil aviation, such as allowing private capital to enter the civil aviation industry and gradually opening up low-altitude airspace. Therefore, China's civil aviation industry has developed rapidly. However, some problems have also followed: the increasing number of flights has caused the airspace environment to be close to saturation, the workload of the controllers continues to increase, the working environment of the controllers is not improved enough, the enthusiasm is difficult to mobilize, and the management is not detailed and scientific. Safety risks have become increasingly prominent, and air traffic control safety assurance links have gradually become an important bottleneck for the development of the civil aviation industry. Therefore, this article builds a bi-level indicator project system based on the four levels of "personnel", "equipment", "environment" and "management", combined with the actual operation of the air traffic control unit, thereby constructing an air traffic control quantitative evaluation index system for safety capability evaluation. This paper adopts the latest hesitation fuzzy theory, which can quantify the linguistic information of the evaluator and increase the flexibility of information expression. The most consistent weighting method is adopted to improve the scientificity of air traffic control safety evaluation. Suggestions for improvement were put forward. The ultimate goal is to get a comprehensive and accurate understanding of the air traffic control safety assurance level, measure the degree of matching between the air traffic control institution's safety capabilities and safety assurance tasks, allocate resources rationally in management, improve air traffic safety assurance capabilities, and promote the rapid and stable development of civil aviation.

Keywords: air traffic control safety, hesitant fuzzy judgments, transportation

1 Introduction

Since the reform and opening up, China's civil aviation industry has ushered in rapid development. From 2005 to 2018, the national passenger throughput increased by more than 10%. In 2019, the growth rate has slowed down due to a high base number. The total transportation turnover volume of 129.27 billion ton-kilometers, 660 million passengers, and 7.526 million tons of cargo and mail were completed throughout the year, up 7.1%, 7.9%, and 1.9% respectively. At the same time, the development of general aviation has accelerated significantly. The Civil Aviation Administration of China has accelerated the restructuring of the general aviation regulatory system and officially released the national visual flight chart. The annual general aviation flight reached 1.125 million hours, an increase of 13.8% year-on-year; the number of licensed general airports reached 246, surpassing the transportation airport for the first time. Innovate the UAV development policy, carry out pilots of UAV logistics distribution, register more than 392,000 UAVs, and UAV commercial flight 1.25

* Corresponding author. *E-mail address*: lzou1_05@sina.com

million hours [13]. The rapid growth of flights and the increasingly busy airspace have brought pressure to ensure safety, and the high sensitivity of civil aviation to safety has caused all civil aviation operating institutions to place safety first in their daily operations.

In the civil aviation industry system, air traffic management is an important part of it. It refers to the use of technical means and equipment to monitor and manage aircraft flying in the air to ensure flight safety and flight efficiency. Due to the development of science and technology and the improvement of management level, China's air traffic control system has made considerable progress in terms of control and surveillance methods and optimization of air routes. The control method has gradually and comprehensively transitioned from the previous single procedure control to the radar control, which has greatly improved the airspace capacity and the safety level of the aircraft; the management has gradually transitioned from the previous administrative command management of the public institution to the enterprise management, and modernization has been introduced. The management methods of the enterprise have improved the operation quality and efficiency of the air traffic control system to a certain extent. However, with the rapid development of the civil aviation industry, higher requirements have been put forward on the guarantee capability of the air traffic control system, and the problem of the mismatch between the air traffic control safety guarantee capability and the safety guarantee task has become increasingly prominent. It is embodied in the following aspects: First, human factors account for a large proportion of air traffic control unsafe incidents, and the control effect is difficult to predict. According to the Air Traffic Control Bureau of the Civil Aviation Administration of China, there have been 119 unsafe air traffic control incidents in the past decade. The survey results show that these unsafe incidents were caused by 272 errors, of which 213 were caused by human factors, accounting for 78% [16]. It can be seen that human factors are already the main cause of unsafe incidents in air traffic control, and also the most important part of safety evaluation. Second, the degree of openness of airspace resources is limited, as Chinese law stipulates that all airspace except for air routes is controlled by the People's Liberation Army Air Force. Affected by the management system, the use of airspace resources has become a bottleneck. Civil aviation's disposable airspace is limited to air routes and the surrounding areas of airports, making it difficult to flexibly face the complex operating environment such as increasing air traffic flow and changing weather in the sky. Coupled with the occupation of airspace resources by the military's transfers and training, if effective coordination and communication are not carried out, the airspace resources will not be effectively used, which will have a negative effect on safety and efficiency. Third, the air traffic control agency is becoming larger and larger, and management methods and incentives cannot meet actual needs. Faced with the rapid increase in the number of flights, air traffic control agencies and personnel have become increasingly large, and the resulting management problems have become increasingly prominent. The management process and the contradiction between the management and the managed person have become increasingly prominent, unreasonable and inefficient. The work process also fetters the safe and efficient operation of the air traffic control industry. At the same time, due to the institutional constraints of public institutions, the incentives for front-line employees are limited. How to improve the enthusiasm of employees is also a problem to be solved. Fourth, a large number of new technologies and new equipment have been put into use in response to the increasing demand for flights. On the other hand, along with the development of science and technology in China, the air traffic control equipment system has gradually changed from foreign imports to imitation and self-made. The application and adaptation of the new domestic air traffic control system also has technology and personal adaptability, and staff learning pressure. These factors all indirectly affect the safety output of the air traffic control system.

The safety management of the air traffic control system is a basic project that is technical, systematic and complex, and has the characteristics of multiple points, wide areas and complex relationships. In air traffic control system safety management research, in-depth exploration of system safety assessment and prediction methods is an important topic for air traffic control safety management and civil aviation safety research. It is also an inevitable choice for reducing civil aviation accidents and strengthening flight safety management.

Air traffic control is a very important part of civil aviation transportation. Due to the characteristics of air traffic control work, "safeguarding safety" has always been the top priority in air traffic control security work. Therefore, effective assessment of air traffic control safety and on the basis of the assessment are of great practical significance to the safety of air traffic control. Safety assessment currently plays a very important role in the safety management of air traffic control, and correct safety assessment is the prerequisite for identifying corresponding management methods. It first needs to conduct a comprehensive and detailed analysis of various factors that affect the safety of air traffic control, then combine the actual data and requirements of air traffic control operations to establish different evaluation models and comprehensive evaluation results, and finally find out the system based on the evaluation results. In order to improve the safety of the entire system, rectification measures are proposed. However, the disadvantage is that the evaluation of indicators mainly depends on the subjective judgment of practitioners. Therefore, the weight of indicators is affected by the personal subjective factors and expressive ability of the evaluator on the one hand, and on the other hand, the evaluator has the ability to describe the impact of various factors on the safety system. The ambiguity is therefore likely to cause the evaluation results to be inconsistent with the actual situation. Through the hesitation fuzzy theory, the results of the evaluation model can be described by quantified values, and the feelings of the evaluator can be matched with the actual situation as much as possible.

The characteristics of the air traffic control system are that there are many influencing factors, human factors account for a large proportion [4]. Various factors have mutual influence. At the same time, due to the large changes in the air traffic control system, it is very difficult to objectively evaluate it. The use of appropriate evaluation methods is critical to the correctness of the results. At present, safety evaluation is an important means of safety management in the air traffic control industry. The research of safety evaluation has great practical significance for the research of air traffic safety management. This paper will be extracted on the basis of expert assessment and actual air traffic control instituion visits. On the basis of key evaluation indicators, the safety of air traffic control is effectively evaluated. Any unsafe incident in the air traffic control system is caused by an accident chain. In order to reduce the probability of unsafe incidents, in-depth analysis of each factor in the accident chain should be carefully examined. Analysis can maximize the safety and quality of operation. At the same time, in the face of various complex factors, it is necessary to simplify all factors in the accident chain through scientific theories. Only through this process can we see the composition of the system and clarify the factors and proportions that affect safety. After determining the factors affecting safety, various qualitative and quantitative methods or computer and other technical means can be used to sort out the correlation between various factors, and on this basis, we can establish an air traffic control safety evaluation model to realize the safety evaluation of air traffic control. The air traffic control safety management department can obtain the safety level of the air traffic control based on the results of the model evaluation, identify the safety hazards in the air traffic safety management by identifying the factors that affect safety, and formulate systems and standards for the indicators that need to be improved. Relevant suggestions can be given for improvement to ensure that the operation of the air traffic control system is in a safe and orderly state, so that the safety level of the entire air traffic control system can be improved. Therefore, the research in this paper has important practical significance for ensuring the safe transportation of aviation.

This paper uses the hesitant and fuzzy linguistic theory to quantitatively evaluate the safety capabilities of air traffic control institutions. The specific ideas are as follows: (1) Through a comprehensive and detailed analysis of the factors affecting air traffic safety, an indicator system for evaluating air traffic safety is established. The indicator system is composed of two hierarchies, with “safety capability of air traffic control institution” as the evaluation target, and the primary indicators include air traffic control institution personnel safety protection capability, air traffic control unit facility equipment safety protection capability, unit operating environment safety protection capability; each primary indicator has secondary indicators; in order to cope with the dynamic adjustment of the index system, 36 secondary indicators have been expanded on the basis of the determined evaluation indicators, which enriches the indicator library under the indicator system and facilitates subsequent research on the subject; (2) This paper fully considers the many situations in the actual application of the safety capability assessment of the air traffic control institution, and interviews the first-line senior controllers and safety management personnel to understand their evaluation of the importance of the safety indicators and the institution’s performance of indicators, so as to understand and grasp the overall safety level of the institution. With hesitant and fuzzy mathematical methods, the experts’ opinions can be flexibly expressed; (3) Establish the most consistent weight optimization model, and scientifically set the multi-attribute evaluation weights; (4) Based on the evaluation results, reasonable suggestions are given to improve the safety level of air traffic control institutions.

The main contributions of this paper is as follows: (1) Fully consider the subjectivity of the air traffic safety control institution's safety capability assessment, and apply hesitant and fuzzy mathematical theories to restore the true views of the front-line personnel on the evaluation indicators to the greatest extent, which is very important for a comprehensive and true grasp of the air traffic safety control institution's safety assurance level significance. (2) Based on the hesitant fuzzy linguistic judgment, an optimization method of maximum consistency weight is proposed to scientifically assign weights to air traffic safety control evaluation. (3) Evaluate the safety capability of an air traffic control institution, and propose targeted improvements based on the evaluation results.

2 Literature review

2.1 Current research status

The origin of the aviation industry comes from the West. With the increasing number of flights, the air traffic control industry has emerged for the safety of aviation flights. Therefore, safety is born with the air traffic control industry. Before the 1970s, air traffic control safety assessments focused on equipment, emphasizing the improvement of mechanical equipment accuracy and failure rate [2]. In the mid−1970s, aviation safety experts discovered that aviation accidents caused by "human factors" accounted for 80% of all accidents. The aviation industry began to study human factors, and safety evaluation began to emphasize human working conditions and compliance with rules [11]. By the end of the 1980s, the evaluation of safety entered a stage of systematic evaluation. In 1987, the Senate Appropriations Committee asked the Federal Aviation Administration (FAA) to develop a "set of standardized safety indicators" for evaluation. To measure the safety performance of air traffic operations has opened the era of systematic assessment of air traffic safety. The extraction of these indicators is of great significance to air traffic safety evaluation [1].

This paper has studied the research of relevant experts and scholars on safety assessment. Lee [8] used the method of fuzzy evaluation to analyze the degree of danger of the system, and made quantitative analysis and judgment on the safety of the system by using the importance of incidents affecting aviation safety and the probability of occurrence. Based on actual cases and aiming at the safety of air traffic management, Felici [5] established a realistic model through the case, and summarized the three system-related factors of technical factors, organizational factors and cost factors. Mimpriss and Savage [10] believes that complex and changeable situations can be decomposed into basic parts and random factors, and applied the ideas and methods of probability theory to quantitative risk assessment. Conrow [3] believes that only when risks are identified can the entire system be managed accurately and efficiently, and the necessity of taking measures can be guaranteed and this is the basis for evaluating system risks. Ternov and Akselsson [12] built a procedural model based on accident-based air traffic control unsafe events to identify air traffic control risks from the complex civil aviation system. Vismari and Junior [15] established an air traffic control safety assessment method based on SPN (Stochastic Petri net), using this method to evaluate air traffic control systems in various countries, and concluded that all countries are increasing air traffic control safety management. Lioua et al. [9] established a DEMATEL-ANP evaluation model and created a new quantitative evaluation method and they successfully mixed DEMATEL and ANP methods to establish a hybrid evaluation model. Through years of research on aviation accidents, Hoc [6] has discovered the key role that human factors play in it. The factors that influence the control activities of controllers in daily command include the following aspects: conflict generation, conflict target recognition, conflict detection and conflict resolution. Hsu [7] has studied the development process of aviation safety system from different times, discussed its impact on emergency safety and its significance from the perspective of organization, and opened up new ideas for the research of safety emergency in aviation industry. Due to certain differences between western countries and China, and differences in management systems and national conditions, China's air traffic control safety evaluation indicators cannot be copied from western countries, and a scientific and reliable evaluation system must be constructed based on China's specific national conditions to propose evaluation indicators suitable for its own system.

2.2 Hesitant fuzzy linguistic judgments theory

In today's society, people are faced with decision-making everywhere in work and life. Especially in the management process of the enterprise, every link in the selection of the plan and the implementation of the plan is full of complicated decision-making issues. When we make decisions on complex issues, we not only need personal wisdom to participate, but more often we need to use the power of the group to ensure the scientific and effective decision-making. In the real world, people's cognition is restricted by their own experience and surrounding environment, so it is difficult for individuals to give definite or accurate evaluations to complex systemic problems. Therefore, how to deal with the uncertainty of evaluation has become an urgent problem to be solved. Through years of research by scholars, many methods to deal with uncertainty have been proposed, and fuzzy set theory is one of the important ones. In 1965, Zadeh [17] proposed the fuzzy set theory, it overcomes the one-or-other theory. The fuzzy set theory uses the fuzzy membership function in the interval $[0, 1]$ to evaluate the system. Attributes are described quantitatively. Since then, fuzzy theory has gradually developed into an effective tool to deal with ambiguity and uncertainty in decision-making. After years of research on fuzzy set theory, many extended forms have been developed, such as classical fuzzy sets, intuitionistic fuzzy sets, fuzzy multi-sets, hesitant fuzzy sets, etc. Because of their different properties, these fuzzy set theories all have suitable application scenarios, and the methods of processing these sets are constantly being researched and developed. The core of people's decision-making is to integrate the opinions of decision-makers in a certain way. However, due to the complexity of the objective world, the limitations of human cognition and the inherent ambiguity of human thinking, it is difficult for people to understand things and make accurate judgments, not because there is only one possible value or there is a certain range of error, but there is a set of possible values. In most cases, in order to obtain a scientific decision-making result, a decision-making organization composed of many experts or decision makers may be invited to provide preference evaluation for a set of options. In the process of decision-making by the decision-maker, or in evaluating a program when meeting the degree of attribute, it is difficult for the decision-making organization to clearly provide a value, but hesitate to a possible value range. In order to more objectively and accurately reflect the various opinions in the decision-making group, based on fuzzy set theory, Torra [14] proposed the concept of hesitant fuzzy set. Compared with more traditional fuzzy sets, hesitant fuzzy sets have unique advantages in describing the hesitation in the decision-making process. It is feasible to use the idea of hesitant fuzzy set to deal with multiple values in a variable. Since then, hesitant fuzzy set theory has been widely used in many decision-making problems. This article also uses hesitant vague language as an evaluation tool for the safety level of air traffic control to determine the evaluation results.

2.3 Air traffic management theories

The air traffic management system is an important part of the civil aviation transportation system. The safety of air traffic control plays a decisive role in the safety of civil aviation. Therefore, the evaluation, monitoring and prediction of air traffic control safety are of great significance to the safety and efficiency of civil aviation transportation.

2.3.1 Air traffic management

Air traffic management is the general term for multiple management behaviors to achieve system safety and economic goals by monitoring, controlling, and coordinating air traffic. Its mission is to effectively maintain and promote air traffic safety, maintain air traffic order, and ensure smooth air traffic. The system characteristics of modern aviation make each element and subsystem play a vital role in the operation of the system. As a subsystem of the aviation system, the development of the air traffic management system is lagging. Errors and operational disturbances will affect the normal aviation activities and even cause catastrophic consequences. With the continuous progress of management and technology, a relatively complete air traffic management system has been established around the world, and airlines and modern airports equipped with modern high-reliability jet aircraft jointly undertake the transportation tasks of civil aviation. Civil aviation transportation flight has become one of the safest transportation methods. Air traffic management has developed along with the development of air transportation. One of the biggest advancements of modern aviation is the establishment of a more complete air traffic control service system and various navigation and surveillance systems, so that civil aviation activities can be carried out in a standardized, orderly and safe manner. The air traffic management system includes three parts: air traffic services, air traffic flow management and airspace management.

(1) Air traffic service

Air traffic services are mainly to manage and control aircraft's air flight and ground activities, and provide aircraft with air traffic control services, flight information services, and warning services. The air traffic service system is complex and involves many departments including front-line air command departments such as area control, approach control, tower control departments, and technical support, weather forecasting and other support departments. As the main body, the air traffic controller integrates all resources to provide air traffic control services for the aircraft.

Air traffic control service is the main task of the air traffic control operation unit. The manifestation is that the controller issues control instructions to the aircraft pilot based on the air traffic situation and various types of information, and the aircraft pilot executes the instructions to prevent aircraft collisions and maintain air traffic. It is divided into the following three parts according to different horizontal and vertical spaces: a). Regional control service: control of air route flight. b). Approach control service: control of approach and departure flight routes. c). Airport control service: the control of activities in the airport area. In order to maintain the efficient operation of air traffic, the control department adopts radar control or procedural control to monitor airborne aircraft, and conducts air-to-air command to the aircraft by means of VHF and high frequency. Radar control is currently implemented in most areas of our country, and a few remote or sparsely populated areas still adopt procedural control.

(2) Flight information service

Flight information service means that air traffic control units provide flight-friendly information to them based on actual conditions and the needs of aircraft pilots or companies. The information provided generally includes: important weather information, changes in airports and related flight equipment, aircraft malfunctions in the air, and other information that may affect flight safety and efficiency.

(3) Alert service

The alert service refers to the service of issuing warnings to related organizations or aircrafts in some special situations. For example, the aircraft encounters special circumstances in the air, and the aircraft requires search and rescue because of accidents.

2.3.2 Airspace management

Airspace management is the management of airspace resources. It simultaneously meets human needs in air traffic and logistics transportation. The airspace elements that have an impact on labor productivity and value are called airspace resources. With the continuous development of air traffic, airspace resources is being mentioned more and more frequently. Because of its scarcity, practicability and non-exclusiveness, airspace resources are a valuable strategic resource in China, where the air traffic market is booming rapidly. At the same time, airspace resources as an economic factor play an important economic role in the civil aviation industry and even the aviation manufacturing industry.

Although China has issued relevant laws and regulations on airspace resources, the existing airspace resources and management system obviously cannot be applied to the status quo of the aviation industry. How to allocate airspace resources scientifically is a huge systematic project, which covers policy formulation, management arrangements, technical requirements, etc. The formulation of reasonable and scientific airspace resource management regulations and laws is essential for the development and future of our civil aviation industry.

China's airspace resource management is organized by the China's Army Air Force. Each relevant flight control department provides traffic control services according to different functions. The airspace management of transportation routes is the responsibility of the civil aviation management department. All airspace is under the jurisdiction of the Air Force.

2.3.3 Air traffic flow management

Air traffic flow management is necessary because of the limitations of airspace resources and airport runway resources. Air traffic flow management is the basic guarantee system to ensure the safety of aircraft flight. Air traffic flow management is simply for aviation, airports and aviation routes. It is necessary to evaluate accuracy and carry out appropriate traffic management, adopt targeted methods to release aircraft, and try to increase air traffic on a safe basis to reduce air congestion. Because of the obvious differences in regional economic development in China, many flights are concentrated, and there are obvious differences in the number of flights between regions. This has led to frequent congestion in air traffic in some first-tier cities, thereby delaying flights.

With the continuous increase of air traffic flow, the problem of air traffic flow management is becoming more and more obvious. The continuous development of the aviation field also provides corresponding challenges and tasks for air traffic flow management. In order to achieve a more reasonable, scientific and efficient air traffic control, it has become one of the first tasks that relevant management departments need to solve. In this regard, it is necessary for relevant departments to proceed from multiple perspectives based on existing management and experience to improve the deficiencies in air traffic flow management, improve air traffic fluency, and promote the long-term development of China's aviation sector.

2.3.4 Principles and methods of air traffic safety management

The purpose of air traffic control safety management is to evaluate, monitor, and predict the various functions of the air traffic control system through necessary means, and to find corrective problems in time, so as to better play the role of supervising the safety of the air traffic control system. A complete air traffic control safety management system must have early warning, alarm, error correction, and improvement functions for potential hazards. Therefore, a comprehensive evaluation system is established to comprehensively evaluate the safety of the system, and timely early warning and improvement of weak links and factors.

Air traffic safety management follows many classic theoretical models as safety management in other industries.

(1) Hain's Law and Murphy's Law

Hein's Law was first proposed by the American engineer Herbert William Heinrich. The core meaning of Hain's Law is: behind every accident, there must be many hidden dangers that have not happened. It can be seen that there are many hidden dangers behind every unsafe incident of air traffic control, and after in-depth exploration of every unsafe incident, the hidden factors involved have very important guiding significance for the formulation of new rules and procedures. According to Hain's Law, if we can detect hidden dangers in time before accidents occur, and take precautions in advance to contain hidden dangers, then the accident itself can be eliminated or even avoided. Therefore, when we want to ensure safety and prevent accidents, we must focus on prevention and eliminate hidden dangers at its source.

Murphy's Law is derived from a Captain named "Murphy". It is a psychological effect. If there are two or more methods to accomplish a task, one of them will cause catastrophic result. Someone will definitely choose this way. Its main content includes four aspects: First, nothing is as simple as it appears on the surface; Second, everything will take longer than you expected; Third, things that will go wrong will go wrong sooner or later; Fourth, if you are afraid of something that is possibly to occur, then it will be more likely to occur. The meaning of its expression is: any event with small probability cannot be ignored, no matter how small the probability is, it may happen.

The goal of air traffic control safety management is to prevent accidents, and accidents are a small probability event that do not occur frequently. These small probability events do not occur in most cases, so they are often ignored by people and cause fluke, and this is often the main reason for unsafe incidents of air traffic control. Therefore, the evaluation of air traffic safety management needs to be scientific and objective, and any factors that may cause unsafe incidents cannot be neglected.

(2) Reason model

In the process of air transportation, 70% of accidents are caused by human factors. In order to determine the interconnection and influence between these factors, a British doctor named Reason established a safety system model according to the condition of the aircraft. It is called the "Reason Model". The meaning of its expression is: the occurrence of accidents can be divided into many different aspects, each of which has loopholes and defects. Unsafe factors exist at all levels and continue to evolve. These individual factors will not directly lead to unsafe incidents, but when these elements work together, it will lead to accidents. These layers are called "Swiss cheese models" because they look like cheese. In air traffic control operations, the idea we need to learn from is that the risk control of every operation link is very important, and any omission can be a cause of risk. When looking for indicators that affect air traffic safety, we divide them into four categories: personnel, equipment, environment, and management, and then select specific indicators based on each of them. When these indicators interact with each other, it is hard to avoid an accident after their resonance.

(3) PDCA cycle

The PDCA model is the Deming cycle (plan-do-check-act), and its meaning is to divide the quality management into four different stages, and according to this procedure, the cycle will continue to operate. Through this procedure, some problems can be successfully handled. However, the remaining problems continue to recycle. These four stages are planning (plan), implementation (do), inspection (check), and disposal (action).

The PDCA cycle is a scientific model that carries out quality control according to this logic and runs cyclically. This model uses system science and system engineering ideas, with the three aspects of man, machine, and environment as the main body of analysis, and analyzes the internal connection between the three factors, so that the three elements of man, machine and environment can be organically combined to make the system achieve the best operating results. The main goal of the system is to correctly, reasonably and effectively deal with the interrelationships between humans, machines and the environment, so that the system as a whole can achieve the optimal operating state, and the most important aspect of the system is to treat humans as the system.

The core part of the company can ensure the overall operational safety by providing a pleasant living and working environment. Many factors and variables can lead to the reduction of the operating efficiency of the air traffic control system. Through the theory of people, equipment, and environmental systems, the factors that lead to the reduction of air traffic control efficiency include four aspects: people (controllers, etc.), equipment (air traffic control equipment, etc.), environment (airspace structure and air traffic control site operating environment, etc.), management (control regulations, etc.). This is a fairly typical system with people as the core and management as the outer edge "human, aircraft, environment and management system".

"Human" refers to air traffic controllers and executors of control instructions (pilots). They are important members of air traffic control operations. Their tacit cooperation will directly affect the quality of operational efficiency, and it may be possible to cause disastrous consequences if communication is not smooth. Many factors can affect the efficiency of control work and airspace flow, including the efficiency of communication between pilots and controllers, handover between sectors, driving skills, and response tolerance.

"Aircraft" refers to the facilities and equipment that the operational units rely on for air command, including communications, navigation, and surveillance equipment. Factors such as the display screen used by the controller, the flight information sign, the choice of color and the size of the monitoring screen, the seat arrangement, the placement of the schedule, and the communication quality of the headset will directly affect the work of the controller.

"Environment" refers to the overall environment of the control operation, which can be divided into three aspects, one is the controlled airspace, air routes, and sector structure; the second is the working environment of the controller; the third is organizational environment, including the establishment of organizational structure, corporate culture, etc.

"Management" is a key component of the air traffic control operation part. It exists in the entire control and command process and has an effect on the three levels of man, machine, and environment. Under the existing airspace structure and operation mode, the factor "management" is the most effective way to improve operational safety. By improving the "management" of factors, it is possible to fundamentally reduce the time for the controller to make information, reduce the load intensity of the controller, and increase the efficiency of air traffic control.

Human, machine, environment, and management factors are external elements that affect the level of control and command, and the use of separation is a direct means to improve the level of operation. Through the research of human, machine, environment and management, the interference of related external factors can be reduced, so as to achieve the goal of improving air traffic control efficiency, ensure air traffic safety, and improve service quality.

3 Methodology

3.1 Guiding ideology for indicator system construction

The operation of air traffic safety control has always revolved around the two major themes of "safety" and "efficiency". Combining with the rapid development of the civil aviation industry and the problems faced in the operation of air traffic safety control, the Air Traffic Control Bureau of the Civil Aviation Administration of China has put forward the goal of "safety, capacity, efficiency, and service", which indicates the direction for the development of the air traffic safety control industry. Therefore, in the process of constructing the air traffic safety control evaluation indicator system, it is necessary to closely focus on the development plan of the Air Traffic Control Bureau of the Civil Aviation Administration of China, starting from the safe and efficient operation of air traffic safety control, and establish a set of systematic indicators that adapt to the actual operating environment. Therefore, the front-line management personnel can identify the risks in operation in time, and complete the disposal in time, and finally achieve the goal of safe and efficient operation of the system. Air traffic safety is affected by many uncertain factors, and the definition of factors is very ambiguous. For example, the risk of equipment, the ability of personnel, and the extent of weather impact are difficult to accurately quantify. These criteria need to be judged based on the experience of experts. Hence, we adopt hesitant fuzzy comprehensive evaluation method to tackle with this difficulty.

3.2 Principles for indicator system construction

With the growth of the aviation industry, the air traffic safety control system has become increasingly sophisticated and complex. There are many links and factors that affect safety. This paper analyzes many risks and links that affect the safety of air traffic control operations and extracts a scientific indicator system that can more comprehensively reflect the safety operation level of air traffic control. According to the REASON model, the final occurrence of air traffic control unsafe events is composed of a series of accident chains, and each link of the accident chain may have problems. The purpose of the safety evaluation indicator system is evaluate and monitor the safety level of the system, and put forward suggestions for improvement, which will ultimately prevent unsafe incidents. Therefore, the following principles should be followed when designing the indicator system:

(1) Comprehensiveness

Due to the complexity of the air traffic control system, various indicators need to fully reflect the operation of the system. In order to ensure the comprehensiveness of the indicators, relevant research materials and opinions from front-line experts are referred to in the indicator selection process.

(2) Scientificness

The confirmation of indicators needs to be based on the objective conditions of the air traffic safety control system, that is, the evaluation indicators can objectively describe the characteristics of each subsystem, and are combined with the actual operating conditions. Therefore, scienticness is an important principle for the establishment of the indicator system.

(3) Hierarchy

The establishment of the indicator system adopts a hierarchical structure, and the secondary indicators are an extension of the primary indicators. Therefore, it is necessary to objectively evaluate the affiliation relationship between the primary and secondary indicators, which is of great significance to the logical hierarchy of the indicator system.

(4) Adaptability

The source of the indicators comes from the analysis of the actual working environment. Therefore, the indicators must be adapted to the actual operating environment. Only in this way can the objective environment be described.

(5) Data Validity

The quantification of indicators requires data accumulation and expert evaluation, so the selection of indicators needs to consider factors such as the availability of data.

3.3 Discovery of evaluation indicators

Evaluation indicators are the key components of the safety capability evaluation index system of air traffic control institutions, and the excavation work on them is the prerequisite and basis for constructing the indicator system. To obtain scientific, comprehensive and objective evaluation indicators, it is necessary to pay attention to methods and follow principles in the mining process. Since it is an assessment of the safety capability of the air traffic control institution, first, it is necessary to accurately find the major categories of factors that affect the safety capability of the air traffic control institution from a comprehensive and systematic perspective, and then conduct an in-depth analysis of these major factors and combine them with the actual operation of the air traffic control institution from the aspects of “basic configuration and basic operation” of the air traffic control institution. At present, the assessment safety checklist used by various air traffic control institutions can be used as an important reference document for determining the indicators. However, the description of air traffic safety issues in the checklist is mostly narrative, so it is necessary to conduct a comprehensive analysis to extract valuable indicators. At the same time, by consulting a large number of relevant documents, such as documents issued by FAA, EUROCONTROL, etc., collect useful indicators; finally, experts in the field of civil aviation safety are invited to provide feedback based on their own work experience. The safety capability assessment indicators of air traffic control institutions were further sorted, screened and refined. Based on the above theoretical basis, we strictly follows the principles of objectivity, scientificity, and data validity of indicators. The early stage mainly focuses on “personnel”, “equipment”, “environment”, “management” that affect the safety of air traffic control operations. The four interrelated elements. We conduct comprehensive analysis, research and expansion, and explore the air traffic safety capability evaluation indicators. We also invite experts with rich control and safety management experience to further filter and refine the indicators based on the actual operation of the air traffic control, remove the indicators with high repeatability and less impact on the air traffic control safety, and use the finalized indicators for the construction of a quantitative evaluation indicator system measuring the safety of air traffic control institutions.

3.4 General framework of index system

The general framework is as follows: there are n evaluators, i.e., $V_f(f = 1, 2, \cdots, n)$; p criteria, i.e., $C_k(k = 1, 2, \cdots, p)$. This paper considers two hierarchies, namely, the hierarchy of evaluators and the hierarchy of indicators. A maximum consistency model is adopted to determine the weights of evaluators and indicators. After all information for the indicators are collected, a TOPSIS-based aggregation method is used to achieve the final evaluation results.

3.4.1 Human factors subsystem indicators c_1

At present, air traffic control activities are completed by the controllers issuing instructions to the pilots, and the related equipment maintenance, weather information, and logistics support are also inseparable from human factors. Therefore, human factors are important factors related to air traffic safety. According to the statistics of aviation accidents over the years, the proportion of accidents caused by human factors is the largest. Human factors are an important part of restricting the level of air traffic management. The evaluation indicators under the human factors system and their descriptions are as follows.

(1) Physical Fitness C_{11}

Physical fitness refers to the degree to which the physical condition of the employee matches the job requirements. Due to the characteristics of the civil aviation transportation industry, most positions in the air traffic control industry implement a shift system. Long-term irregular schedules and night shifts can disrupt the biological clock and cause adverse effects on the human body. In order to reduce human error to the greatest extent, the first-line control personnel engaged in air command need to keep agile thinking and energetic at all times. Better physical fitness has a positive impact on the safety and efficiency of control work.

(2) Mental Quality C_{12}

Psychological quality refers to the degree of matching between the employee's psychological situation and job requirements. As the industry of air traffic control is characterized by many operations, many emergencies, difficult handling, and serious consequences, employees in all links, especially controllers, must have strong psychological qualities. When an emergency occurs in the air, it is necessary to make decisions under high pressure and supervise the pilot's execution in a short time. A employee with good psychological quality is more likely to be able to handle special situations safely and effectively in accordance with procedures when in danger.

(3) Safety Awareness C_{13}

Safety awareness refers to the degree to which employees attach importance to safety in psychology and action. Safety is priority in air traffic control work. It is reflected in the meticulousness of employees' work and whether they always use safety indicators to verify their decisions. In the work process of employees, a high degree of safety awareness must be maintained for each link in order to minimize the probability of accidents.

(4) Training Quality C_{14}

Training quality refers to the achieved effect of the training provided by the institution to employees. As the aviation industry related to the air traffic control industry is a typical high-tech industry, air traffic control practitioners are always facing the upgrading of knowledge. At the same time, controllers regularly conduct various review training and simulator training every year. The effects of these trainings have played a key role in the improvement of employees' personal knowledge, skills and professional quality.

(5) Learning Ability C_{15}

Learning ability refers to the ability of employees to receive institution training and self-learning. On the one hand, in the face of the rapid development of air traffic control technology and the scientific progress of various safety management methods, whether employees have matching learning capabilities is the key. On the other hand, whether employees can take the initiative to learn, find loopholes in their work and put forward reasonable and scientific suggestions also plays a very important role in the development of the institution's business.

(6) Age Structure C_{16}

Age structure refers to the matching degree between the characteristics of the age composition of employees and their mutual influence and institution needs. Age has a certain impact on employees' experience, energy, and knowledge. Especially because the front line of air traffic control is team-based, and the management and control is conducted by two people in coordination, so the reasonableness of age matching is very important to the work performance of the team. A reasonable age structure can play a very positive role in work safety and efficiency.

(7) Cooperation between Individuals and Organizations C_{17}

The degree of cooperation between individuals and organizations refers to the degree of consistency between employees' personal thoughts and behaviors and the goals of the organization. The air traffic control industry has extremely high requirements for safety and efficiency. However, due to the limitations of the public institution system, the incentives for employees are limited, and the demands of some employees cannot be met. How to better unify personal goals and organizational goals is a problem that every air traffic controller needs to solve.

(8) Ability to Deal with Interpersonal Conflict C_{18}

The ability to deal with interpersonal conflicts refers to the ability to deal with conflicts between the leaders and colleagues around the air crew. The process of air traffic control in air command is completed by the controller issuing instructions to the aircraft pilot through radio frequency. An administrator needs to face many aircraft pilots, but due to limited airspace resources, how to allocate time between aircraft pilots will bring conflicts between controllers and aircraft pilots. Whether such conflicts can be handled efficiently will have an important impact on the safety and efficiency of air traffic control. At present, air traffic control implements a "dual-post" systemłtwo controllers form a team to perform air commandand one controller is commanding air while the other one is responsible for the coordination and monitoring of surrounding units. Therefore, how to deal with the different opinions of the two controllers on the air command is also very important. In addition, the work of the controller requires the close cooperation of colleagues in other positions such as the technical support department and the meteorological department. How to handle conflicts with them also affects air safety.

3.4.2 Equipment factors subsystem indicators c_2

Air traffic activities are produced and developed along with the development of aviation technology. With the rapid development of civil aviation, increasingly crowded routes and airspace have put forward higher requirements for the advancement and stability of equipment. Meteorological departments need to rely on weather radars to provide controllers with live weather information and forecasts; control departments need to use communication, navigation, and monitoring equipment to grasp all types of aircraft information, and provide control, intelligence and warning services; technical departments need to conduct various equipment maintenance to ensure its stability. Therefore, the advanced level of the equipment and the stability of the equipment have a great impact on the safety of air traffic. The evaluation indicators under the equipment factors system and their descriptions are as follows.

(1) Depreciation of Equipment C_{21}

The degree of equipment depreciation refers to the degree of matching between equipment stability problems caused by the aging of equipment and work requirements. Air traffic control methods are highly dependent on various electronic equipment, and the stability problems caused by the aging of these equipment will greatly affect aviation safety. At present, air traffic control equipment is mainly composed of air surveillance, communication, network, meteorology, etc. Any equipment failure will cause a decline in control capability or even failure. Therefore, the stability of these equipment has an extremely important impact on air traffic control safety.

(2) Equipment Reliability C_{22}

The reliability of the equipment refers to the degree of matching between the accuracy of the equipment and the work requirements. The accuracy of aviation equipment will affect the control and command methods and the accuracy of aviation intelligence. For example, the current common surveillance methods such as secondary radar and ADS-B have different accuracy. Some methods can more accurately locate the aircraft's position so that the aircraft can be equipped with smaller intervals, thereby increasing the airspace capacity and improving safety.

(3) Advanced Nature of Equipment C_{23}

The advanced nature of the equipment refers to the gap between the equipment and the world-class equipment. The aviation control industry has high requirements for advanced equipment, and the safety output brought by advanced equipment is obvious. For example, more advanced weather radars can more accurately detect the altitude range of dangerous weather and provide controllers and aircraft pilots with more accurate weather information. Therefore, the advanced nature of equipment also plays a very important role in aviation safety.

(4) Adaptability of Software System C_{24}

The adaptability of the software system refers to the degree of matching of the various software systems used daily with the use demand and habits of employees. In order to meet the needs of the air traffic control industry, there are currently various unique software systems for air traffic control. Taking air command as an example, various information of the monitored aircraft will be transmitted to the system for calculation, and then the aircraft information will be displayed in a specially designed interface. Whether the design of the software system meets the controller's use requirements and whether it matches the controller's working habits will determine the use efficiency of software.Software with good adaptability can save the energy of air traffic controller and allow the controller to use more energy to monitor air dynamics, which will have a very positive effect on air safety.

(5) Completeness of Technical Information C_{25}

At present, the main equipment used by most air traffic control institution is still imported equipment. The completeness of technical information refers to the degree of matching between current air traffic control equipment related information and work requirements. Therefore, complete technical information also plays a very important role in air traffic control safety.

(6) Repair Ability of Malfunctioning Equipment C_{26}

The ability to repair malfunctioning equipment refers to that the ATC agency or manufacturer can perform timely maintenance if the equipment fails. As air traffic control equipment is highly dependent on equipment, air traffic control institutions will have main equipment, backup equipment and emergency equipment. However, the impact of simultaneous equipment failure on control command is immeasurable. Therefore, the ability of the technical support department or the equipment manufacturer to repair the equipment in time after equipment failure is particularly important.

(7) Daily Use Status of Spare and Emergency Equipment C_{27}

The daily use status of standby and emergency equipment refers to the degree of matching between the daily use of standby and emergency equipment and the needs of the institution. In consideration of the stability of air traffic control equipment, for many important equipment, the institution will prepare primary, backup and even emergency equipment. Since spare and emergency equipment is rarely used, employees have few actual operations after training, and their proficiency may be insufficient. On the other hand, spare or emergency equipment generally uses relatively inexpensive equipment, which has a short use time and few suggestions for improvement. If the main equipment fails, temporary use of the backup equipment may cause unskilled operations, problems with the details of the equipment use, etc. Therefore, the daily use status of backup and emergency equipment will also affect air traffic safety.

3.4.3 Environment factors subsystem indicators c_3

The air traffic control environment includes both the physical environment of employees' daily work and the environment of the airspace. The quality of the physical environment can affect the work status and motivation of employees. The quality of the airspace environment determines the difficulty of the controller's work and the probability of making mistakes. Therefore, environmental factors also greatly affect air traffic safety. The evaluation indicators under the environment factors system and their descriptions are as follows.

(1) Aircraft Flow C_{31}

Aircraft flow refers to the number of aircraft commanded by a single sector or controller. The current air traffic control regulations have minimum horizontal or vertical separation requirements for aircraft. Since the capacity of each control sector is limited, the risk of aviation safety will rise sharply if overload. In addition, the controller's energy and ability are limited. If the aircraft flow does not match the controller's energy and ability for a long time, then safety will not be guaranteed. Therefore, the aircraft flow is closely related to air traffic control safety.

(2) The Complexity of the Control Sector C_{32}

The complexity of the control sector refers to the difficulty of control caused by factors such as the size of the sector and the difficulty of aircraft deployment. The complex sector has many conflict points and difficult flight deployments, which require the controllers more effort and higher ability. There are many factors that cause the complexity of the sector, which may be due to the large area and too many conflict points, or the complex airspace environment that is more affected by restricted areas and forbidden region. Therefore, the air traffic control risk brought by the complex sector is also huge, and more time, energy and measures are needed to control this risk.

(3) The Rationality of Route Planning C_{33}

The rationality of route planning refers to the extent to which the route planning is beneficial to control and command. There are many factors considered in the design of the route. On the one hand, physical conditions such as navigation stations, airport locations, air restricted areas, and forbidden region need to be considered. On the other hand, whether the planning is conducive to ensuring air safety and accelerating air traffic must also be considered. Reasonable route planning can reduce risks and conflict points in the sector, increase sector capacity and efficiency, and reduce safety risks.

(4) Physical Environment of Control Workroom C_{34}

The physical environment of the control workroom refers to the physical indicators of the working environment of the controller, such as temperature, humidity, air quality and lighting. On the one hand, the controller needs to maintain a high degree of concentration at all times, so it is necessary to create a working environment that makes the controller feel comfortable. On the other hand, since most of the work of the controller requires the use of radar screens, in order to ensure a clear view, most control rooms are in a relatively closed and dark environment, so the control of light and air quality is particularly important.

(5) The Soundness and Rationality of Aviation Regulations C_{35}

The soundness of aviation regulations and their rationality refer to the the comprehensiveness and rationality of the rules and regulations which ensure operational safety and efficiency according to the complexity of actual control work. As the air traffic control industry has extremely low tolerance for danger and high requirements for efficiency, the rules and regulations and operating procedures are very important. Whether the control institution formulates an rational operation manual and risk prevention and control measures that are integrated with its actual operating conditions in accordance with the relevant civil aviation regulations will greatly affect the safety level of the institution.

(6) Abominable Weather Condition C_{36}

Abominable weather conditions refer to weather conditions that have a negative impact on aviation safety and operational efficiency. Aviation operations are greatly affected by air weather, such as turbulence and wind shear in the air, which may directly cause damage to the aircraft and personal injuries, thereby affecting flight safety. Unavailability of the flight level with turbulence and wind shear will cause congestion on the route, and reducing the sector capacity will also increase the difficulty of deployment. If a thunderstorm causes a large-area fly-around or diversion to return , the frequency of air-ground communication will be increased, resulting in congestion of the radio channel and negatively affecting aviation safety.

(7) Open Status of the Air Force Airspace C_{37}

The open status of the airspace of the Air Force refers to the situation in which various types of airspace controlled by the Air Force are open to civil aviation flights. China's current airspace is under the unified management of the Chinese Air Force. Civil aviation can only freely deploy the airspace and air routes around civil aviation airports, which greatly restricts the way controllers mediate air conflicts. When the air route is too congested, or when face to deployment conflicts or the weather in which need fly-around, the civil aviation management department needs to apply for temporary use of air space controlled by air force. This can greatly alleviate the difficulty of deployment of civil aviation flights, and the rational use of airspace will also increase the spacing between air planes and improve the safety of civil aviation transportation. Therefore, the open status of the Air Force airspace has a very important impact on aviation safety.

3.4.4 Management factors subsystem indicators c_4

The air traffic management system is already a very large and complex system. The safe, effective and stable operation of the system requires internal and external close cooperation of various departments, and the management of such numerous departments and personnel has high requirement of the management methods and levels of air traffic control units. Therefore, management factors also have a great impact on air traffic safety. The evaluation indicators under the management factors system and their descriptions are as follows.

(1) Standard Work Process C_{41}

Standard work process refers to the process guidelines for high-repetition and high-risk links in the daily work of air traffic control, which is formulated in accordance with industry regulations and actual operating conditions. There are a large number of highly repetitive links in the air traffic control industry, such as the handover of controllers, opening or closing control sectors, and radar guidance of aircraft. At the same time, there are many risky links, such as handling various special situation of aircraft in air and the ground equipment failures. The development of standard procedures for these links can not only improve the efficiency of work, but also minimize the risks caused by incorrect operation or missing links.

(2) Leadership C_{42}

The leadership refers to the ability of leaders at all levels to resolve various contradictions and conflicts faced by the organization and to motivate their subordinates to jointly accomplish organizational goals. On the one hand, the air traffic control industry faces contradictions and conflicts both between controllers and between leaders and employees. On the other hand, restricted by the limited incentives of public institutions, the aviation industry is unable to meet some of the economic demands of employees. Faced with such a complicated situation, how to unify goals, manage and motivate employees to achieve goals poses a great challenge to the leader's ability. Therefore, the leader's ability is also an important factor affecting aviation safety.

(3) Supervisor-subordinate Communication C_{43}

Supervisor-subordinate communication refers to the frequency and quality of communication between superiors and subordinate within the air traffic control organization. Due to the characteristics of the air traffic control industry, front-line controllers, technical support, and weather forecasters are all shift systems, while the leaders are administrative teams. This results in less communication channels between superiors and subordinates than other industries. Therefore, how to carry out effective communication between the superior and the subordinate, timely communicate the problems in the front-line operation and the thinking dynamics of the personnel and get feedback, which will have a far-reaching impact on the safe operation.

(4) The Rationality of the Organizational Structure C_{44}

The rationality of the organizational structure refers to the degree of matching between the institutional setting of the regulatory agency and the division of power ownership and the safe and efficient development of the industry. With the explosive growth of civil aviation flights in the past two decades, both personnel and organizations in the air traffic control industry have grown rapidly. However, whether the establishment of institutions is reasonable and whether the distribution of power is conducive to the safe and efficient development of the industry is a problem that needs to be treated scientifically. The impact of a reasonable organizational structure on air traffic safety cannot be ignored.

(5) Employees' Recognition of Organizational Goals C_{45}

Employees' recognition of organizational goals refers to the degree to which employees understand and strive to achieve organizational goals. Although the air traffic control institution is a public institution, because of the high requirements for safety and efficiency, many links are more inclined to the corporate management mode. Therefore, the ability to propose clear organizational goals to employees and encourage employees to work together to achieve organizational goals will have an important impact on air traffic control safety.

(6) Cooperation Between Departments C_{46}

Inter-departmental cooperation refers to the degree of mutual compromise between air traffic control departments in order to achieve organizational goals. The air traffic control has developed to a multi-departmental collaboration. The safe and efficient operation of the air traffic system requires the cooperation of control, technical support, meteorology, logistics and other departments. However, conflicts are inevitable when the interests of these departments are not completely consistent, or when there is a gap between individuals in the departments. Therefore, by coordinating the relationship between the departments, when there is a conflict, reasonable arbitration and coordination to make the conflict develop in the direction that is beneficial to the organization's goals can maximize the safety output.

(7) The Degree of Implementation of Rules and Regulations C_{47}

The degree of implementation of rules and regulations refers to the degree to which the rules and regulations are strictly enforced by employees. Due to the high requirements of the air traffic control industry for safety and efficiency, there are a lot of various regulations and procedures manuals. Most of these regulations are derived from the summary of various unsafe incidents or accidents. The inability of employees to implement the rules and requirements well is an important reason for the occurrence of unsafe air traffic control incidents. Therefore, the implementation of rules and regulations has a direct impact on air traffic control safety.

(8) Effective Transmission of Various Types of Information C_{48}

The effective transmission of various types of information refers to the degree to which information related to safety and efficiency is transmitted and understood among employees at all levels. On the one hand, because the leaders of the air traffic control industry are the business team, but the front-line employees are the shift system, so the information transmission process is likely to have problems of untimely, inaccurate and difficult implementation. On the other hand, there are also omissions and errors in information transmission within the front-line operation teams and between departments. In the case analysis of various unsafe incidents in air traffic control, errors, forgotten and omissions are the main reasons for unsafe incidents. Therefore, the effectiveness of information transmission has an important impact on air traffic control safety.

(9) Safety Culture C_{49}

Safety culture refers to the general term for the safety concepts, safety awareness, and various corresponding behaviors that exist in air traffic control institutions and individuals. Under the current air traffic control model, all equipment operations and rules and regulations need to be executed by humans. Human safety concepts and awareness will affect the implementation of all rules and regulations. At the same time, people with strong awareness of security concepts will actively research and discover hidden dangers and loopholes in the work, and put forward reasonable security suggestions. This will have a lasting and long-term impact on air traffic safety.

(10) Investment in Safety Education and Training C_{410}

The investment in safety education and training refers to the human, financial and other resources invested by air traffic control institutions for safety education and training of employees in addition to daily work. The investment in safety education and training can enhance employees' awareness of production safety and the theoretical level of production safety, making it easier for employees to find problems at work, and more proactively implement safety-friendly rules and regulations. However, the current professional safety training resources of air traffic control units are limited, and it is difficult to conduct in-depth training for employees. On the other hand, because front-line employees are tight at work, long-term saturated or even overloaded, they are emotionally resistant to the learning and training organized during rest periods. Therefore, if the investment in this area can be increased, it will be extremely beneficial to the improvement of the safety level of air traffic control.

(11) The Degree of Importance Attached by Leaders to Safety C_{411}

The importance that the leader attaches to safety refers to the degree to which the leaders time and energy devoted to safety work and the material conditions match the needs of the institution. There is a famous saying : a group of sheep led by a wolf can defeat a group of wolves led by a sheepwhich illustrates the importance of leaders. At the same time, the leader can allocate the resources of the institution and decide how much human and material resources can be put into safety work. Therefore, the importance of leaders has a macroscopic impact on the safety level of the entire air traffic control institution.

(12) Safety Inspection Agency C_{412}

Security inspection agency refers to whether the air traffic control agency has an independent security supervision agency and the performance of the security supervision agency. The front-line operation department cannot be an athlete and a referee at the same time, otherwise this will cause problems easily covered up and the difficulty to objectively evaluate the performance of safe work. Professional and independent safety supervision departments can supervise and spot-check safety issues in front-line operations. On the one hand, the system ensures the operation of various regulations and requirements on safety. On the other hand, it can retain professional safety management personnel to improve the internal safety business level of the institution.

(13) Safety Record C_{413}

Safety records refer to the recording, sorting and analysis of daily operating data, violations, and unsafe events. With the rapid development of the civil aviation industry, air traffic control agencies and personnel have become larger and larger, and various management problems have become increasingly prominent. In order to understand the problem clearly, scientific management must rely on big data analysis. Therefore, the record analysis of various operating data and personal safety records provides a basis for timely detection of problems and efficient solutions. In summary, through the analysis of various factors that affect air traffic control safety, combined with relevant research data, the overall indicator system is constructed in this chapter.

3.5 Weights determination

3.5.1 Hesitant fuzzy linguistic judgments description

In order to make an objective and scientific evaluation of indicators in this paper, we invited seven experts of China Civil Aviation Management to evaluate the importance of the indicators. They are senior instructors, inspectors, department directors of front-line operation institutions, head teachers, and senior control personnel from the Civil Aviation Administration of China. The objectivity of the evaluation of the indicators is guaranteed to the greatest extent. However, differences in expert knowledge and experience will affect their judgment on the same indicator and give different evaluation results for the same indicator. At the same time, because experts' judgments of degree may also be vague, experts often use different judgment languages when judging the importance of indicators. When experts are confident of their understanding and belief, they may give a categorical score, for example, a score of 1 represent "this indicator is full important". Some experts can not make a black-and-white judgment. In this case, they give an "inter-valued" answer such as "between 0.5 and 0.8" to present "the importance of this indicator is between important and very important". It is also possible that the experts did not give their own opinions on unfamiliar indicators. In this case, if they do not give judgments, it can reflect the objective situation more accurately. Experts give judgments with complex linguistic terms on the basis of their cognitive styles. In this case, a single linguistic term is insufficient. Rodrfguez et al. put forward the concept of hesitating fuzzy linguistic term set in 2012. Therefore, this paper uses hesitant fuzzy language set to express experts' evaluation of the importance of different indicators related to air traffic safety control. This description method can express linguistic information more flexibly. As it is shown in Figure 1, we divide the hesitant fuzzy linguistic term set into 7 levels: extremely unimportant, very unimportant, unimportant, medium, important, very important and extremely important.

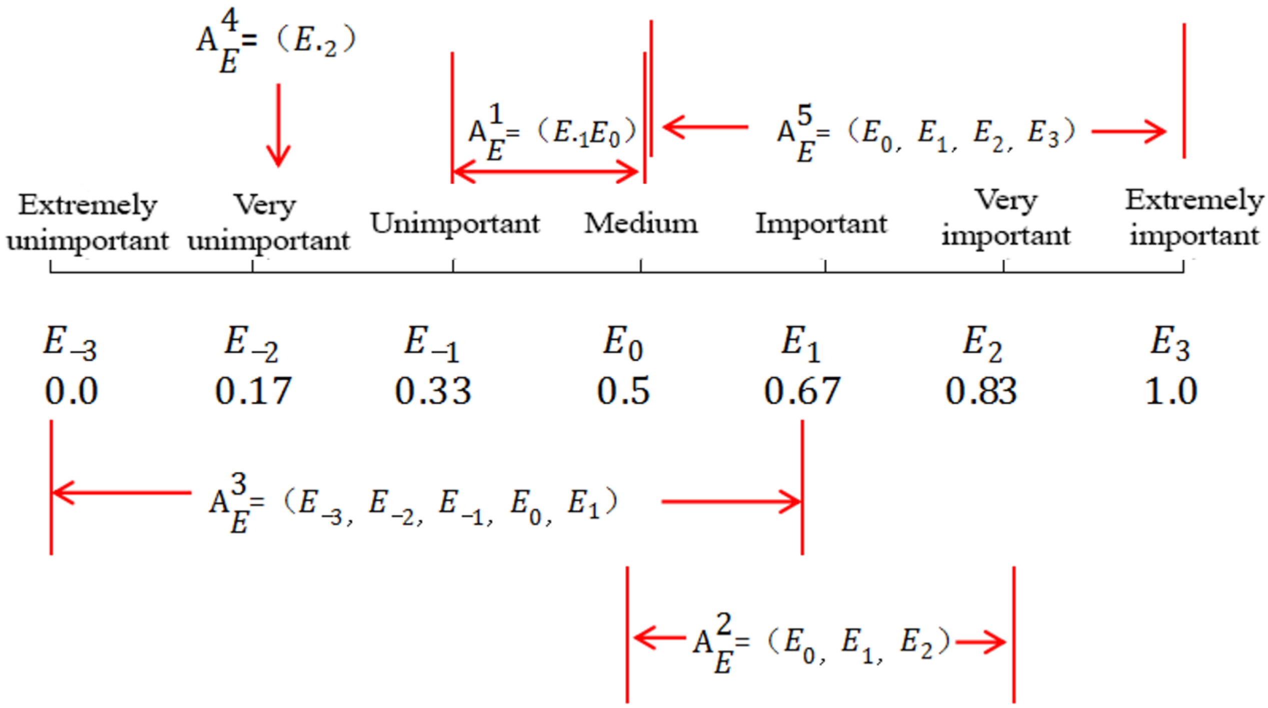

Fig. 1: Examples of hesitant fuzzy numbers

Let $E = \{E_\alpha | \alpha = -\tau, \cdots, -1, \cdots, \tau\}$ be a linguistic term set. A_E^x is introduced to represent the membership degree of a linguistic variable $x \in X$. The application of A_E^x make the better elicitation of linguistic information. Any linguistic value or a rating can be considered as a label for a fuzzy restriction. Such fuzzy restrictions are characterized by a compatibility function which associates each linguistic value with a real number in the interval $[0, 1]$, which represents the compatibility of that linguistic value. There is a 7-scaled score in evaluation. Hence, we have the following information:

$$A_E^1 = \{E_{-1}, E_0\} = \{0.33, 0.5\}$$

$$A_E^2 = \{E_0, E_1, E_2\} = \{0.5, 0.67, 0.83\}$$

$$A_E^3 = \{E_{-3}, E_{-2}, E_{-1}, E_0, E_1\} = \{0.00, 0.17, 0.33, 0.5, 0.67\}$$

$$A_E^4 = \{E_2\} = \{0.17\}$$

$$A_E^5 = \{E_0, E_1, E_2, E_3\} = \{0.50, 0.67, 0.83, 1.00\}$$

In order to compare distance, we have to make the number of values in A_E^x be the same. We let d^+ and d^- denote the maximum and minimum values in A_E^x and introduce a parameter $\eta(0 \leq \eta \leq 1)$ which is determined by expert's attitude. In this case, we can use the extension value $\bar{d} = \eta d^+ + (1 - \eta)d^-$ to extend the shorter elements so that all elements are in the same length. Suppose that the experts' attitude is neutral in this paper, namely $\eta = \frac{1}{2}$ then the extension value $\bar{d} = \frac{1}{2}(d^+ + d^-)$ can be added. The length of a missing judgment is 0, which can be extended by the values that other evaluators use. Assume that we have a blank answer for A_E^6 in this example, we can let A_E^6={0.00,0.17,0.33,0.50,0.67,0.83,1.00}.

3.5.2 Expert weight determination

It has been difficult to determine the experts' weights in multi-criteria decision making problems because of experts' differences in experience, position and cognitive styles. Previous studies has given equal weights or fuzzy weights. However, higher group consensus are important to result agreement and reliability. Therefore, this paper proposes an optimization model to determine weights. The model aims to maximize group consensus. The Euclidean distance between two judgments represents the divergence. First, the experts provide judgments to all indicators in the air traffic safety control evaluation system. Hesitant fuzzy linguistic judgments are adopted to depict the experts' judgments, which are denoted as

$$d_{fk} = \{d_{fk}^l \mid l = 1, \cdots, H, \quad f = 1, \cdots, n, \quad k = 1, \cdots, p\}, \tag{1}$$

where H is the length of d_{fk}.

Similarly, for the indicator importance, the total judgment divergence between one expert f and another expert g is expressed as follows:

$$y(d_{fk}, d_{gk}) = \sqrt{\frac{1}{H} \sum_{l=1}^{H} \sum_{f=1}^{n} \sum_{g=1, g \neq f}^{n} (d_{fk}^l - d_{gk}^l)^2}. \tag{2}$$

The hesitant fuzzy judgments with expert weights are then expressed as

$$\{s_f^V d_{fk}^l \mid l = 1, \cdots, H\},$$

so the weighted sum of the Euclidean distance from one expert judgment score to another is shown as follows:

$$\bar{y}(d_{fk}, d_{gk}) = \sqrt{\frac{1}{H}\sum_{l=1}^{H}\sum_{f=1}^{n}\sum_{g=1,g\neq f}^{n}(s_f^V d_{fk}^l - s_g^V d_{gk}^l)^2}. \quad (3)$$

To determine the best s_f^V to obtain maximum group consensus , all hesitant fuzzy judgments with expert weights should move towards one another. Based on the above analysis, the optimization model minimizing the judgment divergence with expert weights is as follows:

$$\begin{cases} \min_{s_f^V} = \sqrt{\frac{1}{H}\sum_{l=1}^{H}\sum_{f=1}^{n}\sum_{g=1,g\neq f}^{n}(s_f^V d_{fk}^l - s_g^V d_{gk}^l)^2} \\ d_{fk} = \{d_{fk}^l \mid l = 1,\cdots,H, \quad f = 1,\cdots,n, \quad k = 1,\cdots,p\} \\ d_{gk} = \{d_{gk}^l \mid l = 1,\cdots,H, \quad f = 1,\cdots,n, \quad k = 1,\cdots,p, g\neq f\} \\ \sum_{f=1}^{n} s_f^v = 1 \\ s_f^V \geq 0, f = 1,\cdots,n \end{cases} \quad (4)$$

The experts' weights s_f^V obtained from Model (4) represent the minimal sum of the Euclidean distances between all pairs of expert judgments. Therefore, Model (4) generates the optimal experts' weights for group consensus.

3.5.3 Indicators' weights computation

Indicators weights can also be determined from the expert hesitant fuzzy judgments. The indicators' importance judgments from experts are denoted as d_{fk}. This paper applies a weighted average operator to determine the indicators' weights:

Step 1. Due to the characteristics of hesitant fuzzy linguistic judgments, the lengths may be unequal. To ensure all judgments are of the same length, an extension procedure is conducted: $d_{fk} = \{d_{fk}^l \mid l = 1,\cdots,H, \quad f = 1,\cdots,n, \quad k = 1,\cdots,p\}$.

Step 2. Using the experts' weights s_f^V obtained from Model (4), the weighted and extended hesitant fuzzy judgments are derived as follows:

$$\bar{d}_{fk} = \{s_f^V d_{fk}^l \mid l = 1,\cdots,H, \quad f = 1,\cdots,n, \quad k = 1,\cdots,p\}. \quad (5)$$

Step 3. The parameters for the weighted average operator for the hesitant fuzzy linguistic judgments are then calculated as follows:

$$\bar{u}_k = \sum_{f=1}^{n} \bar{d}_{fk}^1, \quad (6)$$

$$\bar{v}_k = \sum_{f=1}^{n} \frac{1}{H-2}(\bar{d}_{fk}^2 + \bar{d}_{fk}^3 + \cdots + \bar{d}_{fk}^{H-1}), \quad (7)$$

$$\bar{\pi}_k = \sum_{f=1}^{n} \bar{d}_{fk}^H. \quad (8)$$

Step 4. The hesitant fuzzy judgments are transformed into triangular intuitionistic fuzzy numbers $(\bar{u}_j, \bar{v}_j, \bar{\pi}_j)$. Using the weighted average operator for the intuitionistic fuzzy numbers, the weight of the k^{th} idicator can be computed as:

$$s_k^C = \frac{\bar{u}_j + \bar{\pi}_j(\frac{\bar{u}_j}{\bar{u}_j+\bar{v}_j})}{\sum_{k=1}^{p}[\bar{u}_j + \bar{\pi}_j(\frac{\bar{u}_j}{\bar{u}_j+\bar{v}_j})]}. \quad (9)$$

Following the above steps, the weights of the indicators are determined.

3.5.4 A topsis based aggregation method

In multi-criteria decision-making problems, TOPSIS can be used to rank the alternative by employing a positive-ideal solution (PIS) and a negative-ideal solution (NIS).

Step 1. Compute the normalized decision matrix and use vector normalization to calculate u_{ik}.

$$u_{ik} = \frac{x_{ik}}{\sqrt{\sum_{i=1}^{r} x_{ik}^2}}, i = 1, 2, \cdots, r. \tag{10}$$

Step 2. The expert weights $s_f^V (f = 1, 2, \cdots, n)$ are calculated by Model (4), and indicators weights $s_k^C (k = 1, \cdots, p)$ are determined using the weighted average operator.

Step 3. The weighted and normalized air traffic safety control evaluation matrix V is then constructed:

$$V = \begin{bmatrix} s_{11}^C u_{1,11}^l & \cdots & s_{413}^C u_{1,413}^l \\ \vdots & \ddots & \vdots \\ s_{11}^C u_{r,11}^l & \cdots & s_{413}^C u_{r,413}^l \end{bmatrix} \tag{11}$$

Step 4. The most and the least preferable criteria are denoted as A^+ and A^- respectively. Therefore, the values of A^+ and A^- are defined as

$$D^+ = \{\max_r v_{ik} | k = 11, 12, \cdots, 413\}, \tag{12}$$

$$D^- = \{\min_r v_{ik} | k = 11, 12, \cdots, 413\}. \tag{13}$$

Step 5. Calculate the Euclidean distance between each air traffic safety control institution evaluation result and D^+:

$$E_i^+ = \sqrt{\sum_{k=11}^{413} (v_{ik} - v_k^+)^2}, \quad i = 1, 2, \cdots, r. \tag{14}$$

Similarly, the Euclidean distance between each air traffic safety control evaluation result and D^- is:

$$E_i^- = \sqrt{\sum_{k=11}^{413} (v_{ik} - v_k^-)^2}, \quad i = 1, 2, \cdots, r. \tag{15}$$

Step 6. The relative closeness of each air traffic safety control institution to the most preferable E^+ is calculated as follows:

$$Y_i^+ = \frac{E_i^-}{E_i^+ + E_i^-}, 0 < Y_i^+ < 1, i = 1, 2, \cdots, r. \tag{16}$$

Step 7. Y_i^+ can be viewed as the comprehensive evaluation score for the air traffic safety control institution. The higher the value of $Y_i^+ (i = 1, 2, \cdots, r)$, the higher the safety level of the air traffic safety control institution.

4 Case study

At present, the air traffic management system is managed by the Air Traffic Control Bureau of the Civil Aviation Administration, the regional air traffic control bureau, and the air traffic control branch (station). The regional air traffic control bureau and the air traffic control branch (station) are responsible for the first-line operation of various air traffic control services, which are directly related with the air traffic safety. Through interviews with seven senior air traffic control experts, the indicators that affect the safety of air traffic control and the performance of a certain regional air traffic control institution under the indicators were evaluated, and the experts' linguistic evaluations were converted into corresponding hesitating fuzzy numbers. A collection of comments on the performance of this indicator system of a certain regional air traffic control institution is divided into 7 levels according to the degree: extremely poor, very poor, poor, average, good, very good, and extremely good. For example, as for the linguistic evaluation of C_{11} physical fitness, expert 1 gave "between not important and important", and was transformed into a hesitant fuzzy set of $\{0.33, 0.5, 0.67\}$. Expert 1 also evaluated the performance of a certain regional air traffic control institution under this indicator. The evaluation language was "between fair and very good", and was transformed into a hesitating fuzzy set of $\{0.5, 0.67, 0.83\}$. According to the Model (4), the respective weights of the 7 experts can be obtained as $s_f^V = \{0.195, 0.183, 0.123, 0.121, 0.100, 0.139, 0.138\}$. Correspondingly, the calculation result of the weighted divergence degree of the group is $\bar{d}(d_{fk}, d_{gk}) = 22.8996$.

Table 1 shows the corresponding weights of the indicators and the expert evaluation performance of the indicators of a certain regional air traffic control institution.

Table 1: Indicators weights and the weighted experts evaluation of the indicators of a certain regional air traffic control institution

Indicator	Score of weighted importance	Importance	Evaluation score	Evaluation
C_{11}	0.5365	0.5 − 0.67	0.6334	average − good
C_{12}	0.8977	0.83 − 1.0	0.7832	good − very good
C_{13}	0.9194	0.83 − 1.0	0.6601	good
C_{14}	0.8012	0.67 − 0.83	0.7547	good − very good
C_{15}	0.7307	0.67 − 0.83	0.4633	bad − medium
C_{16}	0.7466	0.67 − 0.83	0.5410	medium
C_{17}	0.3799	0.33 − 0.5	0.7796	good − very good
C_{18}	0.5481	0.5 − 0.67	0.7002	good − very good
C_{19}	0.4935	0.5	0.5527	medium − good
C_{21}	0.2946	0.17 − 0.33	0.8284	very good
C_{22}	0.9355	0.83 − 1.0	0.8957	very good − extremely good
C_{23}	0.5810	0.5 − 0.67	0.8201	very good
C_{24}	0.6668	0.67	0.7122	good − very good
C_{25}	0.5919	0.5 − 0.67	0.7331	good − very good
C_{26}	0.3836	0.33 − 0.5	0.4992	medium
C_{27}	0.6917	0.67 − 0.83	0.6840	good
C_{31}	0.8656	0.83 − 1.0	0.7320	good − very good
C_{32}	0.8166	0.67 − 0.83	0.6622	good
C_{33}	0.6871	0.67	0.7573	good − very good
C_{34}	0.4643	0.5	0.4809	medium
C_{35}	0.9550	1.0	0.8353	very good
C_{36}	0.8241	0.83	0.7567	good − very good
C_{37}	0.7700	0.67 − 0.83	0.7591	good − very good
C_{41}	0.8288	0.83	0.8336	very good
C_{42}	0.6952	0.67 − 0.83	0.6944	good − very good
C_{43}	0.7495	0.67 − 0.83	0.4062	bad − medium
C_{44}	0.6022	0.5 − 0.67	0.6381	medium − good
C_{45}	0.5617	0.5 − 0.67	0.7058	good − very good
C_{46}	0.6032	0.5 − 0.67	0.8429	very good − extremely good
C_{47}	0.8068	0.67 − 0.83	0.8677	very good − extremely good
C_{48}	0.6920	0.67 − 0.83	0.8790	very good − extremely good
C_{49}	0.8720	0.83 − 1.0	0.7831	good − very good
C_{410}	0.7125	0.67 − 0.83	0.5759	medium − good
C_{411}	0.9351	0.83 − 1.0	0.9482	very good − extremely good
C_{412}	0.7375	0.67 − 0.83	0.8585	very good − extremely good
C_{413}	0.7408	0.67 − 0.83	0.8498	very good − extremely good

After the above data is aggregated by the TOPSIS method, the overall evaluation result is 0.731 (1 is a perfect score), which is between good and very good.

5 Discussions and suggestions

5.1 Evaluation results discussions

Through the evaluation of various indicators of air traffic safety control, as it is shown in Figure 2, the importance-performance evaluation matrix is obtained.

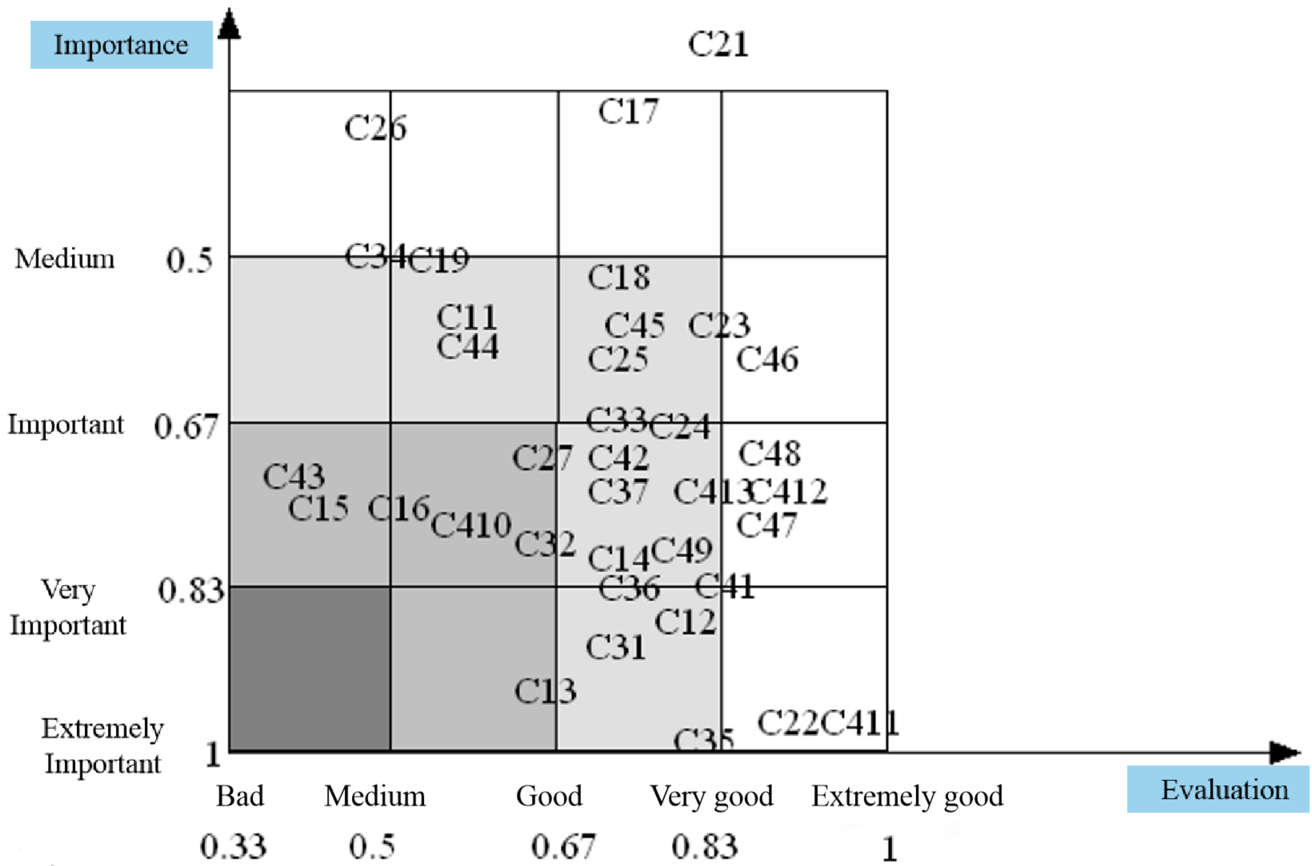

Fig. 2: Importance-performance evaluation matrix

5.2 Suggestions on improvements

The most important thing in the evaluation of air traffic safety control institutions is not to draw conclusions, but to use more scientific methods to find security vulnerabilities, rationally allocate institution resources, and maximize the safety level of air traffic control institutions. Safety performance is generally good, but there are many points that can be improved. We analyze from the following aspects.

Analyze the projects with high importance but poor performance and put forward suggestions for improvement.

(1) C_{15}. The quality of training has a great impact on safety, but the present quality is poor. Through the understanding of experts and front-line employees, due to the heavy safety pressure in the air traffic control industry, leaders at all levels put pressure on safety issues. Whenever an unsafe incident occurs, training and learning of “rectification style” tends to occur, which can only solve the current problems, but cannot provide an effective mechanism for long-term problem solving. At the same time, due to the rapid development of the air

traffic safety control industry, the shortage of front-line staff, and the implementation of shift system for front-line staff, there is a certain degree of resistance to learning and training during the break time, and the staffs' enthusiasm for learning and training is not high. In order to improve the quality of training, it is necessary to consider the following aspects: a). Invest more resources and invite more high-level professional personnel such as senior instructors of the Civil Aviation Administration of China and safety management experts to conduct high-quality safety training for employees. b). Appropriate economic subsidies will be given to employees who use their rest time to participate in training, so as to enhance the enthusiasm of employees. c). Standardize and institutionalize all kinds of training. At present, most of the training of these institutions are basically at the stage of completing training tasks in accordance with the requirements of the superiors. There is less research on the improvement of training quality and efficiency, and more attention needs to be paid to the standardization of training. d). Strengthen the assessment of training results and effects. At present, the assessment standards of various training effects of air traffic safety control institutions are unclear, and the problem of lax requirements is more prominent. Reasonable evaluation standards for various training needs should be formulated, so that the trainees are aware of the goals that the training needs to achieve and their own problems and gaps, and the training effects can be truly implemented.

(2) C_{43}. Communication between superiors and subordinates has a greater impact on security, but the quality is poor. According to the situation learned by the front line and feedback from experts, there are currently two problems in communication between superiors and subordinates: a). The working hours of superiors and subordinates are not uniform. At present, leaders work during administrative shifts, while front-line staffs implement a shift system. Working hours are inconsistent with the leaders' time. There are few opportunities to meet each other and communication is limited. b). The communication channels are limited. Taking the current front-line control department as an example, there are probably more than 60 controllers in an operating department. In the face of so many employees, it is difficult for department leaders to have enough time and energy to understand everyone's ideas, and there is no fixed channel to serve as a bridge for everyone to communicate. In order to improve the quality of communication between superiors and subordinates, the following aspects can be considered: First, leaders should go deeper into the front-line, contact more with front-line employees, and join the shift team to create more opportunities for two-way communication with employees. Secondly, in addition to face-to-face communication, more use of networked means, through Dingding, WeChat and other channels, to learn more about the needs, problems, difficulties and suggestions of employees at work, and to give positive feedback on these issues. Only by maintaining efficient communication between superiors and subordinates can the problems and suggestions be transmitted and resolved in a timely manner, and the safety threshold can be advanced to improve the safety level of the entire air traffic safety control institution.

(3) C_{16}. Learning ability has a greater impact on safety, but the quality is not high enough. At present, the air traffic safety control industry is constantly introducing new monitoring methods and control methods. The employees of the air traffic safety control system not only need to continuously learn new knowledge and technology, but also put forward suggestions on how to improve operational efficiency. Hence, the requirements for the learning ability of employees are higher. However, the current entry requirements for air traffic safety control system employees, especially front-line controllers, have high academic and professional requirements, but the requirements on the actual learning ability and work ability are weak. Therefore, improving the learning ability of employees can start from the following aspects: First, the human resources department should add more investigations on learning ability when recruiting new employees, so that after entry, they can better adapt to the current environment of the air traffic safety control system that emphasizes learning. Secondly, relevant experts should be invited to conduct training on the theme of improving learning ability for employees who have already joined the institution, so as to theoretically improve everyone's cognition and ability of learning. Finally, focus on the assessment of results in daily learning and training, link the assessment results with employee performance management, and increase the enthusiasm of employees for active learning.

Suggestions for the most important projects but not performing well enough.

C_{13}. Safety awareness is essential to air traffic safety control, but the performance is not good enough. The reasons are as follows. a). In actual daily work and training, safety awareness is not taken as the subject of study and inspection, which results in employees focusing more on skills and not paying enough attention to safety awareness. b). The employees have less professional knowledge about safety and safety management, and the theoretical level is not enough. The improvement of personal safety awareness is still at the operational level. c). The definition of safety awareness is rather vague, and the regulatory institution lacks specific and scientific definitions and indicators for investigating safety awareness. For the above problems, we can consider the following aspects to solve: First, relevant experts should be combined with the actual situation of the institution to determine the definition and inspection indicators of safety awareness; secondly, safety awareness training and assessment subjects should be added to the daily training and assessment, so that employees can increase their awareness and attention; finally, establish personal safety operation records, and check the individual's implementation of various assessment indicators through daily records. Each staff should strive to create an atmosphere that actively promotes safety awareness to steadily improve air traffic safety control.

Suggestions for improving some particularly important and relatively good indicators.

(1) C_{31}. The flow of aircraft in the air. Because the controller's energy is limited, coupled with various airspace restrictions in the air, the existence of severe weather will have a direct impact on aviation safety. At present, the flow of aircraft in the air is mainly affected by the following aspects: a). Flight schedule. Due to the rapid economic development, the total number of flights has increased steadily every year since the Reform and Opening Up of China. There are many "Summer Transport" and "Spring Festival Transport" flights per year on an annual basis, while the rest of the period is relatively small; on a daily basis, there are more flights during the day and fewer flights during the night. These characteristics lead to a person's state that may not match the traffic. b). Airspace restrictions. As the current domestic airspace is under the unified management of the China's Liberation Army Air Force, the airspace used by civil aviation is only within the airspace of the airport and the air route. If the Air Force has training and transition tasks that need to occupy airspace resources, the airspace will become very crowded. At this time, air traffic will need to be less than usual to ensure safe operation. c). Weather conditions. When severe weather occurs in the air, on the one hand, the severe weather occupies the airspace, which will reduce the capacity of the airspace. On the other hand, increasing the frequency of land-to-air calls increases the difficulty of conflict and deployment in the air, making the capacity of aircraft smaller. Therefore, reasonable control of the flow of aircraft in the air is very important for air traffic safety. Reasonable flow management can achieve the purpose of matching human and air flow. Specifically, the following aspects can be considered to improve the present situations: a). Use active and effective means to predict flow. In order to control the air flow within a reasonable range, it is necessary to make a reasonable prediction of the flow to minimize the frequency of the large flow exceeding the controller load. The traffic forecast can be obtained by statistics for a certain period of time. After the flight season changes every year, each control room or sector can count the hourly traffic in the area, and summarize the peak period as an open sector to avoid large traffic that exceeds the personnel load. At the micro level, it is necessary to combine the currently ATOM system, secondary radar system and other means to cover the current day, or one or two hours later from the current time to generate a more accurate forecast of air traffic. b). Take active measures to deal with the large air traffic. The current method of dealing with and controlling the flow is mainly to issue the flow limit in time. If the head staff of the front-line operation team predicts that there may be a flow exceeding the controller load, the flow control should be issued in a timely manner to keep the flow within a reasonable range. c). Consider the influence of airspace, weather and other conditions on the flow. When the airspace is limited or there is dangerous weather, the capacity of the airspace will become lower, the control deployment will become complicated, the communication channel will be crowded, and the maximum flow rate that the controller can accept will also decrease. In order to reduce the threat of excessive traffic to the safety of the air traffic control system, it is necessary to continue to improve in these aspects.

(2) C_{12}. Psychological quality. In the air traffic control system, the controller is directly related to the safety of air traffic control. The correct instructions of the controller can ensure the safe and efficient operation of the aircraft. But the controller's wrong instructions can also put the aircraft in danger. This situation is particularly important when there are special circumstances in the air or when the controller issues wrong instructions to resolve the conflict. In real work, on the one hand, the pressure faced by the controller is difficult to effectively relieve, on the other hand, when faced with the emergence of special circumstances in the air, the controller is often affected by the instinctive tension, which makes it difficult to perform the professional level. In order to solve these problems, it is necessary to improve the controller's psychological quality and ultimately improve the controller's ability to resolve stress and deal with special situations. First of all, air traffic safety

control institutions need to focus on the cultivation and guidance of the psychological quality of employees, especially controllers, and devote more resources to help employees learn professional psychological knowledge and improve their ability to withstand stress. Secondly, because special situations are very rare in daily work, training is often carried out by means of simulator training, but the setting of simulators often only pays attention to whether the disposal procedures are complete, and neglects to create a more realistic special situation environment as much as possible. Controllers have a deeper psychological experience, which improves their psychological endurance in the face of unexpected special situations, and enhances the safety of the air traffic control system.

(3) C_{36}. Bad air weather conditions. The severe air weather has a huge impact on flight safety. Today, with such advanced aviation technology, there are still many accidents caused by severe air weather. In the face of all kinds of dangerous weather, the air traffic control institution meteorological department will make forecasts, and the control departments have formulated strict handling procedures, but there are still many problems in actual work. First of all, the weather department is too macro for the air route weather forecast, which is of little significance to the controller or the pilot. The controller's judgment on the weather is mostly derived from the pilot's report based on the airborne radar equipment. There is a delay for the control department's disposal. Secondly, there is little consideration of human factors for various disposal procedures, especially because procedures such as weather return and landing alternates involve many institutions and factors. As a result, the rules and procedures are complete but difficult to implement. Therefore, in order to improve the safety of the air traffic control system in response to severe weather in the air, more accurate weather detection and forecasting methods should be adopted first, especially for airway weather, so that controllers and pilots can predict the weather in advance. Secondly, for the control process involving multiple institutions, it is necessary to communicate effectively with other institutions in advance to avoid compromising the implementation of air traffic safety control.

Indicators that are not important but have poor performance also need to be improved.

(1) C_{34}. The physical environment of the air traffic safety control studio. Because other controllers except those in the tower need to work for a long time at the radar screen, the control hall is often dark. Due to security considerations, the doors of the hall are also usually closed. Over time, due to poor air quality, chest tightness and hypoxia may occur, which may affect the working conditions of the personnel in the control hall. Therefore, there should be an air purifier in the control hall to monitor and purify the air, and place more green plants to make people relax. The brightness of the lighting can be adjusted to create a suitable lighting atmosphere, allowing the control hall staff to concentrate on their work.

(2) C_{19}. Ability to handle interpersonal conflicts. Most parts of air traffic control work have standard operating procedures, which can be completed independently by one person. However, there are also many places that require cooperation between people, and it is inevitable that people will face conflicts between people. For example, air command is implemented with a dual-post system, and the controller and assistant cooperate with each other. Conflicts may arise when opinions are inconsistent; when airspace resources are tight, pilots will question the allocation of airspace resources, and conflicts will also arise; when it is difficult to coordinate with relevant institutions on some issues, conflicts will inevitably occur. At the same time, due to the nature of the work of the air traffic safety control system, front-line personnel on duty basically do not have any contact with the outside world. Coupled with the factor of the shift system, even personnel in the same department may hardly see them. Therefore, it is difficult for employees to effectively exercise and improve their ability to deal with interpersonal conflicts at work. In order to improve the staff's ability to deal with interpersonal conflicts, relevant experts can be invited to give lectures to the staff, so that the staff can examine the conflicts they face from a more professional perspective and guide the interpersonal conflicts in a favorable direction.

(3) C_{11}. Physical fitness. As an air traffic safety controller, on the one hand, he or she faces the stress and pressure of work, on the other hand, he or she often needs to stay up all night, which has a lot of harm to the body. Maintaining good physical fitness will make a person energetic, conducive to maintaining concentration for a long time, and indirectly affect the quality of air command. In order to improve the physical fitness of employees, the institution can provide various fitness facilities and venues for employees to use. On the other

hand, the institution can organize various sports associations and organize interested employees to participate in physical exercise activities, so as to strengthen the physical fitness of employees.

(4) C_{44}. The rationality of the organizational structure. The current air traffic safety control system belongs to public institutions, but it implements corporate management. The organizational structure belongs to the traditional public institution bureau-department-sections-teams and supplemented by various groups such as security groups and training groups. Hence, it is important to maintain a reasonable organizational structure.

6 Conclusions and future research

6.1 Conclusions

Based on relevant research on air traffic safety evaluation, combined with interviews with air traffic control experts and visits to front-line employees, this paper studies the composition of air traffic safety indicators, and finally adopts hesitant and fuzzy linguistic evaluation method, established the maximum consistency weight optimization model to determine the expert weights, adopted the weighted evaluation operator to determine the indicators weights, applied the TOPSIS information aggregation method to evaluate the safety situation of the air traffic control bureau in a certain area, and reached the following conclusions:

Through research and interviews, the first-level indicators of air traffic control safety evaluation are determined as: human factors, equipment factors, environmental factors, and organizational management factors. Under the human factor, there are 9 secondary indicators of physical fitness, psychological quality, safety awareness, professional quality, training quality, learning ability, age structure, cooperation between individuals and organizations, and ability to handle interpersonal conflicts. The equipment factors include 7 secondary indicators of the degree of equipment depreciation, the reliability of the equipment, the advanced degree of the equipment, the adaptability of the software system, the integrity of the technical data, the repair capability of equipment failure, and the daily use of emergency backup equipment. Environmental factors include 7 secondary indicators of the flow of aircraft in the air, the complexity of the sector, the rationality of route planning, the physical environment of the control studio, the sound and reasonable aviation regulations, severe air weather, and the opening of the airspace of the Air Force. Organizational management factors include 11 secondary indicators of standard work processes, the ability of leaders, communication between superiors and subordinates, the rationality of organizational structure, personnel's recognition of organizational goals, coordination between departments, the degree of implementation of rules and regulations, and the effective transmission of various information, safety culture, safety education and training investment, and leaders' emphasis on safety.

Seven civil aviation management experts were invited to evaluate the relevant indicators of the air traffic safety control of a certain area's air traffic control bureau. The result found that the overall score of the air traffic control bureau of the region was 0.731 (1 is a perfect score), which is between good and very good. The more important indicators of poor performance include: C_{15} training quality, C_{43} communication between upper and lower levels, and C_{16} learning ability. The most important but not good enough indicators include: C_{13} safety awareness. Some particularly important but relatively good indicators include: C_{31} aircraft flow, C_{12} psychological quality, and C_{36} severe airborne weather. The indicators of low importance but poor performance include: C_{34} regulating the working environment, C_{19} interpersonal conflict handling ability, C_{11} physical fitness, and C_{44} rationality of organizational structure. This paper puts forward practical suggestions for the above indicators.

6.2 Future research

This paper mainly uses hesitant and fuzzy linguistic methods to study the safety assessment of air traffic control. However, it is limited by factors such as personal ability, literature and research time, and there are some points that can be improved, such as:

(1) Air traffic control safety is a part of civil aviation safety, and air traffic control unsafe incidents may also be caused by the errors of other departments or airports, airlines, and pilots. However, due to the lack of

relevant research materials and resources, the air traffic control unsafe incidents caused by other departments or individuals have not been evaluated.

(2) As the air traffic control system is still undergoing rapid development and transformation along with the development of civil aviation, although relevant information has been studied and the opinions of relevant experts have been heard in the front line of air traffic control in the selection of evaluation indicators, it may still change as the technology and management system change. Hence, the selection of air traffic safety evaluation indicators should be dynamic.

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Appendix

Table 2: Experts evaluations on the importance of indicators (Expert 1, 2 and 3)

Indicator	Expert 1			Expert 2			Expert 3		
C_{11}	0.33	0.5	0.67	0.5	0.59	0.67	0.5	0.5	0.5
C_{12}	0.83	0.92	1	1	1	1	0.67	0.75	0.83
C_{13}	0.83	0.92	1	0.67	0.75	0.83	1	1	1
C_{14}	0.67	0.75	0.83	0.83	0.83	0.83	0.67	0.83	1
C_{15}	0.67	0.75	0.83	0.5	0.67	0.83	0.67	0.67	0.67
C_{16}	0.5	0.67	0.83	0.83	0.83	0.83	0.67	0.75	0.83
C_{17}	0	0.085	0.17	0.17	0.33	0.5	0.67	0.67	0.67
C_{18}	0.33	0.5	0.67	0.67	0.67	0.67	0.5	0.5	0.5
C_{19}	0.33	0.5	0.67	0.5	0.67	0.83	0.33	0.5	0.67
C_{21}	0.17	0.25	0.33	0.33	0.33	0.33	0.67	0.67	0.67
C_{22}	1	1	1	0.67	0.83	1	0.83	0.92	1
C_{23}	0.5	0.59	0.67	0.67	0.67	0.67	0.33	0.5	0.67
C_{24}	0.5	0.59	0.67	0.67	0.75	0.83	0.67	0.67	0.67
C_{25}	0.67	0.75	0.83	0.5	0.59	0.67	0.5	0.5	0.5
C_{26}	0.17	0.25	0.33	0.17	0.33	0.5	0.67	0.67	0.67
C_{27}	0.5	0.67	0.83	0.83	0.83	0.83	0.83	0.92	1
C_{31}	0.83	0.92	1	0.67	0.83	1	0.83	0.83	0.83
C_{32}	0.83	0.92	1	0.5	0.59	0.67	0.67	0.67	0.67
C_{33}	0.5	0.59	0.67	0.5	0.67	0.83	0.67	0.67	0.67
C_{34}	0.33	0.5	0.67	0.67	0.67	0.67	0.5	0.59	0.67
C_{35}	1	1	1	1	1	1	0.83	0.92	1
C_{36}	0.67	0.75	0.83	0.83	0.83	0.83	0.83	0.92	1
C_{37}	0.67	0.75	0.83	0.67	0.67	0.67	0.83	0.83	0.83
C_{41}	0.5	0.59	0.67	0.67	0.75	0.83	0.83	0.83	0.83
C_{42}	0.5	0.59	0.67	0.17	0.33	0.5	0.5	0.59	0.67
C_{43}	0.67	0.75	0.83	0.5	0.67	0.83	0.33	0.5	0.67
C_{44}	0.5	0.59	0.67	0.33	0.42	0.5	0.5	0.5	0.5
C_{45}	0.33	0.5	0.67	0.5	0.59	0.67	0.5	0.5	0.5
C_{46}	0.5	0.67	0.83	0.33	0.42	0.5	0.5	0.5	0.5
C_{47}	0.67	0.67	0.67	0.5	0.67	0.83	0.83	0.92	1
C_{48}	0.67	0.75	0.83	0.67	0.75	0.83	0.5	0.5	0.5
C_{49}	0.83	0.83	0.83	0.5	0.67	0.83	1	1	1
C_{410}	0.5	0.67	0.83	0.83	0.83	0.83	0.5	0.59	0.67
C_{411}	1	1	1	0.83	0.83	0.83	1	1	1
C_{412}	0.67	0.75	0.83	0.5	0.5	0.5	0.83	0.83	0.83
C_{413}	0.5	0.67	0.83	0.67	0.67	0.67	0.83	0.83	0.83

Table 3: Experts evaluations on the importance of indicators (Expert 4, 5, 6 and 7)

Indicator	Expert 4			Expert 5			Expert 6			Expert 7		
C_{11}	0.67	0.67	0.67	0.5	0.5	0.5	0.33	0.5	0.67	0.5	0.5	0.5
C_{12}	0.83	0.83	0.83	1	1	1	0.83	0.92	1	0.67	0.83	1
C_{13}	0.83	0.92	1	0.83	0.92	1	1	1	1	1	1	1
C_{14}	0.67	0.67	0.67	1	1	1	0.67	0.75	0.83	0.83	0.83	0.83
C_{15}	0.83	0.92	1	0.83	0.83	0.83	0.67	0.67	0.67	0.67	0.67	0.67
C_{16}	0.67	0.67	0.67	0.83	0.83	0.83	0.33	0.5	0.67	1	1	1
C_{17}	0.5	0.5	0.5	0.67	0.67	0.67	0	0.17	0.33	0.5	0.5	0.5
C_{18}	0.33	0.5	0.67	0.67	0.67	0.67	0.5	0.5	0.5	0.5	0.5	0.5
C_{19}	0.33	0.33	0.33	0.17	0.33	0.5	0.5	0.5	0.5	0.5	0.5	0.5
C_{21}	0.33	0.33	0.33	0.17	0.17	0.17	0	0	0	0.33	0.33	0.33
C_{22}	1	1	1	1	1	1	0.83	0.83	0.83	1	1	1
C_{23}	0.33	0.5	0.67	0.83	0.83	0.83	0.33	0.5	0.67	0.5	0.5	0.5
C_{24}	0.67	0.67	0.67	0.5	0.67	0.83	0.83	0.83	0.83	0.5	0.5	0.5
C_{25}	0.67	0.67	0.67	0.33	0.33	0.33	0.5	0.5	0.5	0.67	0.67	0.67
C_{26}	0.67	0.67	0.67	0.17	0.17	0.17	0.5	0.5	0.5	0.17	0.17	0.17
C_{27}	0.5	0.5	0.5	0.5	0.5	0.5	0.67	0.67	0.67	0.67	0.67	0.67
C_{31}	1	1	1	0.83	0.92	1	0.67	0.75	0.83	0.83	0.83	0.83
C_{32}	0.83	0.92	1	0.83	0.83	0.83	1	1	1	0.83	0.83	0.83
C_{33}	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.5	0.5	0.5
C_{34}	0.33	0.5	0.67	0.33	0.42	0.5	0.17	0.17	0.17	0.33	0.33	0.33
C_{35}	1	1	1	1	1	1	0.67	0.75	0.83	1	1	1
C_{36}	0.67	0.67	0.67	1	1	1	1	1	1	0.67	0.67	0.67
C_{37}	0.83	0.83	0.83	0.5	0.67	0.83	0.67	0.67	0.67	1	1	1
C_{41}	1	1	1	1	1	1	1	1	1	0.83	0.83	0.83
C_{42}	0.83	0.92	1	0.83	0.83	0.83	0.83	0.83	0.83	1	1	1
C_{43}	0.83	0.83	0.83	1	1	1	0.67	0.75	0.83	0.83	0.83	0.83
C_{44}	0.67	0.67	0.67	0.83	0.83	0.83	0.67	0.67	0.67	0.67	0.67	0.67
C_{45}	0.33	0.5	0.67	0.5	0.5	0.5	0.83	0.83	0.83	0.5	0.5	0.5
C_{46}	0.5	0.5	0.5	0.5	0.67	0.83	0.83	0.83	0.83	0.67	0.67	0.67
C_{47}	0.83	0.92	1	1	1	1	0.83	0.83	0.83	0.83	0.83	0.83
C_{48}	0.5	0.5	0.5	0.67	0.67	0.67	0.67	0.75	0.83	0.83	0.83	0.83
C_{49}	0.83	0.92	1	1	1	1	1	1	1	0.83	0.83	0.83
C_{410}	0.83	0.92	1	0.5	0.5	0.5	0.67	0.75	0.83	0.67	0.67	0.67
C_{411}	0.83	0.92	1	1	1	1	0.83	0.83	0.83	1	1	1
C_{412}	0.83	0.83	0.83	0.5	0.67	0.83	0.83	0.83	0.83	0.83	0.83	0.83
C_{413}	0.83	0.92	1	0.5	0.67	0.83	0.83	0.83	0.83	0.67	0.67	0.67