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Core Competency Quantitative Evaluation of Air Traffic Controller in Multi-Post Mode

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Abstract: In order to quantify the core competency of air traffic controllers (ATCO) in multi-post mode, and analyze the ATCO competency-post fit (CPF) degree, this paper proposes the AFE-TOPSIS evaluation method based on the analytic hierarchy process (AHP), factor analysis (FA), and entropy weight method (EWM). Through the analysis of job tasks, it preliminarily develops an evaluation index library of ATCO core competency. Then, it constructs an improved adaptive multi-dimension core competency model divided into four types of post modes. It proposes a method for determining the combined weight of core competency indexes, where the weights are determined subjectively through AHP, combined with the objective method of FA and EWM. Furthermore, it constructs a comprehensive evaluation model based on AFE-TOPSIS and analyzes the CPF degree by calculating the relative closeness degree of each evaluation index. The empirical analysis results show that the four types of core competency models in General, TWR, APP, and ACC post mode include seven dimensions, such as situation awareness, and workload management, which are also graded into the pyramid hierarchical structure of basic, advanced, and high-level. The calculation of the ATCO CPF degree based on the proposed AFE-TOPSIS method can scientifically assist in the fit of ATCO and multi-post mode.

Keywords: air transportation; air traffic controller; core competency; combination weight; competency-post fit; the technique for order preference by similarity to an ideal solution (TOPSIS)

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1. Introduction

With the rapid development of air transportation, the safety of air traffic operation has been put forward very high requirements. Air traffic management (ATM) has the characteristics of high strength, high risk, and high load. The ability level of air traffic controllers (ATCO) is one of the most essential and complex factors [1]. How to make a practical qualitative and quantitative evaluation of the ATCOs' ability and quality, accurately find out the unfavorable factors affecting the safety of air traffic operation, and make effective adjustments in time to avoid the risk of ATM operation, and rationally allocate team resources are the fundamental theoretical and practical problems that need to be studied and analyzed in the field of aviation human factors [2]. Establishing a scientific and reasonable quantitative evaluation method for the ability and quality of ATCOs, grasping the performance and development trend of their working ability and working status, and adjusting the allocation of team resources in time will help the dynamic improvement of the ability and quality of controllers. It is significant to improve the safety efficiency of control operation, expand air traffic flow, and ensure flight safety. In this paper, the main objective of the scientific study is to achieve multiple classifications and construct an assessment model of ATCO ability, then quantify the ATCO ability in multi-post mode, and finally analyze the fit degree of ATCO between ability and post quantitatively.

Based on this, domestic and foreign scholars have gradually deepened the research on the evaluation of ATCOs' ability, extending from the concept of "skill" to the level of "competency" [3], and successively researched the ATCO competency evaluation model, combined with relevant business scenarios, taking the qualitative and quantitative analysis of ATCOs' ability, professional level, and knowledge application [4]. In 2005, by referring to the internationally accepted research methods of competency framework for professional management and technical personnel [5,6], Oprins Esther et al., developed an initial ATCO competency framework [7] for capacity assessment and job training [8]. The International Civil Aviation Organization (ICAO), the Federal Aviation Administration (FAA), and the European Organization for the Safety of Air Navigation (EUROCONTROL) have also researched the competency characteristics of ATCOs and applied them to training and evaluation, etc. [9]. In 2016, based on the research of Oprins Esther et al., ICAO updated the "Training Manual" (ICAO DOC 9868) [10], through extensive questionnaire survey and analysis, proposed a relatively complete ATCO competency framework, and initially introduced the competency characteristics and performance behavior indexes. Based on the competency framework, Tímea Vas conducted research and application of training for military ATCOs [11]. At the same time, the FAA issued a "Control Job Training Teaching/Evaluation Manual" [12], described the competency of controllers, and proposed 23 secondary indexes from 6 dimensions. Vuckovic et al. [13] proposed 15 secondary indexes from 3 dimensions of individual, organization, and psychology around the ability assessment of controllers. Although a relatively mature ATCO competency framework has been formed abroad, it does not directly apply to China's national conditions and ATM status quo. Because the framework does not address the specific definition of duties, sharing of tasks, ratings, and proficiency levels existing in the organization, which should be adapted to the local context of the organization and the professional experience of ATCOs [10]. It is necessary to design a special adaptive model according to the specific situation within the organization, otherwise, the application effect will not be ideal. At the same time, there are some differences in the operating environment, regulations and standards, facilities and equipment, management concepts, and other aspects between Chinese and foreign air traffic control units, some indexes do not match or apply to China's actual job requirements, and related indexes cannot obtain data support and cannot be quantified. Relevant models must be adapted and localized based on the organizational context.

In 2007, Nuo Xu [14] started research on the competency theory of domestic controllers and put forward 20 competency characteristics of ATCOs through survey data and statistical analysis. Ruishan Sun [15] and Jingqiang Li [16] constructed the explanatory structure model of the ATCO competency, studied the internal structure and connection of the competency model and the influence of its elements on the system, and determined the weight distribution of the indexes according to the centrality and importance ranking [17]. Saiping Liu [18] used Analytic Hierarchy Process (AHP) to establish the competency model of trainee ATCOs; Li Jianqiao [19] constructed the competency model of controller leader and determined the weight of each dimension subjectively according to experience. Longfang Mou [20] used the Entropy method to assign the ATCOs' quality factors, which is more objective and fair than the traditional empirical value method and easy to operate. Xiaofeng Bian [21] conducted a questionnaire survey on the content of the competency framework, used the expert survey method to determine the weight of the 10 elements in groups, and obtained the ranking of competency elements to guide the training of controllers. Some domestic scholars have put forward the framework of the ATCOs' ability and quality or the core competency at the theoretical level. However, based on the competency theory, the system construction of the ATCOs' competency evaluation model in line with the actual ATM in China is still lacking, which is one of the urgent problems that should be solved in the current ATM.

From the perspective of qualitative analysis, the above research mainly puts forward the general competency framework, competency feature element library, and evaluation index model. There needs to be more research on the competency of controllers in specific

jobs and situational conditions, and the descriptive, quantifiable, measurable degree of the ATCO competency evaluation index needs to be higher. With the increasing complexity of the air traffic control production and operation environment, the multi-post mode shows obvious diversity of job characteristics; that is, there are differences in the scope of responsibilities, knowledge level, work experience, work intensity, environmental conditions, job requirements and other aspects between the general post and the professional posts such as tower, approach, and area. The multi-post mode classification and grading competency model for fine management must be studied. At the same time, the competency evaluation model's scientificity, universality, and practicability must also be further verified and optimized. Some scholars have studied the weight of the evaluation index based on the subjective or objective method, and the scientific and reasonable weighting method of the evaluation index system needs further study. At the same time, the application of competency-based evaluation needs to be improved. Therefore, the research questions of this paper mainly include classifying and establishing a multi-dimensional core competency index system, scientifically determining the weight of competency indexes, and finely measuring the competency-post fit degree of ATCOs. The exploration of relevant theories and methods has been carried out around these issues. This paper carries out the task analysis of the multi-post mode [22,23] and studies the core competency most related to professional competency. Focusing on the current ATM production and operation practice, based on the ICAO competency framework, this paper proposes an improved adaptive multi-dimensional core competency model for the multi-post mode's diversity and convergence characteristics. Moreover, it establishes a general classification and grading model for various professional posts, which can assist in enhancing the universality and practicability of the model and apply it to the decision-making of post-adaptation.

The core competency quantitative evaluation mainly focuses on model construction, index weighting, and model application. This paper carries out quantitative evaluation and verification according to the technical route of "analysis of core competency characteristic elements, construction of core competency model of multi-post mode, determination of dimension index weight, competency measurement of benchmark population, and evaluation of competency-post fit degree". It shows the research framework in Figure 1, and the specific research content includes the following three parts.

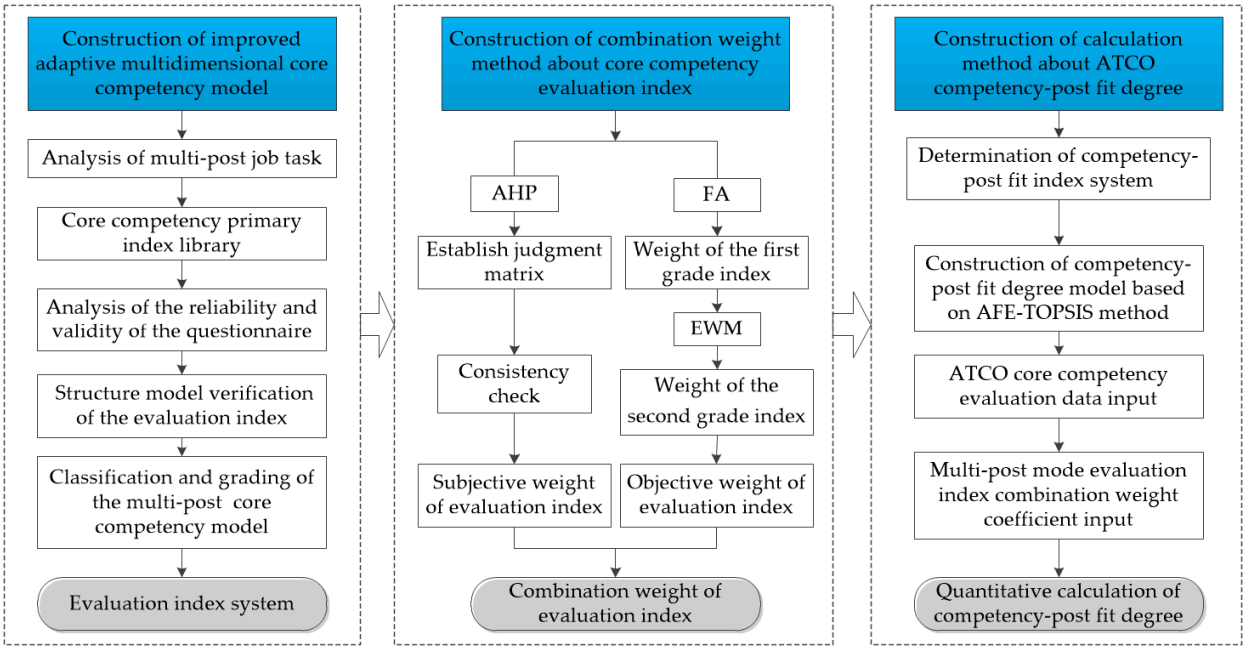

Figure 1. Research framework.

(1) The first part is constructing an improved adaptive multi-dimensional core competency model. Based on literature analysis, expert interview, and work analysis, this paper summarizes ATCOs' core competency index library according to the characteristics, operation environment, and operation rules of posts. It carries out the ATCOs' core competency questionnaire and data analysis to analyze the effective indexes by verifying the structural model. Then it establishes the content and structure of localized multi-dimensional core competency evaluation index according to the local organizational context and constructs the multi-dimensional core competency model of general and professional posts by classification.
(2) The second part proposes a combination weighting method of the ATCO core competency index. Aiming to combine subjective and objective weighting methods based on AHP, FA, and EWM, it proposes the AHP-FA-EWM (AFE) method to determine the weight coefficient of each dimension and secondary indexes of the core competency model.
(3) The third part proposes a calculation method of competency-post fit degree based on the AFE weighting method and the distance method of superior and inferior solution (AFE-TOPSIS). According to combined index weights, it puts ATCOs' core competency evaluation results into the four types of models constructed above and then calculates the fit degree between the core competency index value of each controller and the post requirements based on AFE-TOPSIS.

This paper opens up a new perspective of core competency classification research, expands the application scope of core competency theory in the field of ATM, and puts forward an ATCO core competency evaluation and analysis method based on multi-post mode, which can provide a new auxiliary decision-making basis for ATCO ability evaluation, competency-post fit and fine management of human resources.

2. Construction of Improved Adaptive Multi-Dimensional Core Competency Model

2.1. The Concept of ATCO Core Competency

Competency originated from the article "Testing for competency rather than for intelligence" published by American psychologist David C. McClelland in 1973. McClelland laid out some fundamental theories and techniques of competency research [3] and proposed the classic competency "iceberg model", which mainly includes knowledge, skills, and attitudes, referred to as the "KSA" model [8]. After decades of development, the concept definition of competency theory has been continuously updated from its introduction to its application in the field of air traffic control. ATCO competency refers to the individual characteristics that can be objectively measured and the resulting predictable and performance-oriented behavioral characteristics of the excellent performers in a specific job position, organizational environment, and cultural atmosphere. It is an aspect of personnel performance and can be used to predict successful performance in the work reliably. The core competency of controllers describes how to effectively carry out work and a set of related behavioral abilities based on job requirements for skilled skill performance.

2.2. Construction of Improved Adaptive ATCO Core Competency Index System

The ATCO competency framework proposed by ICAO, from knowledge, skills, and attitudes, puts forward ten competency dimensions, such as situational awareness, traffic and capacity management, separation, and conflict resolution, and lists relevant performance behavior measurement indexes. The content is relatively comprehensive, covering the technical and non-technical capabilities required by the general posts, and is suitable for guiding training and evaluation [10]. However, it does not make adaptive analysis and classification of specific jobs and specific situational conditions. At the same time, it needs the weight coefficient reflecting the importance of dimension indexes, which could be more convenient for the classification and classification application in the actual core competency model. Therefore, based on the ATCO competency framework, combined with the localized operating environment, operating rules, job characteristics, etc., this paper

analyzes, extracts, and supplements the dimensions indexes in the competency framework according to the job requirements, constructs an improved adaptive ATCO core competency index system, and it scientifically empowers the dimension indexes.

Based on summarizing a large number of domestic and foreign literature, combined with job task analysis, referring to the ATM task model [24], according to the controller competency analysis process shown in Figure 2, this paper analyzes the requirements of various control jobs and sorts out the knowledge, skills, attitudes and other factors required by controllers. Through mathematical statistics technology, this paper extracts the key characteristics that affect the ATCO competency in each control seat, such as business ability, work experience, personal characteristics, etc., combined with expert interview opinions, summarizes the quality dictionary of ATCO core competency, and preliminarily formulates the evaluation dimension and secondary evaluation index database of ATCO core competency. Based on the field investigation of an air traffic control unit, the Delphi expert evaluation method is used to consult the control expert team composed of control instructors, senior controllers, business leaders, business managers, and experts from scientific research institutes. The evaluation dimension and the content of the secondary indexes are further improved, and it finally constructs the localized and adaptive primary indexes of the ATCO core competency, as shown in Table 1. The secondary indexes' observable behavior description and measurable behavior data are studied and discussed for the quantitative evaluation of ATCO competency. According to the primary indexes in Table 1, this paper designs and compiles a questionnaire on the adapted ATCO core competency index system. Through the empirical analysis of the questionnaire data, it extracts the localization and adaptability indexes, further explores the index system, and verifies the structural model, and finally constructs the adapted multi-dimensional core competency model.

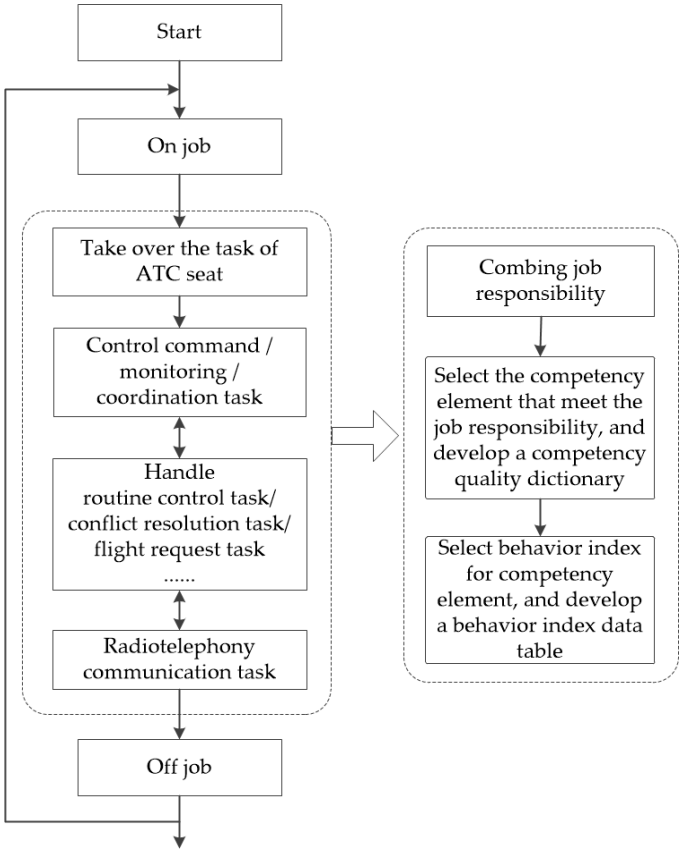

Figure 2. Process analysis of ATCO competency based on the job task model.

Table 1. Primary indexes of ATCO core competency.

Competency Index Code and Name		Description of Observable Behavior
x_1	Monitor the operational situation	Monitors air traffic, meteorological conditions, the status of the ATC systems and equipment, and operational circumstances
x_2	Scan for specific or new information	Acquires information from available systems and any other means available
x_3	Comprehend the operational situation	Integrates information acquired from monitoring and scanning and analyses the actual situation
x_4	Anticipate the future situation	Interprets the situation based on the analysis and predicts the future operational situation
x_5	Recognize indications of reduced situational awareness	Identifies potentially hazardous situations, verifies the accuracy of the information, and predicts operational situations
x_6	Keep aircraft identification	Keep radar identification of aircraft and provides aircraft location information
x_7	Manage the traffic situation	Uses prescribed procedures and a variety of techniques to manage traffic effectively
x_8	Achieve optimal operational performance	Increases safety margins, ensure appropriate sector capacity, maintains focus, reacts appropriately to situations
x_9	Disseminate flight information	Issues clearances and instructions to the flight crews, issues appropriate clearances and instructions promptly, uses available tools to reduce delays and optimize flight profiles, provides flight information and status of facilities promptly
x_{10}	Inform essential traffic and weather information	Informs essential traffic and weather information, issues hazard and safety alerts, traffic proximity information, and weather information to the flight crews when necessary
x_{11}	Detect potential traffic conflicts	Identifies traffic conflicts
x_{12}	Resolve traffic conflicts	Selects the most appropriate separation method, applies appropriate air traffic separation and spacing
x_{13}	Maintain separation between aircraft	Applies appropriate air traffic separation and spacing, issues clearances and instructions that ensure separation is maintained
x_{14}	Maintain separation of aircraft from terrain and known obstacles	Issues clearance and instructions that resolve traffic conflicts and adjusts control actions to maintain separation
x_{15}	Command ability under normal circumstances	Under normal circumstances, the busy degree of the command sector, the hourly capacity of the sector
x_{16}	Command capability in complex situations	Command level in the case of large flow, complex weather
x_{17}	Air traffic control experience	Experience in each position, seat, and major security
x_{18}	Select appropriate mode of communication	Selects a communication mode that takes into account the requirements of the situation
x_{19}	Demonstrate effective verbal communication	Speaks clearly, accurately, and concisely
x_{20}	Demonstrate effective radiotelephony phraseology	Uses standard radiotelephony phraseology, adjusts speech techniques to suit the situation, demonstrates active listening
x_{21}	Select the appropriate method of coordination	Selects the appropriate coordination method, uses the prescribed coordination procedures
x_{22}	Manage emergency and unusual situations	Recognizes the possibility of an emergency or unusual situation developing, determines the nature of the emergency, prioritizes actions, decides upon the most appropriate type of assistance, follows prescribed procedures, provides assistance and takes action when necessary
x_{23}	Manage degraded modes of ATS operations	Detects degraded situation, assesses the impact of a degraded mode, follows prescribed procedures, creates appropriate solutions
x_{24}	Determine possible solutions	Determines possible solutions to a problem based on existing rules and operating procedures, implements an appropriate solution
x_{25}	Manage risks effectively	Applies an appropriate mitigation strategy, perseveres in working through problems without impacting safety
x_{26}	Adapt to differing workload conditions	Manages tasks effectively in response to workload, manages interruptions and distractions effectively
x_{27}	Request assistance when necessary	Determines if and when support is necessary based on workload, asks for help, or accepts assistance when necessary
x_{28}	Use ATS equipment effectively	Selects appropriate resources to support the efficient achievement of tasks, uses the automated ATS equipment to improve efficiency
x_{29}	Self-evaluate to improve performance	Takes responsibility for own performance, improves performance through self-evaluation
x_{30}	Use feedback to improve performance	Seeks and accepts feedback to improve performance, maintains self-control, changes behavior, and responds as needed
x_{31}	Engage in continuous development activities	Maintains awareness of developments and changes in aviation, participates in learning activities

2.3. Classification and Grading of the Core Competency Model in Multi-Post Mode

In order to realize the adaptability and practicability of the ATCO competency model, based on the specific job and situational condition, as well as the diversity of controllers' job tasks, the core competency model must be further classified and graded. This paper proposes the General post model of ATCO core competency, suitable for all business leaders, managers, controllers, trainees, etc. At the same time, it proposes three professional post models of ATCO core competency, which are respectively suitable for tower control unit (TWR), approach control unit (APP), and area control center (ACC) controllers. The above General, TWR, APP, and ACC post model of ATCO core competency are useful the further refined analysis.

Through the job analysis method in human resource management, this paper researches and establishes the ATCO job analysis model. ATM usually includes air traffic flow management, airspace management, alarm service, flight information service, and air traffic control service. TWR, APP, and ACC are the essential ATM service posts, their job responsibilities and work priorities are different, and the requirements for controllers' competencies are also different. The specific core competency requirements of each post are shown in Table 2.

Table 2. The required core competency of multi-post mode.

Post	Task Characteristics	The Most Significant Core Competency Needs
General	control command, sustainable development, and other comprehensive ability	Competencies are relatively balanced
TWR	good ability to deal with unusual situations	x_{22}, x_{23}
APP	accurate conflict resolution capability	x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}
ACC	Detects potential traffic conflicts and resolves conflicts	x_{11}, x_{12}, x_{13}, x_{14}, x_{24}, x_{25}

(1) Compared to front-line personnel posts, general posts are mainly engaged in management work, teaching and training work related to air traffic management business, including unit leaders, business managers and researchers, teaching staff, training staff, and so on.
(2) The most essential ability that TWR controllers should have is to assist the flight crew in dealing with emergencies and unusual situations in a stable and unhurried manner. The most significant core competency indexes required are x_{22} and x_{23}.
(3) The most important thing for the APP controller is to have accurate conflict allocation ability. Whether it is the accuracy of heading guidance, the rationality of speed adjustment, or the ability to grasp the timing of turning, they must firmly grasp the conflict relief ability. The most significant core competency demand indexes are x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, and x_{16}.
(4) The most crucial ability of ACC controllers is to avoid unsafe incidents caused by human factors, to detect potential flight conflicts as soon as possible or in time, and to deal with them in time. The most significant core competency demand indexes are x_{11}, x_{12}, x_{13}, x_{14}, x_{24}, and x_{25}.

The evaluation index system set of the ATCO core competency constructed in the final study is $A = (x_1, x_2, \ldots, x_m)$, where x_i (i = 1, 2, …, m) indicates the competency evaluation index element, m indicates the total number of evaluation indexes; the core competency dimension set is $F = (F_1, F_2, \ldots, F_n)$, where $F_j(i = 1, 2 \ldots, n)$ represents the secondary index set of the extracted factors, and n represents the total number of factors (dimensions). Therefore, based on analyzing the multi-post mode's specific situational conditions and competency needs, it constructs the evaluation index set of ATCO core competency by classification and graded as General, TWR, APP, and ACC models.

Overall, after the comprehensive training, ATCOs must meet the most significant core competency needs of General, TWR, APP, and ACC posts before they have the basic condi-

tions of core competency for such posts. Only after reaching the qualification standards, psychological quality, and physical quality of the specific post, then ATCOs can work in this post after passing the post examination.

3. The Combination Weighting Method of Core Competency Evaluation Index Based on AHP-FA-EWM

The weighting methods of evaluation indexes usually divide subjective and objective weighting. The subjective weighting methods, including expert evaluation method, AHP, etc., are simple but strongly affected by the human factor; objective weighting methods, including correlation coefficient method, FA, and EWM, are not affected by human factors but mainly depend on data samples. Both methods will have the loss of information. The combination weighting method can minimize the loss of information and make the weighting results as close as possible to the actual situation [25]. Therefore, this paper proposes a combination weighting method of multi-dimensional evaluation index for the ATCO core competency based on the combination of the AHP-FA-EWM (AFE) method.

3.1. Index Weight Determination by AHP Method

The AHP method is mainly used to study the calculation of expert scoring weights. First, it must construct a judgment matrix, and then take a consistency test [26,27]. Based on the dimension and secondary index obtained by exploratory factor analysis (EFA) and confirmatory factor analysis (CFA), this paper calculates the average value of each questionnaire item, in which the more significant the average value, the higher the importance and weight of the index. Then, it constructs the order judgment matrix by dividing the average value, calculates the weight of each index, and obtains the subjective weight vector of the ATCO core competency evaluation index as v_i.

Finally, it carries out the consistency test of the m evaluation indexes. Calculating the index CI for judging the consistency of matrix deviation, as follows:

$$CI = \frac{\lambda_{\max} - m}{m - 1} \tag{1}$$

By finding the consistent average random consistency index RI, calculating the random consistency ratio CR as follows:

$$CR = \frac{CI}{RI} \tag{2}$$

If $CR < 0.1$, the constructed judgment matrix satisfies the consistency test, so the calculated weights are consistent [28].

3.2. Index Weight Determination by FA-EWM Method

Compared with the AHP, FA, and EWM are objective weighting methods. Among them, the FA method can use a few common factors to reflect most of the sub-information of the original data and reveal the correlation between the indexes [29]. The EWM combines the information value provided by the entropy value to determine the weight, which can reduce the instability judged by subjective experience [30,31]. Analyzing the effective data of the questionnaire survey, it uses the FA-EWM method to correct the index weight obtained by the AHP, calculate the relative total target weight of the dimension and the secondary index, and construct the index weight system.

3.2.1. Determining the Weight of Dimension Index by the FA Method

The FA method is based on the principle of information concentration of data, and a few common factors are obtained from the dimension reduction of the index, and the weight is calculated by using the index variance interpretation rate. Firstly, the variance interpretation rate after the rotation of the factor is calculated, and then the cumulative

contribution rate of the variance interpretation rate after the rotation of each common factor is obtained. After normalization, the weight of each factor can be obtained as follows:

$$\rho_j = \frac{V_j}{\sum_{j=1}^{n} V_j} \tag{3}$$

3.2.2. Determining the Weight of the Secondary Index by the EWM

First of all, the data in the original score table are standardized, and the calculation method is as shown in Equation (4), where Q represents the sample data set, q is the number of samples, t is one of the samples, $\max(x_i) = \max_{t \in Q}\{x_{ti}\}$, $\min(x_i) = \min_{t \in Q}\{x_{ti}\}$, y_{ti} represents the value of the corresponding element x_{ti} after standardization.

$$y_{ti} = \frac{x_{ti} - \min(x_i)}{\max(x_i) - \min(x_i)} \tag{4}$$

Based on the standardized score table, according to the calculation formula of information entropy (5), the information entropy of each index E_i is calculated to represent the entropy value of the evaluation index i.

$$E_i = -\ln(q)^{-1} \sum_{t=1}^{q} f_{ti} \ln f_{ti} \tag{5}$$

Among them, the calculation formula for each element f_{ti} in the probability matrix is as follows:

$$f_{ti} = \frac{y_{ti}}{\sum_{t=1}^{q} y_{ti}} \tag{6}$$

Generally, the smaller the information entropy of the index is, the greater the difference between different individuals is, and the more information is provided, so the role of the index in the comprehensive evaluation is greater, and the corresponding weight is greater. On the contrary, when the information entropy of the index is larger, it means that the degree of difference between different individuals is smaller, and the amount of information provided is less, so the role in the comprehensive evaluation is smaller, and the corresponding weight is smaller.

The calculation formula for determining the index weight according to the entropy value is as follows:

$$u_i = \frac{1 - E_i}{m - \sum_{i=1}^{m} E_i} \tag{7}$$

Combined with the above FA, the weight of each factor (dimension) to the target layer ρ_j can be calculated by using the factor load coefficient. According to Equation (7), the weight of the measurement item (secondary index) to the factor u_i is calculated; by multiplying the two, the weight of the secondary index to the target layer is obtained as follows:

$$w_i = \rho_j u_i \tag{8}$$

3.3. Combination Weighting Method Based on AFE

Because a single decision-making statistical method may have a large decision-making deviation, the reasonable combination of subjective weight and objective weight of decision attributes is the key problem of multi-attribute decision-making. Therefore, in order to realize the rigorous and scientific index weight as far as possible, this paper proposes a combination weight method based on AHP, FA, and EWM, using the AHP, FA, and EWM to obtain the subjective and objective basic weights of each evaluation index respectively,

which integrates subjective and objective weight methods according to the principle of "minimum information discrimination". It adopts the theory of "minimum information discrimination" as the optimization goal to calculate the combination weight. This method not only takes into account the subjective preferences of decision-makers, but also takes into account the objectivity of actual quantitative characteristics, and the calculation results are more scientific.

Among them, the principle of "minimum information discrimination" means that when the decision maker only grasps the prior probability distribution or some statistical information, the minimum discriminant information of the prior distribution and the target distribution is used as the objective function to integrate and analyze the existing statistical data, so that the target distribution is the closest to the probability distribution under various constraints, so as to judge the overall distribution law. Usually, the discriminant information is used to measure the difference between the two distributions, the distance between the two distributions should be minimized as much as possible [32].

This paper proposes the AHP-FA-EWM (AFE) weighting method based on the principle of "minimum information discrimination", which is more scientific and objective than the single use of the subjective weighting method or objective weighting method.

The index weight obtained by AHP is v_i, and the index weight obtained by the FA and EWM is w_i, the combined weight of the index ξ_i should be as close as possible to the weighted sum. The calculation formula is as follows:

$$\xi_i = \frac{\sqrt{v_i w_i}}{\sum_{i=1}^{m} \sqrt{v_i w_i}} \tag{9}$$

Combined with the weight data of the above AHP, FA, and EWM, the combined weight of each evaluation index of the ATCO core competency ξ_i is calculated by Equation (9).

4. The Calculation Method of the ATCO CPF Degree Based on AFE-TOPSIS

In order to carry out the quantitative evaluation of the ATCO core competency, the matching index system between the ability and the job requirements is established based on the multi-dimensional core competency evaluation model. Based on the combination weighting of the multi-post mode evaluation index, this paper proposes a method to calculate the proximity of the ATCO ability to the optimal scheme of the job requirements based on the AFE-TOPSIS, and then reflect the fit degree between the ability and the job requirement. The TOPSIS is a multi-index evaluation and decision-making method, which is mainly used to evaluate the relative advantages and disadvantages of existing objects, and the relative closeness between the object, and the optimal scheme can be obtained [33,34]. Based on the pros and cons solution distance method, the core competency fit degree evaluation steps [35] are as follows:

Step 1: Based on the adapted multi-dimensional core competency model, the data values of each core competency matching index are calculated through expert scoring evaluation. The original decision matrix X of the ATCO core competency is obtained, as shown in Equation (10). Among them, P represents the sample data set, m represents the total number of evaluation indexes, and x_p^i represents the p ATCO's value of the secondary evaluation index i.

$$X = \begin{vmatrix} x_1^1 & x_1^2 & \cdots & x_1^m \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ x_p^1 & x_p^2 & \cdots & x_p^m \end{vmatrix} \tag{10}$$

Step 2: Standardize the original decision matrix, and mark the dimensionless decision matrix as X', as follows:

$$X' = (x_p^{i'})_{p=1,2,\ldots,|P|,i=1,2,\ldots m} \tag{11}$$

$x_p^{i'}$ represents the normalized value of the corresponding element x_p^i, where $\max(x^i) = \max_{p \in P}\left\{x_p^i\right\}$, $\min(x^i) = \min_{p \in P}\left\{x_p^i\right\}$, is as follows:

$$x_p^{i'} = \frac{x_p^i - \min(x^i)}{\max(x^i) - \min(x^i)} \tag{12}$$

Step 3: Copy p copies of the combined weight vector ξ obtained in the above model construction process to construct the weight vector matrix W of all controllers, as shown in Equation (13); it is normalized and weighted with the dimensionless evaluation matrix X' of controller, as shown in Equation (14), the normalized judgment matrix is multiplied by the corresponding term of the weight matrix to obtain the weighted standardized evaluation matrix Z, as shown in Equation (15).

$$W = \begin{vmatrix} \xi_1 & \xi_2 & \cdots & \xi_m \\ \vdots & \vdots & \vdots & \vdots \\ \xi_1 & \cdots & \xi_i & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ \xi_1 & \xi_2 & \cdots & \xi_m \end{vmatrix} \tag{13}$$

$$Z = W \times X' = \left[z_p^i\right]_{|P| \times m} \tag{14}$$

$$Z = \begin{vmatrix} \xi_1 \cdot x_1^{1'} & \xi_2 \cdot x_1^{2'} & \cdots & \xi_m \cdot x_1^{m'} \\ \vdots & \vdots & \vdots & \vdots \\ \xi_1 \cdot x_p^{1'} & \cdots & \xi_i \cdot x_p^{i'} & \cdots \\ \vdots & \vdots & \vdots & \vdots \\ \xi_1 \cdot x_{|P|}^{1'} & \xi_2 \cdot x_{|P|}^{2'} & \cdots & \xi_m \cdot x_{|P|}^{m'} \end{vmatrix} \tag{15}$$

Step 4: Calculate the positive ideal value and the negative ideal value of each evaluation index. The calculation formulas are as follows:

$$z_i^+ = \max_{p \in P}\left\{z_p^i\right\} \tag{16}$$

$$z_i^- = \min_{p \in P}\left\{z_p^i\right\} \tag{17}$$

The positive and negative ideal schemes are obtained, and the maximum value is defined as follows:

$$Z^+ = (z_1^+, z_2^+, \cdots, z_i^+) \tag{18}$$

Similarly, define the minimum value as follows:

$$Z^- = (z_1^-, z_2^-, \cdots, z_i^-) \tag{19}$$

Step 5: Calculate the relative closeness of each controller's core competency in the collective. According to the positive and negative ideal values of the ATCO core competency evaluation, the Euclidean distance between the core competency evaluation of each controller and the positive and negative ideal values is calculated.

Among them, the Euclidean distance s_p^+ between the ATCO competency evaluation and the positive ideal value and the Euclidean distance s_p^- between the ATCO competency evaluation and the negative ideal value are as follows:

$$s_p^+ = \sqrt{\sum_{i=1}^{m} (z_p^i - z_i^+)^2} \tag{20}$$

$$s_p^- = \sqrt{\sum_{i=1}^{m} (z_p^i - z_i^-)^2} \tag{21}$$

After obtaining the Euclidean distance between the core competency evaluation of each controller and the positive and negative ideal values, the relative closeness of each controller is calculated based on this, which indicates the CPF degree between the controller's ability and the post requirements. Among them, the controller's relative closeness C_p calculation formula is:

$$C_p = \frac{S_p^-}{(S_p^+ + S_p^-)} \tag{22}$$

Moreover $C_p \in [0, 1]$, the larger the value, the higher the fit degree between the ATCO core competency and the post requirement; on the contrary, it means that the fit degree with the post is low.

5. Example Verification and Analysis

5.1. Core Competency Questionnaire Preparation and Research

Based on literature analysis and ATM expert advice, combined with the analysis of job tasks, based on the study that the primary indexes are appropriate, combined with Table 1, a survey questionnaire on the adapted ATCO multi-dimensional core competency index system is compiled. The first part of the questionnaire is the basic information about the personnel, including the job position, qualification level, position, and so on. In the second part of the questionnaire, a revised Likert scale was developed. The respondents score the importance of the indexes. The scoring range of each item was 1–5, which is expressed as "very unimportant", "unimportant", "general", "important", and "very important". The questionnaire contains 31 evaluation index items of the ATCO core competency and sets up an open short-answer question, which can be used for index integrity and additional suggestions.

The questionnaire is aimed at the on-the-job ATCOs and related business leaders and assistants of an air traffic control unit in China. A total of 1203 questionnaires were distributed through We Chat, web pages, and paper forms, and the integrity and authenticity of the answers were tested. The questionnaires with an obvious tendency to answer and all the same answer data for each item were deleted. A total of 978 valid questionnaires are counted, and the effective questionnaire rate is 81.30%. SPSS 26.0 software was used to analyze and process the data of the effective questionnaire, and the average score of each index was calculated.

5.2. Questionnaire Data Analysis

The frequency analysis of 978 valid questionnaires is shown in Table 3. The data statistics show that the number of frontline controllers on jobs such as TWR, APP, and ACC has reached 82.11%, and the number of mature controllers of third-level controllers and above has reached 64.62%. Firstly, this paper studies and analyzes the General model of the comprehensive samples of 978 questionnaires, and then uses the same method to study and analyze the professional post model of the individual samples about TWR, APP, and ACC posts, respectively, for exploring the evolution law of the multi-dimensional core competency model about multi-post mode.

Table 3. Frequency statistics.

Demographic Information		Frequency	Percentage (%)
Age	>50 years old	66	6.75
	40~50 years old	169	17.28
	30~40 years old	418	42.74
	≤30 years old	325	33.23
Work Post	TWR post	171	17.48
	APP post	357	36.50
	ACC post	275	28.12
	Related post	175	17.89
Qualification	≥Second-level ATCO	395	40.39
	Third-level ATCO	237	24.23
	Fourth-level ATCO	118	12.07
	Fifth-level ATCO	132	13.50
	Intern ATCO	96	9.82
Working year	≥20 years	185	18.92
	10~20 years	344	35.17
	5~10 years	216	22.09
	≤5 years	233	23.82
Education background	Master degree and above	74	7.57
	Undergraduate college	888	90.80
	Junior college and below	16	1.64
Total		978	100.0

5.2.1. Project Analysis

In order to verify the feasibility and reliability of the questionnaire items, SPSS 26.0 software is used to analyze the items of the answer scale, the total score of the questionnaire, and the score of each item are analyzed by correlation analysis to test the discrimination of each item. The total score of each item is calculated, through the critical ratio value method, thirty-one items are selected as the first 27% and the last 27% of the test questionnaires. Two groups are used as controls for the independent sample *t*-test. The critical ratio (CR) of each item and the significant difference value of each item are calculated, which are less than 0.05, showing the significance of the items. All thirty-one items have good discrimination, no invalid items, and no deletion is required.

5.2.2. Reliability Analysis

Reliability analysis is usually used to study the reliability and accuracy of the questionnaire. After the SPSS 26.0 software calculation, the reliability coefficient value is 0.965, which is greater than 0.9, indicating that the reliability quality of the questionnaire data is high. For the "item deleted α coefficient", if any item is deleted, the reliability coefficient will not be significantly improved, indicating that any item does not need to be deleted, and thirty-one index elements are proposed for further research and analysis.

5.2.3. Validity Analysis

Validity analysis is usually used to study the rationality and scientificity of the questionnaire items. Exploratory factor analysis (EFA) is used to test the validity of the questionnaire data through a comprehensive analysis of statistical indexes such as KMO (Kaiser-Meyer-Olkin) value, commonality, variance interpretation rate, and factor load coefficient. The KMO value is used to judge the suitability of information extraction, the common degree value is used to exclude unreasonable research items, the variance interpretation rate value is used to explain the level of information extraction, and the factor load coefficient is used to measure the correspondence between factors (dimensions) and measurement items (secondary indexes).

From the perspective of professional analysis, the EFA method initially sets the factor number to eight and analyzes thirty-one core competency evaluation index items. The measurement relationship indexes between the three measurement items of "x_6 keep aircraft identification", "x_7 manage the traffic situation", "x_{17} air traffic control experience" and other factors are not good, so the three items should be deleted. After deletion, the number of factors is set to seven again. For the analysis of 27 index items, the common degree values corresponding to all items are higher than 0.4, and there is no need to delete any item. KMO and Bartlett sphericity tests are performed: the KMO value is 0.910, greater than 0.6, indicating that the data can be effectively extracted information. The sphericity test value is 0, less than 0.05, and the seven factors are judged to be suitable for factor analysis. In addition, the absolute value of the factor loading coefficient is greater than 0.4, and the corresponding relationship between seven factors and 28 items is confirmed, which is consistent with the expectation and does not need to be adjusted. The variance interpretation rates of the seven factors are 16.453%, 13.019%, 10.888%, 10.751%, 10.535%, 8.917%, and 6.038%, respectively. The cumulative variance interpretation rate after rotation is 76.601% > 50%, It shows that the questionnaire data has high construct validity.

Finally, the seven factors (dimensions) extracted are named as follows: F_1 Separation and conflict resolution(SCR), F_2 Situational awareness(SAW), F_3 Communication and coordination(CCO), F_4 Self-management(SFM), F_5 Workload management(WLM), F_6 Traffic and capacity management(TCM), F_7 Non-routine situations management(NRS). Thus, the General model of the ATCO core competency index system is constructed as shown in Figure 3, including seven dimensions and 28 secondary indexes.

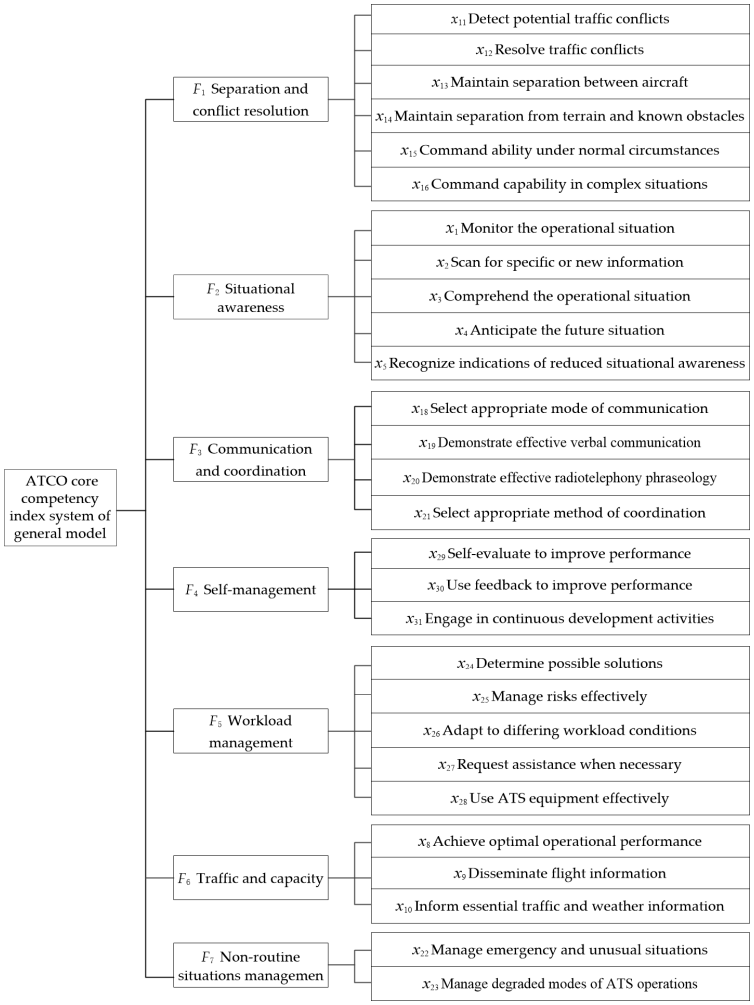

Figure 3. General model indexes of ATCO core competency.

5.2.4. Confirmatory Factor Analysis

Based on the results of the index system selection of the above EFA method, in order to test the structural validity of the model, AMOS 26.0 software is used for confirmatory factor analysis (CFA). CFA can be used for aggregation validity, fitting validity, and discriminant validity analysis. For the samples collected from 978 questionnaires, the fitting results of the general model are shown in Table 4. The results of relevant indexes meet the goodness requirements of the fit standard, and the overall fitting degree of the model is good, indicating that the model construction of the ATCO core competency index is reasonable.

Table 4. CFA fitting results of the general model.

Commonly Used Indexes	x^2/df	RMSEA	RMR	CFI	NFI	TLI
Reference standard	<5	<0.10	<0.05	>0.9	>0.9	>0.9
Test results	4.635	0.061	0.025	0.945	0.931	0.936

In summary, the structural validity and discriminant validity of the ATCO core competency index system are good, and the verified structural model is shown in Figure 4.

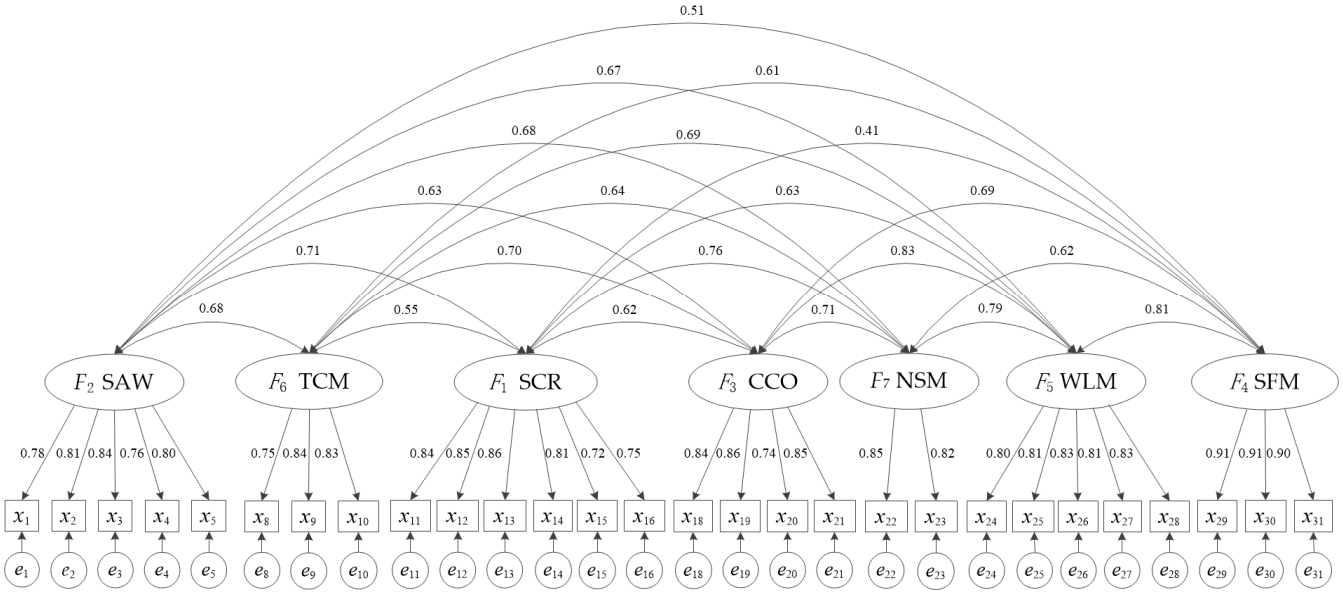

Figure 4. Structure model of general air traffic controller core competency.

5.2.5. The Classification and Grading Construction of the Adapted ATCO Core Competency Model

Using the above EFA and CFA methods, the adapted ATCO core competency model is classified into four categories: General post, TWR post, APP post, and ACC post model. The index system is shown in Table 5.

(1) ATCO core competency model of the General post

According to the core competency index content and index weight research results of 978 questionnaires, the General core competency model is constructed as seven dimensions and 28 secondary indexes.

Table 5. Adapted multi-dimensional core competency model in multi-post mode.

General Model		TWR Model		APP Model		ACC Model	
Dimension	**Secondary Index**	**Dimension**	**Secondary Index**	**Dimension**	**Secondary Index**	**Dimension**	**Secondary Index**
F_1 Separation and conflict resolution	x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}	F_1 Separation and conflict resolution	x_{11}, x_{12}, x_{13}, x_{14}	F_1 Separation and conflict resolution	x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}	F_1 Situational awareness	x_1, x_2, x_3, x_4, x_5, x_6
F_2 Situational awareness	x_1, x_2, x_3, x_4, x_5	F_2 Situational awareness	x_1, x_2, x_3, x_4, x_5	F_2 Situational awareness	x_1, x_2, x_3, x_4, x_5, x_6	F_2 Separation and conflict resolution	x_{11}, x_{12}, x_{13}, x_{14}, x_{24}, x_{25}
F_3 Communication and coordination	x_{18}, x_{19}, x_{20}, x_{21}	F_3 Self-management	x_{29}, x_{30}, x_{31}	F_3 Self-management	x_{29}, x_{30}, x_{31}	F_3 Communication and coordination	x_{18}, x_{19}, x_{20}, x_{21}
F_4 Self-management	x_{29}, x_{30}, x_{31}	F_4 Workload management	x_{24}, x_{25}, x_{26}, x_{27}, x_{28}	F_4 Workload management	x_{24}, x_{25}, x_{26}, x_{27}, x_{28}	F_4 Self-management	x_{29}, x_{30}, x_{31}
F_5 Workload management	x_{24}, x_{25}, x_{26}, x_{27}, x_{28}	F_5 Communication and coordination	x_{18}, x_{19}, x_{20}, x_{21}	F_5 Communication and coordination	x_{18}, x_{19}, x_{20}, x_{21}	F_5 Traffic and capacity management	x_8, x_9, x_{10}
F_6 Traffic and capacity management	x_8, x_9, x_{10}	F_6 Traffic and capacity management	x_8, x_9, x_{10}	F_6 Traffic and capacity management	x_7, x_8, x_9, x_{10}	F_6 Workload management	x_{26}, x_{27}, x_{28}
F_7 Non-routine situations management	x_{22}, x_{23}	F_7 Non-routine situations management	x_{22}, x_{23}	F_7 Non-routine situations management	x_{22}, x_{23}	F_7 Non-routine situations management	x_{22}, x_{23}

(2) ATCO core competency model of the TWR post

According to 171 questionnaires of the TWR post controllers, the above methods are used for factor analysis and model verification. The chi-square degree of freedom ratio x^2/df is 1.939 < 5, and the overall fitting degree of the model is good. The ATCO core competency model of the TWR post is constructed as seven dimensions and 26 secondary indexes.

(3) ATCO core competency model of the APP post

According to 357 questionnaires of the APP post controllers, the same method as above is used for factor analysis and model verification. The chi-square degree of freedom ratio x^2/df is 2.295 < 5, and the overall fitting degree of the model is good. The ATCO core competency model of the APP post is constructed with seven dimensions and thirty secondary indexes.

(4) ATCO core competency model of the ACC post

According to 275 questionnaires of the ACC post controllers, factor analysis and model verification are carried out by using the same method as above. The chi-square degree of freedom ratio x^2/df is 3.118 < 5, and the overall fitting degree of the model is good. The ATCO core competency model of the ACC post is constructed with seven dimensions and 27 secondary indexes.

5.2.6. The Comparison of ATCO Core Competency Models of Multi-Post Mode

According to the different tasks of specific jobs, the above four classification and grading models generally show certain convergence and differences in structure and content. The specific performance is as follows:

(1) The four types of model structure are the same, they all maintain the seven dimensions of Separation and conflict resolution, Situational awareness, Self-management, Workload management, Communication and coordination, Traffic and capacity management, and Non-routine situations management. However, the ranking of the extracted factor load coefficients is different, which is manifested in the order of dimension naming. The main reason is that the dimensional importance of various models is different, that is, the focus of various posts is inconsistent. The General, TWR, and APP post models mainly focus on the competency dimension of F_1 Separation and conflict

resolution, and the ACC post model mainly focuses on the competency dimension of F_1 Situational awareness.

(2) The content of the model is the composition of the secondary indexes of each dimension, which is basically about 28 items. The model of the APP post contains up to thirty items, and the TWR model contains only 26 items. The number of secondary indexes is ranked as APP > General > ACC > TWR, which is consistent with the order of command difficulty coefficient and workload of various posts.

(3) The competency indexes of each model are consistent with the multi-post competency needs analyzed in Table 2. The competency index content of the General post model is relatively balanced, taking into account the seven dimensions. The significant competency requirements of TWR, APP, and ACC posts are non-routine situations management abilities (x_{22}, x_{23}), accurate separation and conflict resolution abilities in complex situations (x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}), and the abilities to discover potential flight conflicts and resolve risks (x_{11}, x_{12}, x_{13}, x_{14}, x_{24}, x_{25}), which are reflected in various core competency models and constitute an important part of the model.

5.3. Weight Calculation of Core Competency Evaluation Index

(1) Index weight of multi-post core competency model

For all kinds of model survey questionnaire samples, the index weights are calculated based on the above core competency combination weights method of AFE. The combined weights of each evaluation index are calculated by Equation (7), and the secondary index combined weights of the General, TWR, APP, and ACC models are obtained. The results are shown in Table 6.

(2) Dimension weight of the multi-post core competency model

According to the results of Table 5, the weight of each dimension of the core competency model of multi-position mode is calculated, as shown in Figure 5 and Table 7. As mentioned above, the four types of models have convergence in the structural model, and the radar maps of the weights of each dimension are generally consistent.

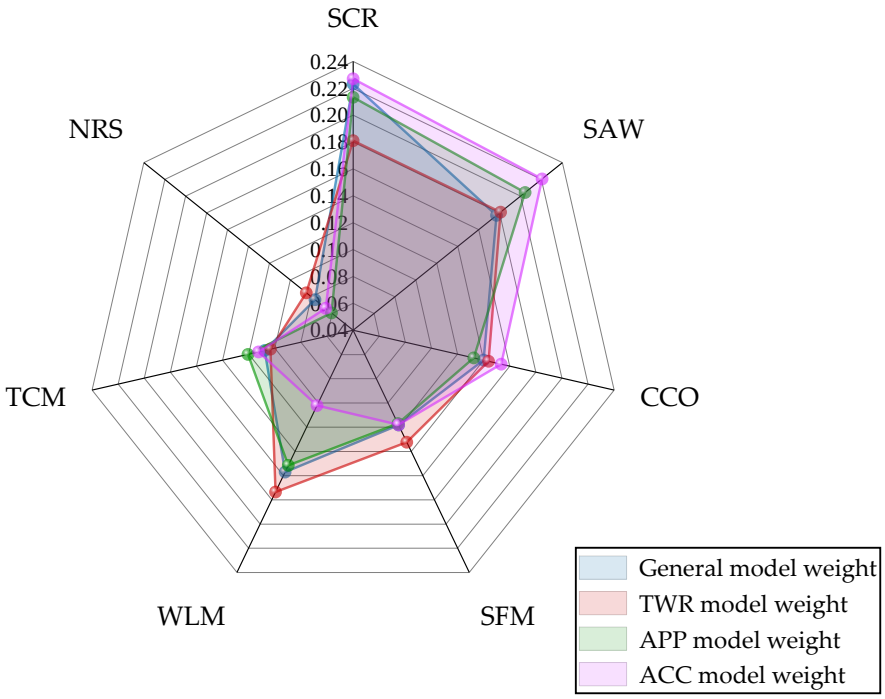

Figure 5. Core competency model dimensions of multi-post mode.

Table 6. Combined weights of each index about the ATCO core competency model.

Secondary Index	Combined Weights of Each Index			
	General Model	TWR Model	APP Model	ACC Model
x_1	0.0347	0.0337	0.0347	0.0354
x_2	0.0362	0.0366	0.0355	0.0368
x_3	0.0330	0.0348	0.0317	0.0350
x_4	0.0367	0.0392	0.0346	0.0383
x_5	0.0365	0.0366	0.0352	0.0386
x_6	—	—	0.0326	0.0365
x_7	—	—	0.0285	—
x_8	0.0343	0.0330	0.0283	0.0370
x_9	0.0360	0.0346	0.0310	0.0376
x_{10}	0.0375	0.0357	0.0328	0.0378
x_{11}	0.0344	0.0461	0.0337	0.0364
x_{12}	0.0347	0.0423	0.0334	0.0404
x_{13}	0.0356	0.0443	0.0337	0.0405
x_{14}	0.0394	0.0484	0.0356	0.0486
x_{15}	0.0411	—	0.0402	—
x_{16}	0.0380	—	0.0368	—
x_{17}	—	—	—	—
x_{18}	0.0331	0.0345	0.0310	0.0365
x_{19}	0.0330	0.0327	0.0305	0.0380
x_{20}	0.0413	0.0438	0.0401	0.0436
x_{21}	0.0326	0.0328	0.0309	0.0354
x_{22}	0.0349	0.0406	0.0272	0.0297
x_{23}	0.0416	0.0441	0.0334	0.0364
x_{24}	0.0317	0.0350	0.0302	0.0285
x_{25}	0.0306	0.0354	0.0294	0.0327
x_{26}	0.0313	0.0336	0.0308	0.0344
x_{27}	0.0325	0.0362	0.0315	0.0329
x_{28}	0.0310	0.0334	0.0297	0.0349
x_{29}	0.0382	0.0445	0.0377	0.0371
x_{30}	0.0392	0.0419	0.0390	0.0393
x_{31}	0.0409	0.0462	0.0403	0.0417

Table 7. Combined weights about each dimension of the core competency model.

Dimension of Core Competency	Combined Weights of Each Dimension			
	General Model	TWR Model	APP Model	ACC Model
Separation and conflict resolution (SCR)	0.2232	0.1811	0.2133	0.2271
Situational awareness (SAW)	0.1771	0.1810	0.2043	0.2206
Communication and coordination (CCO)	0.1400	0.1438	0.1325	0.1535
Self-management (SFM)	0.1183	0.1325	0.1171	0.1181
Workload management (WLM)	0.1571	0.1736	0.1516	0.1022
Traffic and capacity management (TCM)	0.1078	0.1033	0.1206	0.1125
Non-routine situations management (NRS)	0.0765	0.0847	0.0606	0.0662

At the same time, there are some differences in the value of each dimension weight. On the one hand, the dimension weight values of the four models all show three levels. The dimension with the smallest level of weight values is the traffic and capacity management, and non-routine situations management, which is called the basic core competency, representing the basic ability to meet the post requirement. The dimension with the medium level of weight values is workload management, self-management, and communication and coordination, which is called advanced core competency, representing the important non-technical ability required for the development of the post. The dimension with the largest level of weight value is separation and conflict resolution, and situational awareness,

which is called high-level core competency, representing the common ability characteristic of excellent performance controllers. The pyramid hierarchical structure diagram of the above core competency dimensions is as follows in Figure 6.

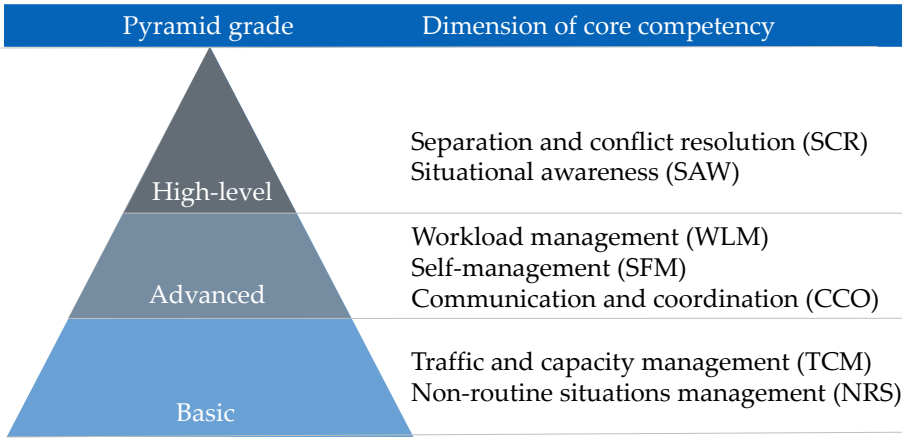

Figure 6. Pyramid hierarchical structure diagram of the core competency dimensions.

On the other hand, the dimension of the ATCO core competency model is compared horizontally. The TWR model has the largest weight in the dimension of non-routine situations management, which is consistent with the characteristics of the TWR post in the face of massive non-routine situations treatment tasks. The largest weight of the traffic and capacity management dimension is the APP model, because of the reason that the most onerous tasks faced by the APP posts are traffic flow and sector capacity management. The largest weight of the separation and conflict resolution dimension is the ACC model, which is determined by the ACC posts characteristics of detecting flight conflicts early and resolving risks timely.

The convergence and difference of the above four core competency models are determined by specific job posts and situational conditions, so their scope of application also shows specific adaptability. The General core competency model can be applied to comprehensive management posts such as instructors, assistants, leaders, and various professional posts. The core competency model of TWR, APP, and ACC posts is more suitable for controllers and leaders in ATC seats of professional posts, in which the model is closer to the production and operation situation of the professional post.

5.4. The Calculation of ATCO Core Competency Fit Degree

According to the matching index system between the core competency and job requirements, the ATCO core competency in multi-post mode is evaluated. And the CPF degree of each item with the full score is set to reach 1, indicating the optimal matching degree target level, as the evaluation reference standard for test controllers. According to the CPF degree value calculated by the total sample data, combined with the experience of the ATCO post ability performance, when the CPF degree reaches 0.5 and above, the ATCO can meet the core competency requirement of the post. The closer the CPF degree value is to 1, the better the fit between the ATCO and the post.

Based on the empirical analysis of the ATCO core competency evaluation, four ATCOs named A, B, C, and D are randomly selected to evaluate the core competency in another ATC unit. The experts score the controllers around the thirty-one indexes of the core competency evaluation index system. Each item can be scored 0–5 points, and the total scores of the four evaluation objects are 144 points, 146 points, 148 points, and 146 points, respectively.

In order to quantitatively study the fit degree between four controllers and multiple posts, the core competency evaluation performance matrix of ATCOs A, B, C, and D is input, and the relative closeness degree of four controllers under the core competency General

model, TWR model, APP model, and ACC model is calculated based on the AFE-TOPSIS method. The calculation results of the CPF degree are shown in Figure 7 and Table 8.

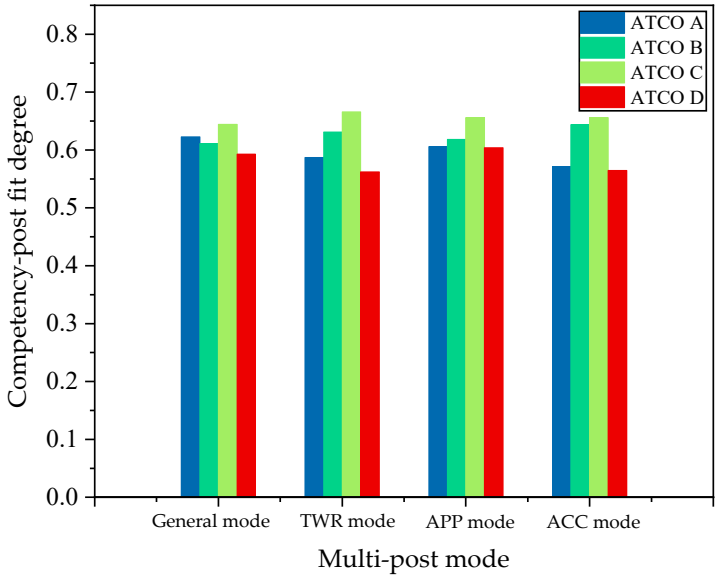

Figure 7. ATCO competency-post fit degree of multi-post mode.

Table 8. Relative proximity and ranking of multi-post mode.

Evaluation ATCOs	Evaluation Results	General Model C_p	Ranking	TWR Model C_p	Ranking	APP Model C_p	Ranking	ACC Model C_p	Ranking
A	144	0.6227	2	0.5869	3	0.6058	3	0.5711	3
B	146	0.6112	3	0.6307	2	0.6185	2	0.6439	2
C	148	0.6444	1	0.6659	1	0.6558	1	0.6559	1
D	146	0.5928	4	0.5618	4	0.6038	4	0.5646	4

Each ATCO shows different fit degrees for different posts, which is consistent with their respective job expertise. At the same time, the overall fit degree of the four controllers is ranked as follows: C > B > A > D. C can be well qualified for any post of the four types, A is most suitable for the general post, B is most suitable for the ACC post, and D is most suitable for the APP post. From the perspective of rational allocation of human resources and giving full play to the core competency advantages of each controller, it is recommended that A, B, C, and D be engaged in ATC assistant post, ACC post, TWR post, and APP post respectively, which can achieve the optimal matching scheme.

6. Conclusions

The main conclusions of this paper are as follows:

(1) As a data-based ability evaluation method, the adapted ATCO core competency evaluation can effectively quantify the ATC ability level of multi-post mode. The proposed General core competency model includes seven dimensions and 28 secondary indexes, the dimensions contain SCR, SAW, CCO, SFM, WLM, TCM, and NRS. The model can effectively explain the core competency indexes required for excellent performance ATCOs, as well as the hierarchical attributes of basic core competency, advanced core competency, and high-level core competency, which provides theoretical guidance and a practical basis for the evaluation and training of ATCOs.

(2) The ATCO core competency shows the diversity of multi-post mode, this paper proposes a refined model analysis method of classification and grading to identify the convergence and difference of the General model, TWR model, APP model, and ACC

model in the ATCO core competency dimension and secondary indexes. Through the personalized modeling method, it realizes the differentiated representation of the weight of each dimension. The proposed AFE method for determining the weight of the ATCO core competency index based on the combination weighting method of AHP-FA-EWM can give full play to the advantages of subjective and objective weighting methods and more accurately and scientifically reflects the importance of evaluation indexes.

(3) In order to support the ATCO effectiveness evaluation and team resource management, based on the classification and grading model of core competency, this paper proposes a calculation method of the ATCO core competency-post fit degree based on the AFE-TOPSIS. It can effectively evaluate the matching degree of ATCO individual effectiveness and post requirements, effectively distinguish the overall arrangement level of the post candidate's ability, and help to meet the overall matching of personnel and posts to the greatest extent, which can realize the full use of their abilities and the efficient management of human resources.

In the future, this paper will take the busy degree of the ATC sector, the characteristics of the ATC seat, the workload, and the fatigue process into further consideration, study the ATCO CPF degree of specific sectors and specific seats in multi-post mode, and reveal the mechanism and changing trend of the ATCO refined seat CPF.

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