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RESEARCH ARTICLE

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Risk evaluation for the task transfer of an aircraft maintenance program based on a multielement connection number

Abstract This paper proposes a framework for evaluating the efficacy and suitability of maintenance programs with a focus on quantitative risk assessment in the domain of aircraft maintenance task transfer. The analysis is anchored in the principles of Maintenance Steering Group-3 (MSG-3) logic decision paradigms. The paper advances a holistic risk assessment index architecture tailored for the task transfer of maintenance programs. Utilizing the analytic network process (ANP), the study quantifies the weight interrelationships among diverse variables, incorporating expert-elicited subjective weighting. A multielement connection number-based evaluative model is employed to characterize decision-specific data, thereby facilitating the quantification of task transfer-associated risk through the appraisal of set-pair potentials. Moreover, the paper conducts a temporal risk trend analysis founded on partial connection numbers of varying orders. This analytical construct serves to streamline the process of risk assessment pertinent to maintenance program task transfer. The empirical component of this research, exemplified through a case study of the Boeing 737NG aircraft maintenance program, corroborates the methodological robustness and pragmatic applicability of the proposed framework in the quantification and analysis of mission transfer risk.

Keywords risk evaluation, maintenance steering group, analytic network process, task transfer, maintenance program

1 Introduction

The reliability of the aircraft maintenance program stands as a crucial prerequisite for ensuring the ongoing airworthiness safety of aircraft operations (Insley and Turkoglu, 2020; Junqueira et al., 2020). As civil aircraft accrue flight hours and flight cycles, coupled with feedback on failures and operational challenges, there arises the continual need for revisions in the aircraft maintenance program (Samaranayake and Kiridena, 2012). A pivotal foundation for the perpetual development and adjustment of these programs lies in the risk assessment associated with task transfer within the maintenance program. Task transfer, when executed effectively, serves to broaden the scope of maintenance activities, mitigate potential risks, and enhance maintenance efficiency (Ren et al., 2017; Zimmermann and Mendonca, 2021).

The Maintenance Steering Group-3 (MSG-3) methodology assumes a central role in guiding risk assessment concerning maintenance program task transfer (Bai and Zuo, 2011; Zuo et al., 2011). In accordance with the Civil Aviation Administration of China (CAAC)'s Advisory Circular (AC–121/135–67), the development of maintenance programs for both new and derivative aircraft should adhere to the reliability-centered maintenance concept, with a firm reliance on the latest MSG-3 methodology throughout the development process (CAAC, 2006). The reliability centered maintenance logical decision diagram, as proposed within the MSG-3 methodology, is integral to the maintenance program development process. Consequently, the MSG-3 method has emerged as the principal tool employed by airline operators and manufacturers for the development, revision, and dynamic management of maintenance programs.

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Its utility extends beyond the determination of initial scheduled maintenance requirements to encompass the refinement and optimization of these requirements.

However, it is imperative to acknowledge that the MSG-3 methodology represents a singular approach and guidance document, potentially lacking comprehensive coverage for the specific demands involved in aircraft maintenance program development, thereby imposing certain limitations. An apparent deficiency exists in the availability of robust theoretical underpinnings for aircraft maintenance program development and enhancement, along with the absence of recommended risk assessment techniques suitable for quantitative analysis of maintenance program task transfer (Pontecorvo, 1984; Duffuaa and Raouf, 2015; Regattieri et al., 2015; Sun et al., 2018).

Numerous scholars have conducted extensive research and achieved noteworthy results in the assessment of risk profiles and optimization of decisions at various stages of aviation maintenance program development and implementation. For instance, Jia et al. (2018) applied the *K*-means clustering algorithm and the analytic hierarchy process (AHP)-entropy value method to model maintenance intervals within the maintenance schedule of civil aircraft under low utilization, thereby facilitating safety and reliability assessments in a more objective manner. Gao et al. (2014) addressed aviation maintenance safety issues by identifying critical organizational factors through system dynamics modeling and analysis. Kucuk and Yilmaz (2019) explored aviation maintenance safety factors through risk mapping and rated various index factors to enhance the performance of maintenance strategy objectives and sustainability.

It is essential to note that the majority of the aforementioned risk assessments primarily focus on the initial development of maintenance programs and often lack in-depth consideration of risk assessment during program updates and revisions. Various risk assessment methods are available for maintenance programs, including set pair analysis, the AHP, Bayesian theory, fuzzy cognitive maps, intuitionistic fuzzy sets, and the entropy power method (Ostrom and Wilhelmsen, 2008; Chen and Huang, 2015; Shi et al., 2016; Azadeh et al., 2017; Yazgan, 2018). Notably, Duan and Yuan (2015) and Shi et al. (2016) proposed the set-pair analysis method, which encompasses certain and uncertain indicators in the assessment system, enabling trend analysis of different indicators and proving its effectiveness in the context of aircraft maintenance systems. Additionally, Azadeh et al. (2017) employed the AHP method to calculate the weights of critical indicators within the maintenance process, facilitating an analysis of safety and reliability. Nevertheless, the AHP method encounters challenges in obtaining accurate indicator weights for complex, interconnected maintenance program design processes and validating independence conditions between hierarchical levels (van Horenbeek and Pintelon, 2014).

In comparison to the AHP method, the analytic network process (ANP) offers a superior understanding of the relationships involved in maintenance task transfer and delivers more precise indicator weighting outcomes.

This paper introduces a method for quantitatively assessing the risk associated with task transfer within aircraft maintenance programs, which is subsequently exemplified and validated. The method commences by constructing a comprehensive maintenance program task transfer index system through an analysis of the fundamental principles underlying task transfer within MSG-3. Subsequently, the weights of task transfer index factors are determined through the integration of the ANP. Furthermore, the assessment of the reliability level of task transfer work within the maintenance program is enriched through the introduction of multielement connection number set pair analysis. The outcome of this process yields a quantitative assessment of the overarching risk associated with task transfer within aircraft maintenance programs, alongside a determination of compliance with ongoing airworthiness criteria.

Through this method, one can not only gain insights into the static risk situation surrounding task transfer but also discern its dynamic developmental trajectory. This methodology proves particularly apt for addressing the risk evaluation of maintenance program task transfer, characterized by its inherent fuzziness, uncertainty, and informational asymmetry. Consequently, maintenance program developers and continuing airworthiness validation authorities can employ this method to forecast risk trends and promptly address any impediments hindering maintenance program revisions.

2 Description of the problem and methodology

2.1 Description of the problem

The MSG-3 *Airline/Manufacturer Maintenance Program Planning Document* serves as a fundamental reference for directing the development of maintenance programs. This document delineates the maintenance program into four distinct sections: The systems/powerplant maintenance program, the aircraft structure maintenance program, the zonal inspection maintenance program, and the lightning/high intensity radiated fields program. Each section of the document includes its explanatory content, accompanied by corresponding logical decision diagrams or procedures. The inspection requirements for each section are formulated in accordance with the analysis methodology provided in MSG-3.

Within the maintenance program development process, the zonal inspection and maintenance work types exhibit similarities in approach patterns and inspection intervals. When the other logical requirements for maintenance program analysis are satisfied, the zonal inspection work can be seamlessly integrated through maintenance task transfer, thereby contributing to the reduction in the volume of aircraft maintenance activities.

The principles governing the transfer of maintenance tasks are as follows:

(1) General visual inspection (GVI) tasks found in the system/powerplant program, which are also categorized as nonsafety tasks (e.g., fault category 6, 7, or 9), should be transferred to the zonal inspection program.

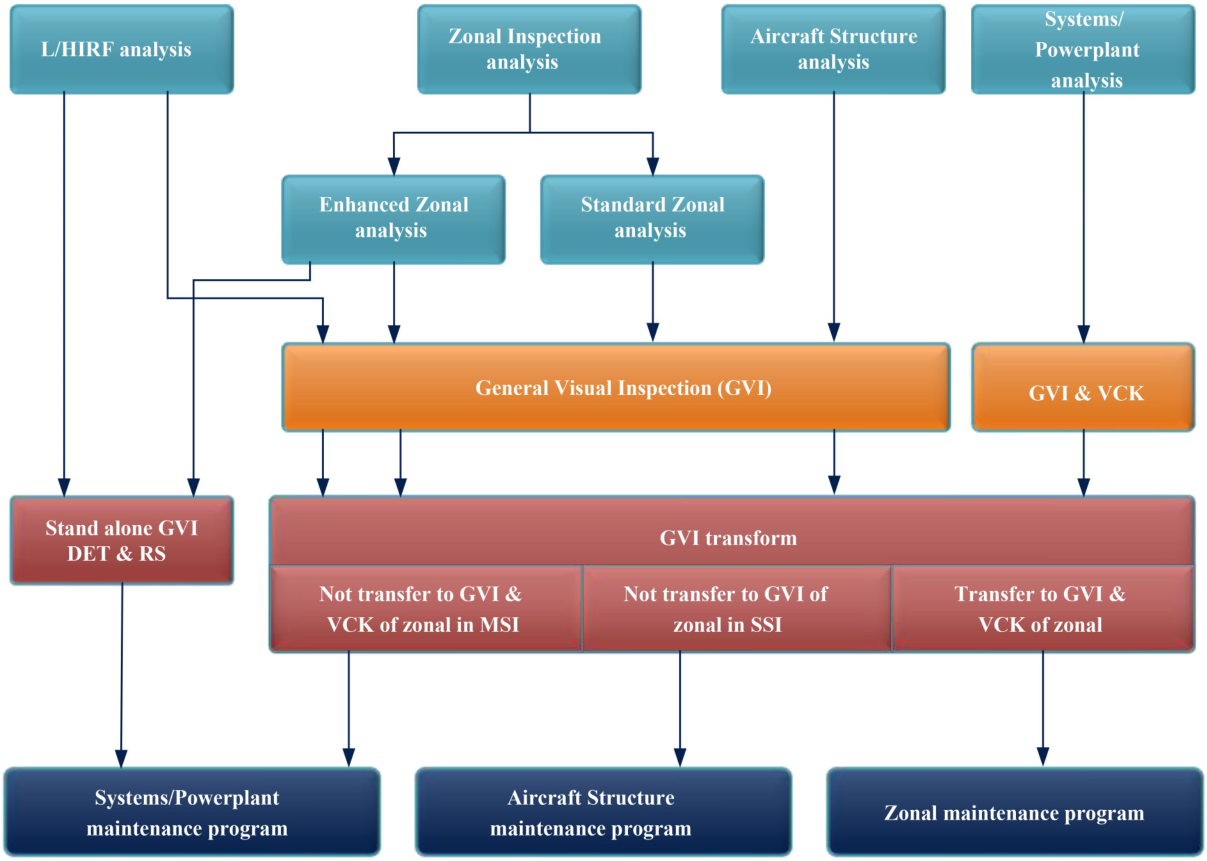
(2) GVI tasks located within the lightning/high intensity radiated fields program, which are classified as Class B tasks, should be transferred to the zonal inspection program.

(3) Similar to the criteria outlined in Principles (1) and (2), GVI tasks within the structural inspection program, which do not impose airworthiness restrictions or have minimal impact on fatigue damage or environmental damage (ED), should be transferred to the zonal inspection program.

The process of transferring and consolidating tasks within the maintenance program is depicted in Fig. 1. Based on the aforementioned principles, it becomes evident that MSG-3 provides solely a qualitative delineation of the guiding principles for task transfers. In essence, the transfer and amalgamation of maintenance programs hinge upon the validity and applicability of the maintenance tasks. However, the document does not furnish specific techniques and methodologies for assessing the reliability and risk associated with task transfers, nor does it offer recommendations for corresponding assessment approaches. Consequently, the evaluation of task transfers and their integration into maintenance programs rests upon the judgment of manufacturers, experts, and airline personnel possessing specialized knowledge and practical experience. Regrettably, this process currently lacks the support of robust quantitative data determination methods for facilitating adjustments throughout the transfer of maintenance programs.

2.2 Methodology

First, in accordance with the MSG-3 document and informed by practical maintenance experience and reference materials (Ren et al., 2017), a comprehensive set of factors for evaluating the risk associated with task transfers is established. This endeavor focuses on four key facets: Density, significance, exposure level, and workforce



Abbreviations: L/HIRF: Lightning/High Intensity Radiated Field; VCK: Visual Check; DET: Detailed Inspection; RS: Repairs; MSI: Maintenance Significant Item; SSI: Structure Significant Item

Fig. 1 Flow chart of task transfer for aircraft maintenance program.

considerations. Subsequently, the primary-level factors are further refined to construct a suite of risk factors specifically tailored for the targeted assessment of task transfers.

Second, an assessment model for risk, denoted as the Risk Identical Discrepancy Contrary (I.D.C.) assessment model and grounded in the principles of ANP, is devised. This model is designed to dissect decision-related challenges and objectives, culminating in the creation of an objective-centric decision model.

Third, the analysis employs multielement connection number set pair analysis to scrutinize both static and dynamic risk factors. Particular attention is given to the construction of the set pair potential and the partial connection coefficient within the multielement connection number framework, facilitating a comprehensive evaluation of risk posture.

Finally, the research culminates in the evaluation of risk probability and reliability pertaining to a zonal inspection item postmaintenance task transfer within the Boeing 737NG aircraft maintenance program, specifically within the context of the zonal maintenance program. This evaluation serves as a litmus test for the efficacy of the risk assessment methodology. The schematic representation of the research design and its key steps is outlined in Fig. 2, with Table 1 providing a comprehensive listing of notations employed in the subsequent models.

Table 1 Notation list

Parameter	Description
N	A total number of representational properties
S	Number of identical properties
P	Number of contrary properties
F	The number of properties that are neither contrary nor identical
μ	The degree of connection of the set pair
n	Multielement connection number
a	The degree of identical
b	The partial identical component in discrepancy
c	The neutrality component in discrepancy
d	The partial contrary component in discrepancy
e	The degree of contrary
$\boldsymbol{W}$	A supermatrix
$\boldsymbol{W}_{ij}$	A matrix of all network element ranking weights
$\boldsymbol{B}_s$	A judgment matrix
$\boldsymbol{U}$	A five-level reliability assessment semantic set
μ^+	The set pair connection degree for task transfer reliability assessment
P_r	The probability of task for transfer risk
λ	The correction factor for the probability of task transfer risk

3 Multielement connection number set pair analysis

Multielement connection number set pair analysis, as elucidated by Wang et al. (2010), Xie et al. (2017), and Zhao and Wan (2018), constitutes a comprehensive analytical process rooted in the construction of set pairs within a deterministic/uncertain system. This methodology quantifies the levels of similarity, disparity, and contrary association between two sets by means of the set pair, with these attributes further delineated and characterized using the I.D.C. model.

Given two sets, $\boldsymbol{A}$ and $\boldsymbol{B}$, the resulting set pair is denoted as $\boldsymbol{H} = (\boldsymbol{A}, \boldsymbol{B})$, encompassing a total of N representational properties. Within this framework, there exist S identical properties, P contrary properties, and a number of properties that do not fall into either the

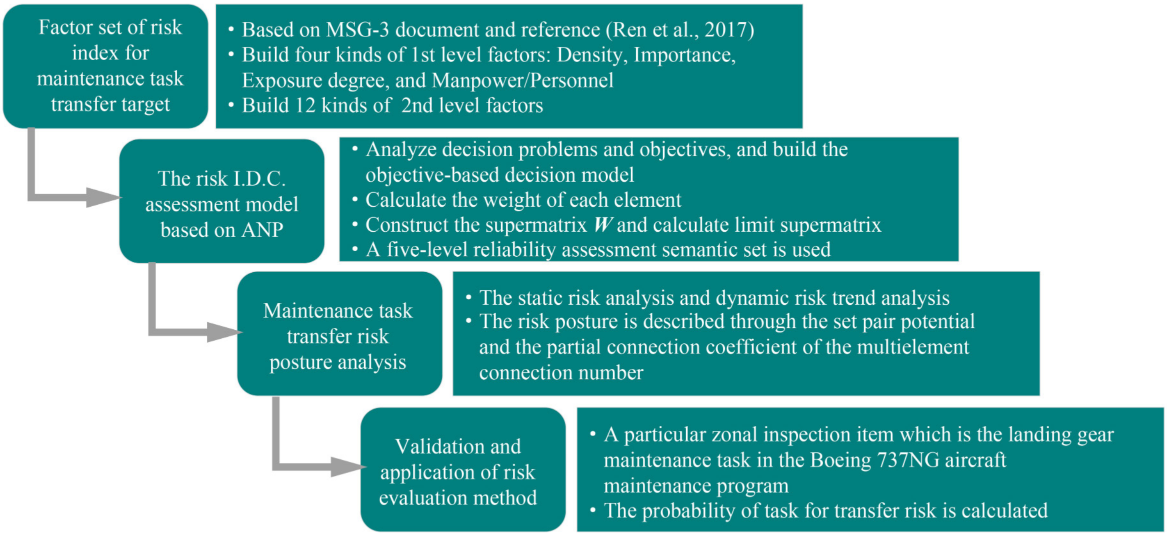


Fig. 2 Research design and key steps.

contrary or identical categories, denoted as $F = N - S - P$. Consequently, the degree of connection within the set pair, or the ternary-element connection number, can be expressed as follows:

$$\mu = \frac{S}{N} + \frac{F}{N}i + \frac{P}{N}j. \tag{1}$$

If $a = S/N$ represents Identical, $b = F/N$ represents Discrepancy, and $c = P/N$ represents Contrary, then Eq. (1) can be written as: $\mu = a + bi + cj$, where $i \in [-1, 1]$ is discrepancy coefficient, $j \equiv -1$ is contrary coefficient, μ is the connection function, and $\forall a, b, c \in [0, 1]$, $a + b + c = 1$. Based on the definition of the ternary-element connection number provided above, it becomes evident that the variation in the degree of discrepancy, represented by bi, can serve as an indicator of the deterministic/uncertain states within the system under certain conditions. Consequently, in practical applications, it is common to extend this element to form a multielement connection number, and the expression can be formulated as follows:

$$\mu = a + b_1 i_1 + b_2 i_2 + \cdots + b_n i_n + cj, \tag{2}$$

where $i_n \in [-1, 1]$, and $a + b_1 + \cdots + b_n + c = 1$, $\forall a, b_n, c \in [0, 1]$.

When n = 3, based on the multielement connection number Eq. (2), the five-element connection number equation can be written as:

$$\mu = a + bi + cj + dk + el, \tag{3}$$

where $a + b + c + d + e = 1$, and $\forall a, b, c, d, e \in [0, 1]$; a is the degree of identical, b is the partial identical component in discrepancy, c is the neutrality component in discrepancy, d is the partial contrary component in discrepancy, and e is the degree of contrary.

The partial connection coefficient within a multielement connection number functions as a descriptor of the tendency for partial changes, whether they are on the higher or lower side. It encapsulates the developmental trajectory of the I.D.C. within a deterministic/uncertain system connection state. Specifically, when examining the *n*th order derivative of a partial connection coefficient, it signifies that the current connection component has shifted positively relative to the previous connection component, indicating an upward trend. Such an upward trend suggests an enhancement in the condition of the target factor and a decrease in risk. Conversely, when the *n*th order derivative is negative, it indicates a downward direction, signifying a deterioration in the condition of the target factor and an increase in risk. If the *n*th order derivative is zero, it signifies a migration in the uncertain direction, denoting a mediating trend of uncertainty. This trend suggests that the target factors are undergoing a mixed state of improvement and deterioration.

Based on the foregoing description, each order partial connection coefficient within the five-element connection numbers is defined as follows.

First order of partial connection coefficient:

$$\partial\mu = \partial a + i\partial b + j\partial c + k\partial d, \tag{4}$$

where $\partial a = a/(a+b)$, $\partial b = b/(b+c)$, $\partial c = c/(c+d)$, and $\partial d = d/(d+e)$.

From Eq. (4), it can be noted that μ indicates that a is at the same level as b and that a has developed from b. ∂a quantitatively portrays the degree of development of a from b. Similarly, ∂b, ∂c, and ∂d also quantitatively indicate the quantitative degree of development between b, c, d and e, respectively. It is evident that the first-order partial connection coefficient serves as a representation of the positive developmental trend within the I.D.C. deterministic/uncertain state of the five-element connection numbers at the holistic level.

Second order of partial connection coefficient:

$$\partial^2\mu = \partial^2 a + i\partial^2 b + j\partial^2 c, \tag{5}$$

where $\partial^2 a = \partial a/(\partial a + \partial b)$, $\partial^2 b = \partial b/(\partial b + \partial c)$, and $\partial^2 c = \partial c/(\partial c + \partial d)$.

Third order of partial connection coefficient:

$$\partial^3\mu = \partial^3 a + i\partial^3 b, \tag{6}$$

where $\partial^3 a = \partial^2 a/(\partial^2 a + \partial^2 b)$, and $\partial^3 b = \partial^2 b/(\partial^2 b + \partial^2 c)$.

Fourth order of partial connection coefficient:

$$\partial^4\mu = \partial^4 a, \tag{7}$$

where $\partial^4 a = \partial^3 a/(\partial^3 a + \partial^3 b)$.

Building upon the interpretation of Eq. (4), Eqs. (5)–(7) can be elucidated as portraying the system's state trends in the second, third, and fourth orders. Consequently, they reflect the corresponding state trends based on the quantitative values derived from the aforementioned equations.

To ensure the utmost reliability and credibility of the partial connection coefficient, a conservative approach entails selecting the most conservative values for each of the connection coefficient components. This approach prioritizes caution and prudence in assessing the system's state. When calculating the first-order partial connection coefficients, $i = 0$, $j = 0$, $k = -1$; when calculating the second-order partial connection coefficients, $i = -1$, $j = -1$; and when calculating the third-order partial connection coefficients, $i = -1$.

4 The task transfer risk evaluation model

4.1 Establishment of the task transfer risk evaluation factor system

The systems/powerplant maintenance program, the structure maintenance program, the lightning/high-intensity radiation field protection analysis maintenance program, and the zonal maintenance program are analyzed in accordance with the maintenance task transfer principles and the task transfer process delineated in Fig. 1. We present the requested comparisons as follows:

(1) A comparison between the GVI of the enhanced zonal analysis and the zonal inspection carried out in the standard zonal analysis is conducted.

(2) An evaluation is performed to compare the GVI of the system/powerplant with that of the structure, in contrast to the zonal inspection found in the standard zonal analysis.

(3) Further analysis is undertaken to compare the GVI of the lightning/high-intensity radiation field protection analysis with the zonal inspection of the standard zonal analysis. If the task transfer requirements meet the specified criteria, the consolidation of maintenance tasks is executed. It is noteworthy that, with a focus on ensuring reliability, the inclusion of either a GVI or a visual inspection originating from the system/powerplant unit and structural analysis should be referenced within the zonal inspection tasks outlined in the Maintenance Review Board Report (MRBR).

Drawing from actual aircraft maintenance characteristics, practical maintenance experience, and insights from Ren et al. (2017), the evaluation criteria for standard zonal maintenance task transfer risk analysis encompass four crucial dimensions: Density, Importance, Exposure degree, and Manpower/Personnel.

Density degree: This metric quantifies the density of parts within the zonal area, considering the number of parts and their proximity. It also reflects the complexity of inspecting system equipment and structural elements in the zonal area. The degree accounts for factors such as the number and proximity of parts, structural items, system equipment, and piping conductors within the zonal area.

Importance degree: It evaluates the impact of various accessories within the zonal area on aircraft safety and cost-effectiveness. This assessment considers whether damage to accessories in the zonal area has the potential to cause functional failures in surrounding systems or structures.

Exposure degrees: These are further divided into ED and accidental damage (AD) degrees. ED degree: Assesses how the area is influenced by environmental factors, including temperature, vibration, fluids (hydraulic, chemical, fuel, and moisture), and other environmental elements. The ED degree is determined by the highest influence level among these factors. AD degree: Measures the probability of AD to the zonal area, taking into account factors such as ground operation equipment, external object damage, weather effects, frequency of maintenance activities, liquid spillage, passenger activities, and more. Similar to the ED degree, the AD degree is based on the highest influencing factor degree. The final Exposure degree is determined as the maximum value between the ED and AD degrees.

Manpower and Personnel: These considerations primarily affect zonal inspection intervals and work proficiency, taking into account the human resources required for effective inspections.

In summary, the risk factor set for maintenance task transfer encompasses these elements, as outlined in Table 2.

Table 2 Factor set of risk index for maintenance task transfer target

Target risk	1st level factors	2nd level factors
Aircraft maintenance program task transfer risk status	Density	Number of parts
		Inspection difficulty
	Importance	Security influence
		Economic effect
	Exposure degree	Temperature
		Vibration
		Liquid
		External object damage
		Weather
		Ground operation equipment
	Manpower/Personnel	Inspection interval
		Work proficiency

4.2 The risk internal control assessment model based on ANP

The ANP represents an advancement and extension of the AHP. A notable distinction between the two methods lies in their treatment of interdependencies among elements within a hierarchical structure.

AHP necessitates that elements between different levels and elements within the same level maintain strict independence and exert no influence on one another. Consequently, AHP encounters difficulties when expressing the complex constraint relationships that may exist within a hierarchy. In contrast, ANP is designed to accommodate nonindependent recursive hierarchical structures. It achieves this by articulating the relationships among indicator elements within the system through a network structure. This approach provides a more accurate representation of the relationships among system elements and is better suited for decision-making processes within complex systems.

In the context of assessing the risk state of maintenance program task transfers, which is influenced by numerous factors and characterized by intricate relationships, the rational allocation of weight relationships becomes a fundamental concern in designing the assessment model.

The ANP addresses this challenge by dividing system elements into two components:

The Control Layer: This layer includes the problem's objective and the decision criteria, with dominance residing solely in the objective element.

The Network Layer: Comprising elements governed by the control layer, the network layer forms a network structure of mutual influence. This network is represented by a supermatrix $\boldsymbol{W}$, which quantifies the degree of mutual influence among the elements. The final stabilized weights are derived through a limit operation (Markov chain) applied to the supermatrix.

The operational steps for ANP are as follows.

Step 1: Analyze the decision problems and objectives and construct the objective-based decision model. This involves establishing the control and network layers of the ANP method based on an analysis of the maintenance task transfer principles and the task transfer process outlined in Fig. 1. In the control layer, the primary objective is the assessment of aircraft maintenance program transfer risk status, while the criteria correspond to the 1st level factor items outlined in Table 2. The network layer connections are established based on the control layer, with the 2nd level factors from Table 2 forming clusters. The model structure is visually represented in Fig. 3.

Step 2: Calculate the weight of each element. The significance of elements influencing the decision objective varies, and this variation determines the importance weights assigned to each element, typically assessed using a 1–9 scale. Establish interrelationships among the criteria, elements, and sets of elements, considering the relationships of influence and being influenced.

Step 3: Construct the supermatrix $\boldsymbol{W}$. Within the ANP framework, the control layer comprises m elements denoted as C_1, C_2, $\cdots$, C_m, while the network layer consists of n element sets represented as N_1, N_2, $\cdots$, N_n. To establish the supermatrix, consider the following procedure.

Choose an element from the control layer, denoted as C_s (s =1, 2, $\cdots$, m), as the criterion. Select an element e_{jl} (l = 1, 2, $\cdots$, n_j) from the element set N_j as the subcriterion. Compare the elements within element set N_i pairwise based on their influence on e_{jl}, constructing a judgment matrix $\boldsymbol{B}_s$. Calculate the ranking vectors (w^{jl}_{i1}, w^{jl}_{i2}, $\cdots$, $w^{jl}_{in_i}$) using the eigenvalue method. Conduct a consistency check to verify whether the computed eigenvectors meet the consistency criteria. If they satisfy the compatibility condition, these vectors serve as the

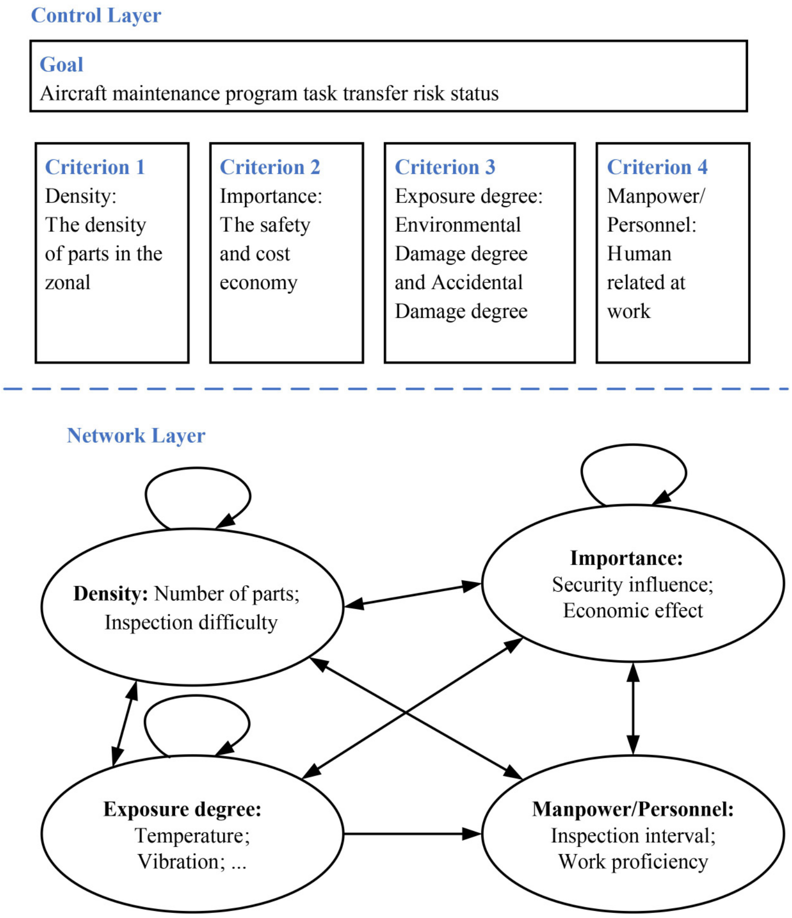


Fig. 3 ANP model structure.

ranking weights for network elements. Formulate a matrix containing all network element ranking weights, denoted as $\boldsymbol{W}_{ij}$:

$$\boldsymbol{W}_{ij}=\begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jn_j} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jn_j} \\ \vdots & \vdots & \vdots & \vdots \\ w_{in_i}^{j1} & w_{in_i}^{j2} & \cdots & w_{in_i}^{jn_j} \end{bmatrix}. \tag{8}$$

The column vector of $\boldsymbol{W}_{ij}$ is the influence ranking vector, which is the influence of the elements in N_i on the elements in N_j. If there is no influencing relationship between elements, then $\boldsymbol{W}_{ij}=0$. Combining the inter-influence ranking vectors of all network layer elements to obtain a supermatrix of control elements, which can be written as:

$$\boldsymbol{W}=\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix}. \tag{9}$$

Normalizing the matrix $\boldsymbol{W}$ obtains the weighted supermatrix $\overline{W}$.

Step 4: Calculate the limit supermatrix. Stabilize the supermatrix and calculate the limit relative ranking vector for each supermatrix:

$$W^{\infty}=\lim_{k\to\infty}(1/n)\sum_{k=1}^{n}\overline{W}^{k}. \tag{10}$$

If this limit is found to be convergent and unique, the values associated with the corresponding rows of the original matrix represent the stability weights of each evaluation indicator.

Once the weights for the elements of task transfer risk are determined, the risk assessment criteria for maintenance task transfer are established. These criteria are integrated with existing risk assessment levels, resulting in the formulation of a five-level reliability assessment semantic set, which is expressed as:

$$\boldsymbol{U}=\{u_k\}=\{u_1,\ u_2,\ u_3,\ u_4,\ u_5\}. \tag{11}$$

The reliability is expressed in terms of its degree of conformity: “frequent”, “reasonably probable”, “remote”, “extremely remote”, and “extremely improbable”. If m experts rate the reliability levels, the assessment is as follows:

$$\boldsymbol{U}_{RL}=\frac{\left\{\sum\limits_{k=1}^{m}u_k\right\}}{m}. \tag{12}$$

Based on the five-element connection number Eq. (3), the reliability I.D.C. assessment model for task transfer is given by combining the risk factor weights and reliability rating results, which can be expressed as:

$$\begin{aligned}\mu^{+}&=\boldsymbol{W}\cdot\boldsymbol{U}_{RL}\cdot\boldsymbol{E}^{\mathrm{T}}\\ &=(w_1,\ w_2,\ \cdots,\ w_n)\begin{bmatrix} u_{11} & u_{12} & u_{13} & u_{14} & u_{15} \\ u_{21} & u_{22} & u_{23} & u_{24} & u_{25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ u_{n1} & u_{n2} & u_{n3} & u_{n4} & u_{n5} \end{bmatrix}\begin{bmatrix} 1 \\ i \\ j \\ k \\ l \end{bmatrix}\\ &=\sum_{s=1}^{n}w_s u_{s1}+i\sum_{s=1}^{n}w_s u_{s2}+j\sum_{s=1}^{n}w_s u_{s3}+k\sum_{s=1}^{n}w_s u_{s4}+l\sum_{s=1}^{n}w_s u_{s5}\ ,\end{aligned} \tag{13}$$

where μ^{+} is the set pair connection degree for task transfer reliability assessment; $\boldsymbol{E}$ is the coefficient vector matrix of the connection degree; and $a=\sum_{s=1}^{n}w_s u_{s1}$ is the identical degree, which indicates the level of task-shifting reliability that is “frequent”. Similarly, $b=\sum_{s=1}^{n}w_s u_{s2}$, $c=\sum_{s=1}^{n}w_s u_{s3}$, $d=\sum_{s=1}^{n}w_s u_{s4}$, and $e=\sum_{s=1}^{n}w_s u_{s5}$ indicate the level of task-shifting reliability that is “reasonably probable”, “remote”, “extremely remote”, and “extremely improbable”, respectively.

4.3 Maintenance task transfer risk position and reliability analysis calculations

The risk internal control model for maintenance task transfer serves a dual purpose. It encompasses both static risk analysis for maintenance program development and the capacity for dynamic risk trend analysis, facilitating the reliability assessment of maintenance task transfer within the context of maintenance program optimization. To comprehensively analyze and manage these risks in both static and dynamic scenarios, it is essential to characterize the risk posture using the set pair potential and the partial connection coefficient of the multielement connection number. The set pair potential represents the tendency of the connection between parameters a, b, c, d, and e within a five-element connection number. It is generally expressed by comparing the values of parameters a, b, c, d, and e. The set pair potential is denoted as $shi(\mu^{+})$, and its definition is as follows:

$$shi(\mu^{+})=\frac{a}{c}. \tag{14}$$

Based on the value of Eq. (14), the set pair potential can be categorized into three situations: “same”, “balance”, and “reverse”. The determination of the risk situation can be made by referring to the set pair potential classification table provided in the references (Wang et al., 2015; Kumar and Garg, 2018).

When the result falls into the “same” situation, it indicates that the risk factor associated with task transfer in the current state of the maintenance program has a low impact on the overall risk level of the maintenance program. Conversely, the “balance” situation suggests that the risk level has an equal impact, resulting in a medium level of risk. In the “reverse” situation, a high risk level is indicated. The determination of the set pair potential thus reveals the degree of influence of each factor within the current set of risk indicators in the maintenance program. This information guides the prioritization of optimization efforts within the maintenance program work. Additionally, by analyzing the partial connection coefficient of each order of the five-element connection number, deviations in elements can be identified. The results of this analysis reflect the trends and changes in the state of I.D.C. connection, contributing to the reduction of risk levels and the enhancement of the reliability of maintenance task transfer within the development of maintenance programs.

The quantitative calculation of task transfer risk probability primarily relies on the transfer factor and task transfer correction factor (Ren et al., 2017):

$$P_r = \lambda\mu, \tag{15}$$

where λ is the correction factor for the probability of task transfer risk, and its value is taken as 1.3×10^{-4}.

5 Example analysis

5.1 Model calculation

To validate the effectiveness of the risk assessment and reliability analysis method for task transfer within the maintenance program development process, a specific zonal inspection item pertaining to the maintenance of the landing gear in the Boeing 737NG aircraft maintenance program (version D626A001-MRBR2007) was assessed for risk probability and reliability. This task involves maintenance activities related to the landing gear damping struts and has been transferred from the previous iteration of the system/powerplant maintenance program to the current version of the zonal maintenance program, as outlined in Table 3.

The set of indicator factors, in conjunction with the set of judgment semantics, has been employed to assess task transfer risk factors and reliability levels. These assessments were conducted based on the judgments provided by ten experts. The panel of experts contributing to the data judgments consists of 1) Four aircraft machinery maintenance engineers with expertise in both line maintenance and scheduled maintenance within the airline industry; 2) Four maintenance engineering managers responsible for developing maintenance work cards and overseeing safety inspections within the engineering management departments of airlines; and 3) Two scholars from the Civil Aviation University of China, specializing in mechanical courses and engaged in related research projects. Subsequently, Super Decision software was utilized to determine the weights assigned to indicator factors using the ANP method. The outcomes of this analysis are presented in Table 4. Furthermore, the data pertaining to the assessment of reliability levels can be found in Table 5. To facilitate normalization, the risk level assessment data are presented in Table 6.

Table 3 Boeing 737NG maintenance task transfer data

Task number of zonal inspection	Task number of system inspection	Task number of structure inspection
32-800-00	32-30-1.10, 32-30-1.2B, 32-30-1.4B, 32-30-1.5, 32-30-1.9, 32-30-6.1, 32-30-6.2, 32-30-6.3, 32-30-6.8, 32-30-6.9, 32-50-1.2, 32-50-1.3	32-21-01, 32-21-02, 32-21-03, 32-21-04, 32-21-05, 32-21-06

Based on the data in Tables 4–6, the multielement connection number and each order partial connection coefficient of the maintenance task transfer risk can be calculated according to Eqs. (3)–(13), as shown in Tables 7 and 8.

5.2 Risk calculation and analysis

Based on the relationships among the connection components a, b, c, d, and e in the five-element connection number, as detailed in Table 7, and with reference to the five-element connection number potential table in the literature (Liu et al., 2019), the posture results for the first-level factors are as follows.

For the first-level factor “Density”, the five-element connection number is $\mu_1 = 0.55 + 0.20i + 0.15j + 0.10k + 0.00l$. Since $a > e$, $a > b$, $b > c$, $c > d$, and $d > e$, the situation is classified as the same potential level 1.

For the factor “Importance”, the situation is also the same potential level, specifically 53.

Table 4 Weight of task transfer risk factors calculated according to ANP

1st level factor	Weight	2nd level factor	Weight
Density	0.1009	Number of parts	0.0274
		Inspection difficulty	0.0735
Importance	0.5257	Security influence	0.2855
		Economic effect	0.2402
Exposure degree	0.1399	Temperature	0.0040
		Vibration	0.0024
		Liquid	0.0024
		External object damage	0.0455
		Weather	0.0069
		Ground operation equipment	0.0787
Manpower/Personnel	0.2335	Inspection interval	0.1636
		Work proficiency	0.0699

Table 5 Assessment of reliability level for maintenance task transfer

2nd level factor	Reliability level assessment data				
	Extremely improbable	Extremely remote	Remote	Reasonably probable	Frequent
Number of parts	4	2	3	1	0
Inspection difficulty	6	2	1	1	0
Security influence	1	6	1	2	0
Economic effect	5	2	1	1	1
Temperature	1	1	2	5	1
Vibration	2	2	1	5	0
Liquid	3	2	2	2	1
External object damage	1	1	1	5	2
Weather	8	1	1	0	0
Ground operation equipment	9	1	0	0	0
Inspection interval	6	2	1	1	0
Work proficiency	4	2	2	1	1

Table 6 Normalization of the risk level assessment data

2nd level factor	Normalization of the risk level assessment data				
	Low risk	Relatively low risk	Moderate risk	Relatively high risk	High risk
Number of parts	0.4	0.2	0.3	0.1	0
Inspection difficulty	0.6	0.2	0.1	0.1	0
Security influence	0.1	0.6	0.1	0.2	0
Economic effect	0.5	0.2	0.1	0.1	0.1
Temperature	0.1	0.1	0.2	0.5	0.1
Vibration	0.2	0.2	0.1	0.5	0
Liquid	0.3	0.2	0.2	0.2	0.1
External object damage	0.1	0.1	0.1	0.5	0.2
Weather	0.8	0.1	0.1	0	0
Ground operation equipment	0.9	0.1	0	0	0
Inspection interval	0.6	0.2	0.1	0.1	0
Work proficiency	0.4	0.2	0.2	0.1	0.1

The factor “Exposure degree” is in the same potential level 7.

The factor “Manpower/Personnel” falls into the same potential level 1.

The five-element number for the entire system is $\mu = 0.41 + 0.30i + 0.11j + 0.14k + 0.04l$. This outcome signifies that the general risk situation for maintenance task transfer is at the same potential level 7, which indicates a strong same potential. Consequently, the system’s risk level is low, and the reliability of the maintenance program task transfer is high. The first-level factors (“Density”, “Exposure degree”, and “Manpower/Personnel”) all share the same strong potential, suggesting low risk in the task transfer process, signifying excellence without necessitating additional special attention. However, “Importance” falls into the weak same potential category, signifying that some consideration and attention to risk should be applied during the aircraft maintenance program development process.

For the entire Boeing 737NG zonal inspection task program, the overall system situation exhibits a strong potential. This suggests a low system risk level and high reliability for the task transfer items in the maintenance program, allowing for the implementation and scheduling of maintenance work.

Based on Table 7, the integrated first-order partial connection coefficient is $0.58 + 0.74i + 0.43j + 0.77k$, which falls into the reverse potential, indicating an overall downward trend in maintenance safety and an overall first-order upward trend in maintenance risk. This implies that, theoretically, the reliability of maintenance tasks may decrease when consolidation occurs, aligning with actual maintenance processes. Notably, all three factors exhibit a reverse potential in the partial connection coefficients,

Table 7 Value of connection number and the first-order partial connection coefficient of the maintenance task transfer risk

2nd level factor	Multielement connection number			Partial connection coefficient	
	Weight	Five-element connection number	Situation	1st-order	Trend
Number of parts	0.2716	$0.40 + 0.20i + 0.30j + 0.10k + 0.00l$	Same	$0.67 + 0.40i + 0.75j + 1.00k$	Decline
Inspection difficulty	0.7284	$0.60 + 0.20i + 0.10j + 0.10k + 0.00l$	Same	$0.75 + 0.67i + 0.50j + 1.00k$	Decline
Total	1.0000	$0.55 + 0.20i + 0.15j + 0.10k + 0.00l$	Same	$0.73 + 0.56i + 0.61j + 1.00k$	Decline
Security influence	0.5431	$0.10 + 0.60i + 0.10j + 0.20k + 0.00l$	Balance	$0.14 + 0.86i + 0.33j + 1.00k$	Decline
Economic effect	0.4569	$0.50 + 0.20i + 0.10j + 0.10k + 0.00l$	Same	$0.71 + 0.67i + 0.50j + 0.50k$	Increasing
Total	1.0000	$0.28 + 0.42i + 0.10j + 0.15k + 0.05l$	Same	$0.40 + 0.81i + 0.39j + 0.77k$	Decline
Temperature	0.0287	$0.10 + 0.10i + 0.20j + 0.50k + 0.10l$	Reverse	$0.50 + 0.33i + 0.29j + 0.83k$	Decline
Vibration	0.0171	$0.20 + 0.20i + 0.10j + 0.50k + 0.10l$	Same	$0.50 + 0.67i + 0.17j + 0.83k$	Decline
Liquid	0.0171	$0.30 + 0.20i + 0.20j + 0.20k + 0.10l$	Same	$0.60 + 0.50i + 0.67j + 0.50k$	Increasing
External object damage	0.3254	$0.10 + 0.10i + 0.10j + 0.50k + 0.20l$	Balance	$0.50 + 0.50i + 0.17j + 0.71k$	Decline
Weather	0.0492	$0.80 + 0.10i + 0.10j + 0.00k + 0.00l$	Same	$0.89 + 0.50i + 1.00j + 1.00k$	Decline
Ground operation equipment	0.5625	$0.90 + 0.10i + 0.00j + 0.00k + 0.00l$	Same	$0.90 + 1.00i + 1.00j + 1.00k$	Decline
Total	1.0000	$0.59 + 0.10i + 0.05j + 0.19k + 0.07l$	Same	$0.85 + 0.68i + 0.21j + 0.72k$	Increasing
Inspection interval	0.7006	$0.60 + 0.20i + 0.10j + 0.10k + 0.00l$	Same	$0.75 + 0.67i + 0.50j + 1.00k$	Decline
Work proficiency	0.2994	$0.40 + 0.20i + 0.20j + 0.10k + 0.10l$	Same	$0.67 + 0.50i + 0.67j + 0.50k$	Increasing
Total	1.0000	$0.54 + 0.20i + 0.13j + 0.10k + 0.03l$	Same	$0.73 + 0.61i + 0.57j + 0.77k$	Decline
System total	1.0000	$0.41 + 0.30i + 0.11j + 0.14k + 0.04l$	Same	$0.58 + 0.74i + 0.43j + 0.77k$	Decline

Table 8 Calculation table of the second-, third-, and fourth-order partial connection coefficients of maintenance task transfer risk

2nd level factor	Partial connection coefficient					
	2nd-order	Trend	3rd-order	Trend	4th-order	Trend
Number of parts	$0.63 + 0.35i + 0.43j$	Decline	$0.64 + 0.45i$	Increasing	0.59	Increasing
Inspection difficulty	$0.53 + 0.57i + 0.33j$	Decline	$0.48 + 0.63i$	Decline	0.43	Increasing
Total	$0.56 + 0.48i + 0.38j$	Decline	$0.54 + 0.56i$	Decline	0.49	Increasing
Security influence	$014 + 0.72i + 0.25j$	Decline	$0.17 + 0.74i$	Decline	0.18	Increasing
Economic effect	$0.51 + 0.57i + 0.50j$	Decline	$0.48 + 0.53i$	Decline	0.47	Increasing
Total	$0.33 + 0.67i + 0.34j$	Decline	$0.33 + 0.67i$	Decline	0.33	Increasing
Temperature	$0.60 + 0.54i + 0.26j$	Decline	$0.53 + 0.69i$	Decline	0.43	Increasing
Vibration	$0.43 + 0.80i + 0.17j$	Decline	$0.35 + 0.83i$	Decline	0.30	Increasing
Liquid	$0.55 + 0.43i + 0.57j$	Decline	$0.56 + 0.43i$	Increasing	0.57	Increasing
External object damage	$0.50 + 0.75i + 0.19j$	Decline	$0.40 + 0.80i$	Decline	0.33	Increasing
Weather	$0.64 + 0.33i + 0.50j$	Decline	$0.66 + 0.40i$	Increasing	0.62	Increasing
Ground operation equipment	$0.47 + 0.50i + 0.50j$	Decline	$0.49 + 0.50i$	Decline	0.49	Increasing
Total	$0.56 + 0.77i + 0.22j$	Decline	$0.42 + 0.78i$	Decline	0.35	Increasing
Inspection interval	$0.53 + 0.57i + 0.33j$	Decline	$0.48 + 0.50i$	Decline	0.43	Increasing
Work proficiency	$0.57 + 0.43i + 0.57j$	Decline	$0.57 + 0.43i$	Increasing	0.57	Increasing
Total	$0.55 + 0.52i + 0.42j$	Decline	$0.51 + 0.55i$	Decline	0.48	Increasing
System total	$0.44 + 0.63i + 0.36j$	Decline	$0.41 + 0.64i$	Decline	0.39	Increasing

except for Exposure degree, which remains in the same potential. Thus, the risk of Exposure degree for objective factors remains stable, while Importance, Density, and Manpower/Personnel factors all experience an increase in maintenance risk as tasks are consolidated.

Referring to Table 8, the integrated second-order partial connection coefficient is $0.44 + 0.63i + 0.36j$, indicating a second-order downward trend in maintenance task transfer risk. The third-order partial connection coefficient $0.41 + 0.64i$ demonstrates an uncertainty potential of $0.41/0.64 \approx 0.64$, suggesting a downward trend with uncertainty in risk. In contrast, the fourth-order partial connection coefficient, 0.39, implies that the same potential is smaller than the reverse potential ($a < b$). Therefore, the same potential of maintenance task transfer risk is smaller than the uncertainty potential, indicating an upward trend in risk at the fourth-order potential level.

Furthermore, concerning the factors related to maintenance task transfer and the general risk trend, factors such as "Density", "Importance", and "Manpower/Personnel" exhibit a decreasing trend in the first-, second-, and third-orders, indicating an increasing risk level for these indicators. However, there is an increasing trend in the fourth-order, signifying a positive trend in risk factors and a mitigated increase in risk. These factors should be considered when optimizing and revising maintenance programs and developing aircraft maintenance programs by air operators.

The "Exposure degree" factor demonstrates an upward trend in the first- and fourth-orders, suggesting improvement in this factor and a reduced impact on system state risk. However, it exhibits a downward trend in the second- and third-orders, indicating fluctuating changes in its impact on the maintenance program task transfer project and opposing trends in the upward trend.

The overall maintenance task transfer risk displays a decreasing trend at the first-, second-, and third-order levels and an increasing trend at the fourth-order level. This indicates that the general system risk trend aligns with the majority of factors in the system. The increase in the number of task transfer items in the maintenance program leads to an increasing risk trend and a deterioration in the reliability of the maintenance program.

Regarding secondary factors, particular attention should be given to factors classified as "balance" and "reverse", such as temperature and external object damage in this example.

This analysis underscores that the transfer of maintenance tasks in scheduled maintenance program revisions can, to some extent, increase the risk of aircraft maintenance. Air operators need to consider the risk trends of factors during task transfer when developing aircraft maintenance programs and implementing maintenance work in conjunction with their maintenance resources and technical conditions.

Based on the five-element connection number of the maintenance task transfer risk factors and the risk factor weights from Table 4, along with the connection number of the general system risk, $\mu = 0.41 + 0.30i + 0.11j + 0.14k + 0.04l$, the risk connection number for maintenance task transfer can be calculated using the mean value method. The risk connection number for task transfer, μ, is determined to be 0.45, indicating a lower risk level.

Using Eq. (15) and the resulting risk connection number, along with the task transfer risk correction factor, which is taken as 1.3×10^{-4}, the probability of task transfer risk can be calculated as 5.85×10^{-5}.

Referring to the risk classification criteria for aircraft reliability levels in the airworthiness regulations issued by the Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA), as shown in Table 9, the risk level of maintenance task transfer and consolidation into the Task 32-800-00 maintenance program is deemed to be within acceptable levels, as illustrated in Fig. 4.

The preceding calculations and analyses provide a quantitative assessment of the risk associated with maintenance task transfer. This information is invaluable for proposing proactive and effective measures for risk prevention and control. Consequently, it facilitates the development of scientifically sound, cost-effective, and reliable aircraft maintenance programs with heightened attention to safety and economic considerations in the context of aircraft maintenance task transfer.

For instance, it becomes possible to establish appropriate inspection intervals, with a particular focus on the impact of external object damage and temperature on the overall zonal inspection and maintenance program. This approach can effectively reduce the risk associated with maintenance tasks following task transfer and enhance maintenance reliability, ultimately elevating the safety standards of aircraft maintenance.

5.3 Sensitivity analysis

The ANP method entails an intricate interplay between the weights assigned to its constituent factors, which in turn are linked to the network structure and the relative dominance weights of each factor. Altering these weights inevitably induces corresponding modifications in the associated weights. Therefore, it becomes imperative to conduct a weight sensitivity analysis while keeping the ANP network structure unaltered.

In the course of this weight sensitivity analysis, a systematic approach is followed. Initially, in accordance with the criteria outlined in Section 4.2, the significance of elements influencing the decision objective undergoes variation. This variation is employed to establish

Table 9 Standard for quantifying risk levels in airworthiness regulations

Probability/h		1.0	1.0×10^{-3}	1.0×10^{-5}	1.0×10^{-7}	1.0×10^{-9}
Quantifying risk levels	EASA	Frequent (level 10)	Reasonably probable (level 7)	Remote (level 5)	Extremely remote (level 3)	Extremely improbable (level 1)
	FAA	Likely (level 7)		Unlikely (level 4)		Extremely unlikely (level 1)

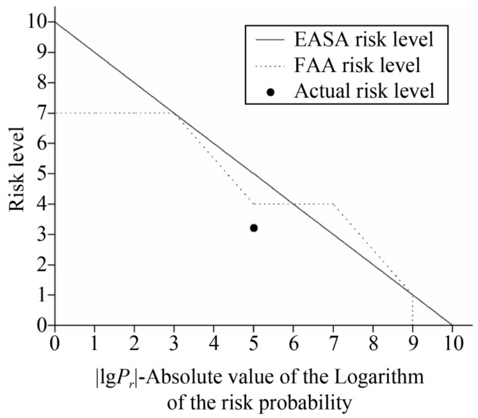


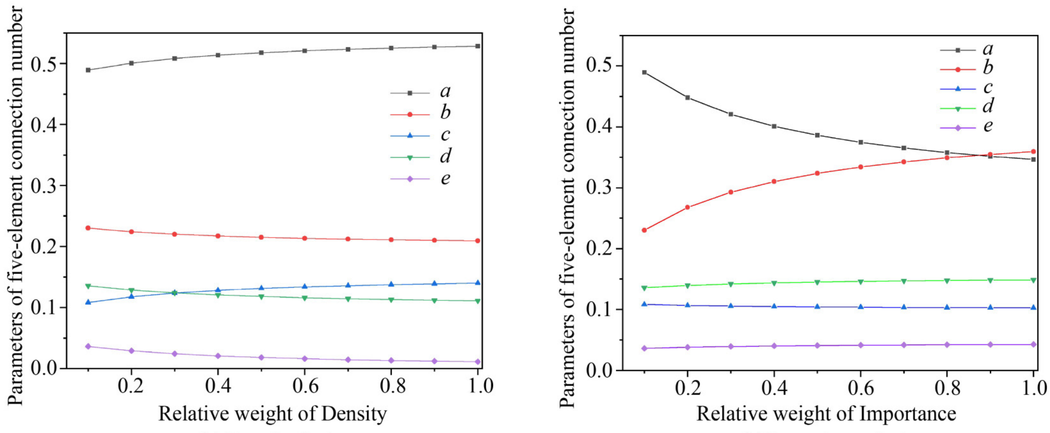
Fig. 4 Quantitative assessment of risk level for maintenance task transfer.

importance weights for each element, typically assessed on a 1–9 scale. These weights serve as a basis for delineating the interrelationships among the criteria, elements, and the entire set of elements. Subsequently, the relative weights of the factors earmarked for analysis as first-level indicators of task transfer risk undergo variation.

Next, the weights of distinct factors within the present structure are computed utilizing the supermatrix. The resulting weight values are then employed in conjunction with expert judgments, as delineated in Table 6. This combined information facilitates the calculation of a five-element connection number, including the number of first-order partial connection coefficients. These calculations shed light on the repercussions of varying relative weights on the risk associated with the task transfer of the maintenance program.

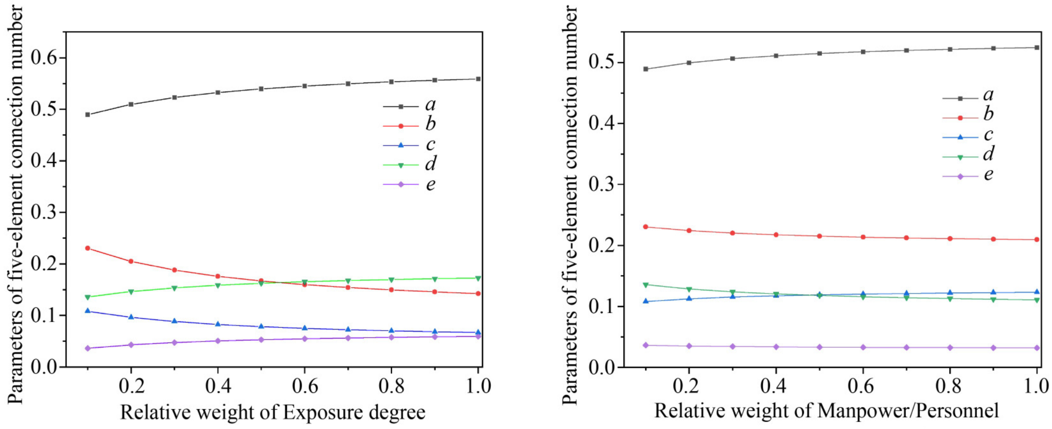
Figure 5 illustrates the evolution of individual coefficients comprising the overall five-element connection number as the relative weight of the first-level factor undergoes variations within the existing framework. In Fig. 5(a), it is evident that when the relative weight of the Density factor exceeds 0.3, the relationships shift from $a > e$, $a > b$, $b > c$, $d > c$, $d > e$ to $a > e$, $a > b$, $b > c$, $c > d$, $d > e$. This transition results in a change in the total five-element connection number from its initial state of 7 to a new state of 1. Remarkably, this change sustains a consistent trend of strong similarity, implying a negligible impact on risk.

Moving to Fig. 5(b), when the relative weight assigned to the Importance factor surpasses 0.88, the relationships shift from $a > e$, $a > b$, $b > c$, $d > c$, $d > e$ to $a > e$, $a < b$, $b > c$, $d > c$, $d > e$. Consequently, the system's total



(a) Density factor

(b) Importance factor



(c) Exposure degree factor

(d) Manpower/Personnel factor

Fig. 5 Trend of the coefficient of the five-element connection number with relative weight.

five-element connection number shifts from level 7 to level 61, signifying a shift from strong similarity to weaker similarity. This, in turn, amplifies the overall risk situation. Therefore, when configuring the weights for the Importance factor, it is crucial to exercise caution and avoid setting its relative weight above 0.88.

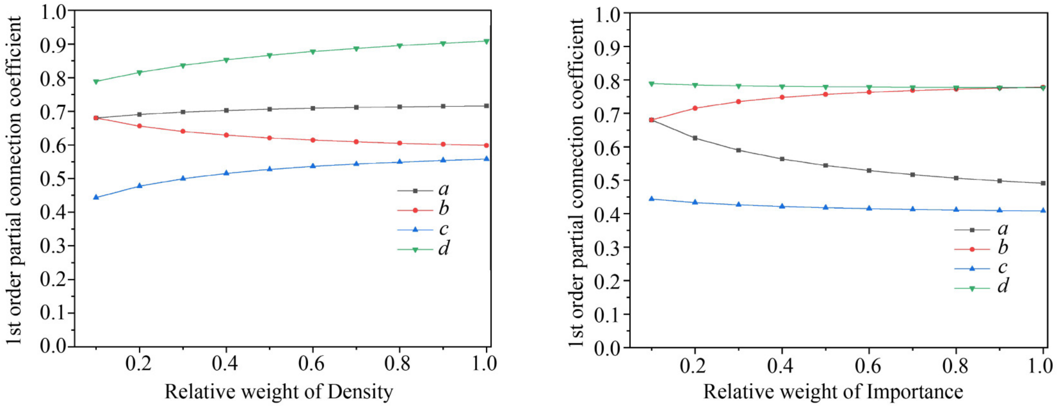
Figure 5(c) reveals that once the relative weight of the Exposure degree factor exceeds 0.53, $a > e$, $a > b$, $b > c$, $d > c$, $d > e$ becomes $a > e$, $a > b$, $d > b$, $d > c$, $d > e$, with the coefficient d being only marginally less than a. This discrepancy indicates a logical relationship error, emphasizing the importance of not setting the relative weight of the Exposure degree factor above 0.53 within the present structure to prevent the overall system from entering an indeterminate state.

Turning to Fig. 5(d), when the relative weight assigned to the Manpower/Personnel factor exceeds 0.5, $a > e$, $a > b$, $b > c$, $d > c$, $d > e$ becomes $a > e$, $a > b$, $b > c$, $c > d$, $d > e$. This transition results in the total five-element connection number for task transfer shifting from level 7 to level 1, with the overall task transfer situation maintaining a robust similarity, thus causing minimal impact on risk.

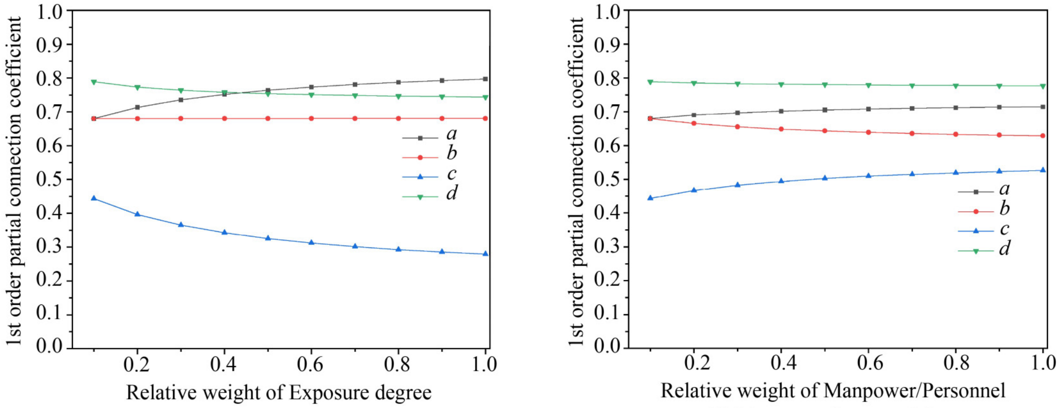
An analysis of the weights of the first-level factors reveals that the Density factor and Manpower/Personnel factor exert relatively minimal influence on task transfer risk. In contrast, the Importance factor has a considerable influence on task transfer risk, with an excessive weight exacerbating the risk. Notably, an imprudent allocation of weight to the Exposure degree factor can lead to a state of uncertainty within the overall system, necessitating particular attention.

Figure 6 illustrates the shifting pattern of the total first-order partial connection coefficient as the relative weights of each first-level indicator undergo changes within the current structure. Notably, for all three factors except the Exposure degree factor, the first-order partial connection coefficient exhibits a downward trend, denoted as $a < d$. This signifies an overarching decline in maintenance safety and a corresponding increase in maintenance risk. However, for the Exposure degree factor, when the relative weight exceeds 0.45, $a > d$ is observed, indicating a prevailing upward trend in maintenance safety.

This section conducts an assessment of how the weights assigned to the first-level factors influence the overall five-element connection number. The sensitivity analysis serves as a means to discern the first-level factors that exert a significant influence on risk. This insight, in turn, informs subsequent research endeavors



(a) Density factor
(b) Importance factor



(c) Exposure degree factor
(d) Manpower/Personnel factor

Fig. 6 Trend of the 1st-order partial connection coefficient with relative weight.

aimed at devising low-risk scenarios for the program's task transfer process.

6 Conclusions

This paper expounds upon the theory of set pair analysis and the I.D.C. assessment model within the context of evaluating task transfer risk within aircraft maintenance programs. The study encompasses a comprehensive risk trend analysis validated through practical examples.

First, an I.D.C. assessment model for evaluating the risk associated with task transfer in maintenance is established. This model is grounded in the definition of the five-element connection number and incorporates weights derived from ANP calculations.

Subsequently, the study delves into the risk assessment of a specific zonal inspection item, specifically the landing gear maintenance task within the Boeing 737NG aircraft maintenance program, following its transfer to the zonal maintenance program. The current status of this task transfer is assessed, revealing a level 7 status, signifying a low-risk state, based on the interplay of its connection components. However, the relatively weak similarity in the first-level factor "Importance" underscores the need for attention to risk considerations in the task transfer process of aircraft maintenance programs. Further computation of the first-order partial connection number elucidates the evolving risk state of the system, enabling the pinpointing of vulnerabilities in task transfer and the formulation of corresponding preventive measures, encompassing both first- and second-level factors.

In future investigations, it is imperative to address the limitations and deficiencies inherent in the factor weights. This can be achieved through weight sensitivity analysis to ascertain key factors and enhance result robustness, as well as the utilization of comprehensive weight assignment methods to elevate weight accuracy. Furthermore, owing to the lucidity of the mathematical model and its clear physical implications, the risk evaluation method can facilitate automated risk assessment in the realm of maintenance program task transfers in forthcoming research endeavors.

Competing Interests The authors declare that they have no competing interests.

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