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Analytic network process in risk assessment and decision analysis ☆

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ABSTRACT

In risk assessment and decision analysis, the analytical network process (ANP) is widely used to assess the key factors of risks and analyze the impacts and preferences of decision alternatives. There are lots of comparison matrices for a complicated risk assessment problem, but a decision has to be made rapidly in emergency cases. However, in the ANP, the reciprocal pairwise comparison matrices (RPCM) are more complicated and difficult than AHP. The consistency test and the inconsistent elements identification need to be simplified. In this paper, a maximum eigenvalue threshold is proposed as the consistency index for the ANP in risk assessment and decision analysis. The proposed threshold is mathematically equivalent to the consistency ratio (CR). To reduce the times of consistency test, a block diagonal matrix is introduced for the RPCM to conduct consistency tests simultaneously for all comparison matrices. Besides, the inconsistent elements can be identified and adjusted by an induced bias block diagonal comparison matrix. The effectiveness and the simplicity of the proposed maximum eigenvalue threshold consistency test method and the inconsistency identification and adjustment method are shown by two illustrative examples of emergent situations.

1. Introduction

Over the past few decades, risk assessment and decision analysis has been an active research area (for instance: [33,4,13,11,18,24,53,54,55,56,48,20,50,28,29,30,31]). The decision analysts have to make quick and efficient decision for multi-criteria decision making (MCDM) problems such as identifying the key factors of the risk and the potential risk, determining risk level and risk consequences, analyzing the uncertain variables of a decision, considering different preferences, etc. For instance, the emergency managers have to select emergency prevention alternatives, emergency pre-response plans, emergency response alternatives, and emergency recovery alternatives [14].

The AHP (analytical hierarchy process), as a widely used MCDM method, is often implemented in the Benefit–Opportunity–Cost–Risk (BOCR) analysis to improve the effectiveness of risk assessment and decision analysis [52,46,1]. There are several assumptions when the AHP is applied to make decisions, such as, the independence between higher level elements and lower level elements, the independence of the elements within a level, and the hierarchy structure of the decision problem [38,47]. However, in reality, risk assessment and decision analysis problems are often too complicated to be structured hierarchically. In addition, the interactions of decision attributes within the same level and the feedbacks between two different levels are important issues that should be considered during the decision making process. Therefore, the AHP method does not work accurately when solving such decision problems [39].

The analytical network process (ANP), as an extensive and complementary method of the AHP, was introduced and further developed by Saaty [39,40,41,42,43,44,45,46]. The ANP method can be used to make decision problems that cannot be structured hierarchically and does not have the inner-independent and outer-independent assumptions. Since its introduction, the ANP method is applied to diverse areas. For instance, Lee and Kim [21] suggest an improved information system (IS) project selection method using the ANP within a zero–one goal programming model to solve the IS project selection problems. Hafeez et al. [10] provide a structured framework for determining the key capabilities of a firm using the ANP. Karsak et al. [16] employ the ANP to evaluate the interrelationships among customer needs and product technical requirements (PTRs) while determining the importance levels of PTRs in the house of quality (HOQ).

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Table 1
The average random index.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Niemira and Saaty [27] develop an imbalance-crisis turning point model to forecast the likelihood of a financial crisis based on an ANP framework. Chung et al. [7] employ the ANP to select and evaluate different product mixes in a semiconductor fabricator. Kahraman et al. [17] employ the ANP to obtain the coefficients of the objective function and propose a fuzzy optimization model for Quality function deployment (QFD) planning process using the ANP. Bayazit and Karpak [3] develop an ANP based framework to assess the implementation of total quality management (TQM). Aktar and Ustun [2] suggest an integrated approach of Archimedean Goal Programming (AGP) and Analytic Network Process (ANP) to evaluate the suppliers and determine their periodic shipment allocations given a number of tangible and intangible criteria. Caballero-Luque et al. [5] present a model based on the ANP to help organization managers to verify if their website contents are appropriate for satisfying the goals they have established.

In addition to the above fields, the ANP has also widely been used in risk assessment and decision analysis. For instance, Lu et al. [26] apply the ANP to deal with the degree of risk for the main activities of an urban bridge project. Raisinghani et al. [32] utilize the ANP to provide insight into optimum-seeking decision processes by managers and studies the 'systems with feedback' where the e-commerce strategy may both dominate and be dominated directly and indirectly by the business-level strategy. Dagdeviren et al. [8] employ the ANP to identify the faulty behavior risk (FBR) that is significant in work system safety. Besides, Levy and Taji [22] propose a Group Analytic Network Process (GANP) approach to support hazards planning and emergency management under incomplete information.

In the ANP, similar to the AHP, two issues need to be solved for a reciprocal pairwise comparison matrix (RPCM hereinafter): consistency test and inconsistent element(s) identification and adjustment. However, these issues are more complicated in the ANP than in the AHP since there are more comparison matrices in the ANP. There exist many studies in consistency test [35,34,12,36,25,51,23,6,15,19]. The most well-known consistency index for the pairwise comparison matrices in the AHP/ANP is the consistency ratio by Saaty. That is, $CR=CI/RI<0.1$, where the consistency index $CI=(\lambda_{\max}-n)/(n-1)$, RI is the average Random Index based on matrix size n, and $\lambda_{\max}$is the maximum eigenvalue of matrix A [36]. If the CR is less than 0.1, the comparison matrix passes the consistency test. Otherwise, the entry in the corresponding comparison matrix should be revised. For the inconsistent elements identification method, it does not have a commonly accepted method for the AHP/ANP. In the AHP software *Expert Choice*, an error matrix $\varepsilon_{ij}=a_{ij}(w_j/w_i)$ is constructed to identify the most inconsistent element [42].

When the ANP is applied to assess and analyze the factors of the existing risk and potential risks, as well as the impacts of a decision for an emergent event, the consistency of the comparison matrix and the inconsistent elements should be identified and adjusted as soon as possible. The risk assessment and decision analysis of an emergent event is a typical time-critical information service that is highly dependent on time and information. To improve the efficiency of response decision making in risk assessment and decision analysis, in this paper, a maximum eigenvalue threshold index method is proposed as the new consistency index for the ANP. A bias block diagonal matrix consisting of the inconsistent comparison matrices is introduced to rapidly identify and adjust the inconsistent elements in the original inconsistent comparison matrices when the ANP is applied to the risk assessment and decision analysis.

The remaining of this paper is organized as follows. Section 2 briefly reviews the traditional consistency test method and analyzes the issues of consistency test in the ANP. In Section 3, a maximum eigenvalue threshold method is introduced as the consistency index for the ANP. A block diagonal matrix is introduced to test the consistency of all comparison matrices simultaneously. The judgment process of the proposed method is also presented. An induced bias block diagonal matrix for inconsistency identification and adjustment is also proposed. In Section 4, two numeric examples are used to illustrate the proposed consistency index and the inconsistency identification method. Section 5 concludes the paper and discusses future research directions.

2. Existing consistency test method for the ANP

2.1. Existing consistency test method

The risk assessment and decision analysis is often complicated in nature and there are inconsistency issues when different attributes or criteria in the process of risk assessment and decision analysis are compared. 'Inconsistency itself is important because without it, new knowledge that changes preference cannot be admitted' [46, p. 15]. The inconsistencies can be classified into two types, cardinal inconsistency and ordinal inconsistency. For instance, suppose attribute A is 2 times important as attribute B, and attribute B is 3 times important as attribute C; however, attribute A is only 4 times important as attribute C instead of 6 times. Likewise, the values of A is bigger than B, B is bigger than C, and however C is bigger than A, namely, $A>B$, $B>C$, but $C>A$. Both of these issues are called inconsistency [36]. The final risk assessment and decision analysis could be inaccurate if the priority vectors are calculated from the inconsistent comparison matrix. Therefore, the consistency of each comparison matrix has to be tested before the comparison matrices are used to assess risk and analyze a decision. If the consistency test for the comparison matrix is failed, the inconsistent elements in the comparison matrix have to be identified and revised; otherwise, the result of risk assessment and decision analysis is unreliable.

The traditional consistency test method, which is also the most widely used consistency index, is the consistency ratio (CR) [36]:

$$CR=\frac{CI}{RI}<0.1 \tag{2.1.1}$$

where $CI=(\lambda_{\max}-n)/(n-1)$is the consistency index, RI is the average random index based on Matrix Size shown in Table 1, $\lambda_{\max}$is the maximum eigenvalue of matrix A, and n is the order of matrix A.