Research on Critical Technical Elements Recognition Method Based on AHP

Lingyu Sun¹, Lili Zhu¹, ², Ce Liu¹, Xiaoya Liu¹, Zhilong Li¹

¹School of Mechanical Engineering, Hebei University of Technology, Tianjin, 300130, China
²E-mail: 156184758@qq.com

Abstract. The assessment of technology-readiness level is widely used in the multi-disciplinary manufacturing field. The identification of critical technical elements is a key step in the assessment of technology-ready level, and it is an important guarantee to reduce risks in the project or product development process and reduce development costs. The identification of traditional critical technical elements generally adopts the expert scoring method. Through discussion, the list of critical technical elements of final consistency is obtained. The results are subjective and uncertain, resulting in the loss or redundancy of critical technical elements, which directly affects the key to technical readiness. Quantitative identification of technical elements. To this end, this paper proposes a method for identifying critical technical elements using the AHP principle. Firstly, the judgment matrix is established according to the criterion and the importance degree scale. The consistency matrix is used to check and adjust the judgment matrix according to the consistency ratio. Then the summation method and the square root method are used to solve the importance of each sub-technical element. Finally, according to the importance degree. Quantitative evaluation results identify critical technical elements and validate their validity by example pairs. The results show that the method combines qualitative analysis with quantitative analysis and has good engineering application value.

1. Introduction

Technology Readiness Level (TRL) is to develop grading standards according to certain principles and to classify a type of technical system or project to each level according to different stages to quantify the maturity of each technical system or project degree. It can reduce risks in the project or product development process and reduce development costs. The key to the assessment of the level of technology readiness is to find the critical technical elements (CTEs) of the project. The critical technical elements refer to the technical units that have a significant impact on performance costs during the development of the system or project, or at specified times and regulations. Within the scope of the fee, the performance requirements and tasks required to complete the project are novel. The accuracy of the identification of critical technical elements will directly affect the effectiveness of the technical readiness evaluation. In general, if the identification of critical technical elements is incomplete, it may cause technical blind spots in the project development process, thus affecting the progress and performance of the project; identifying too many critical technical elements will result in waste of development costs and delay in project progress.

At present, the traditional process of identifying CTE generally adopts the expert scoring method, that is, according to the characteristics of the project or system, the work/technical/functional structure is decomposed, the technical unit is found, the list of cte is manually screened, and then the experts score and give opinions. Through discussion, a list of critical technical elements for final consistency.
In general, this method has a lot of drawbacks. Because the number of experts is small, that is, the sample is small, the result is subjective and uncertain [1]. In literature [2], the critical technology elements recognition method based on rough set and information entropy is adopted. Although the evaluation results of this method are small, the evaluation results of this method mainly depend on the rationality of the design of the questionnaire. If the aspects considered in the design of the questionnaire are biased in terms of system performance and function, it will lead to deviations in the evaluation results.

To this end, this paper proposes to use the AHP principle to identify critical technical elements. AHP is a combination of qualitative methods and quantitative methods to transform unstructured complex problems into multi-level single targets. By quantitatively comparing the two relative importance degrees at the same level, and through simple calculation, the importance degree of the scheme is obtained, and the final goal is determined. AHP mainly from the evaluator to the evaluation of the nature of the problem, the understanding of the elements, more qualitative than the general quantitative method for qualitative analysis and judgment. Applying the Euclidean distance to the AHP operation, the extreme expert opinions are uniformly excluded, so that the final decision result can better reflect the expert's opinion.

2. Based on AHP Critical Technology Elements Identification Method

The critical technology elements identification method needs to evaluate each sub-technical element. The evaluation criteria are generally based on the CTE criterion in the US Technical Readiness Assessment Manual [3] (2009). According to the characteristics of China's large-scale projects, the criteria are as follows: 1) The technology has a significant impact on system performance, schedule, cost, and actual use; 2) the technology may cause major development risks or demonstrate verification risks; 3) the technology is new or re-packaged for new Related environment; 4) The technology has been modified from previous successful applications. According to the criteria, the experts analyze each sub-technical element one by one and evaluate the critical technical elements.

AHP (Analytic Hierarchy Process) is a decision analysis method proposed by American operations researcher Professor Saaty. This method generally divides the elements related to decision-making into three levels according to the principle: the target layer, the criterion layer and the solution layer, and uses a quantitative and qualitative analysis to calculate the weight of the scheme to solve a problem. It has been used to solve multi-level unstructured and complex decision-making problems, and has been widely used in various fields such as management decision-making, economic projects, investment, and personnel evaluation.

The process of using AHP to accurately identify critical technical elements is shown in Figure 1:

Step 1: Prepare the work; identify the problem, collect information, information about the progress, cost, performance, function, etc. of the project or system, and the main information of each technical element;

Step 2: Perform work structure decomposition (WBS) or technical structure decomposition (TBS), and layer the system step by step according to the function, to find the most basic constituent unit, that is, the sub-technical elements. Establish a hierarchical sorting structure, the top is the target layer, the bottom is the scheme layer, and the middle is the criterion layer or the index layer [4]. As shown in Figure 2, for the identification of center technical elements, the target layer is the critical technical element, the criterion layer is the identification criterion given by the expert, and the scheme layer is the sub-technical element found;

Step 3: Select the appropriate experts to set up an expert evaluation team and give the experts the appropriate weight. It is imperative to ensure the quality of the evaluation, and to ensure the impartiality, scientificity and authority of the members of the expert group based on the individual basic information, knowledge level, scientific research level, and level of appraisal [5].

Step 4, the expert scores the sub-technical elements according to the judgment criteria and establishes a judgment matrix. If there is a significant difference between one expert and other experts, the expert should re-evaluate.

Step 5: Check whether the judgment matrix has consistency. If there is consistency, directly calculate the importance degree of each sub-technical element. If not, perform judgment matrix
consistency adjustment, and then calculate each sub-parameter for the adjusted judgment matrix. The weight of the technical elements.

Step 6: According to the importance opinions of each expert on the sub-technical elements, the extreme expert opinions are excluded, and finally the critical technical elements are determined according to the importance of the sub-technical elements after excluding the extreme expert opinions.

**Figure 1.** Critical technology element identification steps

**Figure 2.** Hierarchical ranking structure

### 3. Judgment Matrix Establishment, Consistency Check and Adjustment

#### 3.1 Judgment Matrix Establishment

Set the technical elements of the \( n \) Project experts \( m \). In the analytic hierarchy process, in order to quantify the judgment, the center is to find a quantitative description of the relative importance of the two schemes to a certain criterion. The AHP method uses the 1-9 scale method, as shown in Table 1. Quantitative scales are given to define the judgment matrix for evaluating different situations. 

\[
A = (a_{ij})_{n \times m}, \quad \text{element } a_{ij} \text{ in judgment matrix representing sub-technology element } i \text{ break relative to sub-technical element } j \text{ degree of importance. The form of } A = (a_{ij})_{n \times m} \text{ is generally}
\]
Table 1. 1-9 Scales

| Factor ratio factor          | Scales |
|-----------------------------|--------|
| Equally important           | 1      |
| Slightly important          | 3      |
| Obvious main                | 5      |
| Strongly important          | 7      |
| Extremely important         | 9      |
| The Intermediate Value of Two Neighboring Judgements | 2, 4, 6, 8 |

Note: If the ratio of factor $i$ to factor $j$ is $a_{ij}$, then the ratio of factor $j$ to factor $i$ is $(a_{ij})^{-1}$.

3.2 Judgment Matrix Consistency Test

According to the principle of AHP, define: if $a$ is a reciprocal matrix, then there is $a_{ij} = (a_{ij})^{-1}$ ($i,j=1,2,3,\ldots,n$) and have $a_{ij} = a_{ji}$ ($i,j,k=1,2,3,\ldots,n$) when, $A$ is called a consistency matrix. If the judgment matrix established by the experts is consistent, it means that the expert's judgment is completely logical. However, the subjective factors such as expert knowledge level, knowledge experience and perceptual selectivity will inevitably affect the information in the judgment matrix, and the judgment matrix established by the experts may be inconsistent because of the ambiguity of the sub-technical elements themselves.

How to determine the consistency of the established judgment matrix, Saaty defines the consistency ratio $CR$ and give advice: when $CR$ if it is less than 10%, the information of the judgment matrix is considered to be reasonable, that is, the expert's opinion is reasonably acceptable. Otherwise, the correction judgment matrix needs to be adjusted to meet the consistency ratio requirement [6]. $CR$ the solution method is:

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

In equation (2), $CI$ --- Consistency indicator, the larger the value indicates the greater the degree of deviation of the judgment matrix. The solution method is:

$$CI = (\lambda_{\text{max}} - n)(n - 1)^{-1}$$

In equation (3), $\lambda_{\text{max}}$ --- Judging the maximum eigenvalue of matrix $a$, and

$$A \cdot \alpha = \lambda_{\text{max}} \cdot \alpha$$

In the equation (4), $\alpha$ --- Feature vector, normalized to get the weight vector $W$.

$\lambda_{\text{max}}$ Solving: For simple second-order third-order matrices, the solution method in linear algebra can generally be used to solve the eigenvalues. As the scheme (sub-technical elements) increases, the order also increases, which can be solved by using Matlab.

In equation (2), $RI$ --- Average stochastic consistency index, the following table 2 is the average.
random consistency index obtained by computing 1000 times of the 1-14 order positive reciprocal matrix in the literature [7].

| Order number | RI  |
|--------------|-----|
| 1            | 0.0 |
| 2            | 0   |
| 3            | 0.52|
| 4            | 0.89|
| 5            | 1.12|
| 6            | 1.26|
| 7            | 1.36|
| 8            | 1.41|
| 9            | 1.46|
| 10           | 1.49|
| 11           | 1.52|
| 12           | 1.54|
| 13           | 1.56|
| 14           | 1.58|

### 3.3 Judgment Matrix Consistency Adjustment

When calculating the consistency ratio $CR$ when the value is greater than 10%, it indicates that the unreasonable part needs to be corrected in the information given by the expert. According to the method of the degree of deviation in the literature [8], the logical relationship in the judgment matrix is analyzed, and the judgment matrix is corrected. The specific method steps are as follows:

1. In the judgment matrix, for any two sub-technical elements $i, j$ the discriminant information of the relative importance judgment is defined as $a_{ij}^k$.

   \[ a_{ij}^k = a_{ik} \times a_{kj} \quad (k = 1, 2, 3, \ldots, n \text{ And } k \neq i, j) \quad (5) \]

   Therefore, any one of the judgment matrices $a_{ij}$ corresponding to $(n-2)^k$, discriminating information indicating the expert's sub-technical elements $i$ And sub-technical elements $j$ discriminating opinions on the relative importance of other sub-technical elements, sub-technical elements of the output $i$ and sub-technical elements $j$ relative importance.

2. Use $\beta_y$ represents each element in the judgment matrix $a_{ij}$ the offset index is solved as shown in Equation 5.

   \[ \beta_y = \sum_{k=i, j}^n \left( \frac{(a_{ij} - a_{ij}^k)^2}{(a_{ij})^2} \right) \quad (6) \]

3. Compare and calculate $\max(\beta_y)$ find out what it corresponds to $a_{ij}$, and then $a_{ij}$ is the most contradictory element between the judgment opinions of experts in the judgment matrix and the logical reasoning.

4. Correcting expert discriminating opinions through logical relationships, that is, the most contradictory elements according to equation 6 $a_{ij}$ replace until the consistency requirement is met.

\[ a_{ij} = n - \left( \prod_{k=i, j}^n a_{ik} a_{kj} \right)^{\frac{1}{2}} \quad (7) \]

### 4. Critical Technical Element Weight Calculation

The method of analytic hierarchy process to solve the weights of sub-technical elements generally has the following four methods: square root method, summation method, eigenvector method and least square method. Each method can solve the importance degree. The eigenvector method has been used in the previous solution consistency. The eigenvector corresponding to the largest eigenvalue is the weight vector, and normalization is the importance. The following is the method of summation and root-square method to solve the importance.

#### 4.1 Summation Method

1. Normalize each column element of the judgment matrix, and the general terms of the elements are:
\[ a_{ij} = a_{ij} \left( \sum_{k=1}^{n} a_{kj} \right)^{-1} \quad (i, j = 1, 2, 3, \ldots, n) \]  

(8)

(2) Add the normalized judgment matrix of each column by row:

\[ \tilde{W} = \sum_{j=1}^{n} a_{ij} \quad (i = 1, 2, 3, \ldots, n) \]  

(9)

(3) Pairs of vectors \( \bar{W} = \left( \bar{W}_1, \bar{W}_2, \ldots, \bar{W}_n \right) \) Normalized processing:

\[ W_i = \tilde{W}_i \left( \sum_{i=1}^{n} \tilde{W}_i \right)^{-1} \quad (i = 1, 2, 3, \ldots, n) \]  

(10)

\[ W = (W_1, W_2, \ldots, W_n) \]  

That is, the weight of each sub-technical element sought.

4.2 Square Root Method

(1) The elements of 1a are multiplied by a new vector;

(2) To open each component of the new vector to the nth power;

(3) Normalize the resulting vector into a weight vector

\[ W_i = \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} \left( \sum_{i=1}^{n} \left( \prod_{j=1}^{n} a_{ij} \right)^{1/n} \right)^{-1} \quad (i, j = 1, 2, 3, \ldots, n) \]  

(11)

\[ W = (W_1, W_2, \ldots, W_n) \]  

That is, the weight of each sub-technical element sought.

Either one of the above three methods is obtained, and each expert is based on the criterion, the weight of each sub-technical element [9].

5. Elimination of Extreme Expert Opinions

Although experts’ own judgments are reasonable, there may be differences among different experts’ judgments, that is, there may be inconsistencies in decision-making in judging experts’ evaluation opinions in view of the possible inconsistencies in expert decision-making. In the literature [10], the Delphi method is proposed to deal with expert opinions. On this basis, the reliability distribution function of expert knowledge is proposed. The expert knowledge integration method is proposed through the description of expert knowledge. Finally, a prediction conclusion is drawn that is in line with the future development trend. This method is time-consuming. This paper makes the following adjustments to this problem. The method based on Euclidean distance eliminates extreme expert opinions. The importance of sub-technical elements of each expert opinion is arranged in high and low order. When the order is consistent, the critical technical elements and non-critical technical elements are the same, indicating that the expert opinions tend to be consistent; When there are inconsistencies, calculate the variance of expert opinions, definition \( W^p = \left( W_1^p, W_2^p, \ldots, W_n^p \right) \) \( \hat{p} \) the evaluation opinions of the experts on the importance of the sub-technical elements. And steps are as follows:

Step 1: according to the evaluation opinions of various experts, the ranking of sub-technical elements, definition \( r^p = \left( r_1^p, r_2^p, r_3^p, \ldots, r_n^p \right) \) Representative \( p \) Experts \( n \) The ranking of the importance of a sub-technical element,
Step 2: weighting the ranking according to the weight of the expert, defining \( r = (r_1, r_2, r_3, \ldots, r_n)^T \) for the weighted ranking situation.

Step 3: The euclidean distance is solved for each expert ranking opinion. 
\( d_p \) - the opinion of No. \( p \) expert and Euclidean distance of the average ranking vector.

\[
d_p = \left[ (r_1^p - r_1)^2 + (r_2^p - r_2)^2 + (r_3^p - r_3)^2 + \cdots + (r_n^p - r_n)^2 \right]^{1/2}
\]  

Step 4: according to the results of Euclidean distance, remove the most extreme expert opinions.

Step 5, the remaining experts’ ranking opinions are weighted and averaged according to the weight of the experts, and the ranking of the importance of the final sub-technical elements is obtained \[11\].

\[
R_i = \sum_{p=1}^{m} E_p r_i^p \left( \sum_{p=1}^{m} E_p \right)^{-1}
\]  

In equation (13), \( R_i \) -- The importance ranking of the final sub-technical elements, \( E_p \) -- The weight of the number \( p \) experts.

Step 6: the key technology elements are obtained, and the reasons why the non-key technology elements are not selected are explained.

6. Application Examples
Taking an industrial robot as an example, in the design and manufacture of a robot project system, the main technical elements involved are servo drive technology, high precision and high strength transmission technology, multi-axis coordinated motion control technology, structural finite element analysis and optimization technology, and driving transmission parameter matching technology. Five experts were invited to give weights of 0.22, 0.18, 0.18, 0.28 and 0.14 to five technical elements according to the criteria, authority, familiarity and fairness of judgment. The judgment matrices of five technical elements are established respectively:

\[
A_i = \begin{bmatrix} 1 & 2 & \% & 5 & 3 \\ \% & 1 & \% & 4 & 2 \\ 2 & 3 & 1 & 3 & 3 \\ \% & \% & \% & 1 & \% \\ \% & \% & \% & 3 & 1 \end{bmatrix}
\]

\[
A_2 = \begin{bmatrix} 1 & 3 & \% & 3 & 2 \\ \% & 1 & \% & 1 & \% \\ 2 & 4 & 1 & 4 & 2 \\ \% & \% & \% & 1 & \% \\ \% & 3 & \% & 3 & 1 \end{bmatrix}
\]

\[
A_3 = \begin{bmatrix} 1 & 2 & \% & 7 & 2 \\ \% & 1 & \% & 2 & \% \\ 3 & 3 & 1 & 4 & 2 \\ \% & \% & \% & 1 & \% \\ \% & 5 & \% & 3 & 1 \end{bmatrix}
\]

\[
A_4 = \begin{bmatrix} 1 & 2 & \% & 1 & 1 \\ \% & 1 & \% & \% & \% \\ 3 & 3 & 1 & 2 & \% \\ \% & \% & \% & 1 & \% \\ \% & 3 & \% & 2 & 1 \end{bmatrix}
\]

\[
A_5 = \begin{bmatrix} 1 & 2 & \% & 1 & 1 \\ \% & 1 & \% & \% & \% \\ 3 & 3 & 1 & 2 & \% \\ \% & \% & \% & 1 & \% \\ \% & 3 & \% & 2 & 1 \end{bmatrix}
\]

Calculated by MATLAB

\[
CR_1 = 0.0596 \quad CR_2 = 0.0711 \quad CR_3 = 0.0411 \quad CR_4 = 0.0979 \quad CR_5 = 0.0787
\]

\[
W^1 = (0.2770, 0.1727, 0.3747, 0.0613, 0.1142)^T \quad W^2 = (0.2610, 0.0804, 0.3815, 0.0804, 0.1967)^T
\]

\[
W^3 = (0.1726, 0.1549, 0.3406, 0.0886, 0.2433)^T \quad W^4 = (0.2554, 0.0924, 0.3821, 0.0562, 0.2139)^T
\]

\[
W^5 = (0.1718, 0.0724, 0.2289, 0.2702, 0.2566)^T
\]

\[
r^1 = (r_1^1, r_2^1, r_3^1, r_4^1, r_5^1)^T = (2, 3, 1, 5, 4)^T \quad r^2 = (r_1^2, r_2^2, r_3^2, r_4^2, r_5^2)^T = (2, 4, 1, 4, 3)^T
\]
The weighted importance ranks as follows:

\[ r^1 = (r^1_1, r^1_2, r^1_3, r^1_4, r^1_5) = (3, 4, 1, 5, 2) \]
\[ r^2 = (r^2_1, r^2_2, r^2_3, r^2_4, r^2_5) = (2, 4, 1, 5, 3) \]
\[ r^3 = (r^3_1, r^3_2, r^3_3, r^3_4, r^3_5) = (4, 5, 3, 1, 2) \]

The weighted importance ranks as follows:

\[ r = (r_1, r_2, r_3, r_4, r_5) = (2.46, 3.92, 1.28, 4.26, 2.36) \]

The Euclidean distances calculated by equation (12) are as follows:

\[ d_1 = 2.0913 \quad d_2 = 0.8795 \quad d_3 = 1.0265 \quad d_4 = 1.1196 \quad d_5 = 4.1537 \]

From the result of Euclidean distance calculation, we can see that the judgment of the fifth expert is obviously different from the opinions of other experts. Therefore, the last expert's opinion is omitted. According to formula (13), the result is as follows:

\[ R_1 = 2.21 \quad R_2 = 3.74 \quad R_3 = 1 \quad R_4 = 4.79 \quad R_5 = 2.42 \]

According to the expert opinions, the importance ranking of each parameter of expert opinions is: multi-axis coordinated motion control technology, servo drive technology, driving parameters matching technology, high-precision and high-strength transmission technology, structural finite element analysis and optimization technology. According to the experts' opinions, the first four are all key technology elements. Structural finite element analysis and optimization technology are not key technology elements, because in industrial robots, the focus is on the repetitive positioning accuracy, that is, the positioning situation under the same load.

7. Conclusion

Because of the difference of expert's prior knowledge, learning, research field and the complexity of objective things, it is subjective and time-consuming to recognize the traditional key technology elements. It has certain advantages to identify key technology elements based on AHP method.

1. This method transforms the qualitative problem into a problem that combines quantitative and qualitative methods. In the process of identification, it does not depend entirely on the subjective ideas of experts and is more objective.
2. In the process of identification, each expert makes a judgment matrix for each sub-technical element according to the criterion of identification, and calculates the importance of each sub-technical element according to the judgment matrix of each expert, which saves the experts from discussing one sub-technical element item by item, thus saving unnecessary time and cost.
3. In the process of calculating the importance and checking and adjusting the consistency of judgment matrix, we can rely on computer, which is scientific and accurate.

At the same time, the AHP method also has some shortcomings in identifying key technical elements: when expert decision-making opinions are inconsistent, the use of euclidean distance can only eliminate very few extreme opinions. The next step is to improve the consistency and coordination of expert decision-making.

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