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Cutting tools evaluation model based on TRIZ and AHP-FCE

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INTRODUCTION

Cutting tool plays a very important role in the cutting system of machining. The selection of the cutting tool can affect not only the quality of product, but also the accuracy and efficiency of machining process tremendously.

However, in the actual production process, the selection of cutting tool is normally based on the relevant manuals or the experience of process designers, which usually leads to decline the product quality and raise the production cost. According to current research, evaluating cutting tools before they come into use is an ideal solution to address this issue. Some progress has been made after years of study. Dan Wu adopted the method of multi-factor evaluation to build the machine tools evaluation model and assigned the weights of the indicators by AHP[1]. Lan Li established an evaluation model, which set the quality, time and cost as the total optimization [2]. The model applied with using fuzzy mathematics. Depending on the previous researches, Xianchun Tan built the indicators system for green manufacture by taking into account the factors of environment and resources [3].Wen Mao combined the model with fuzzy clustering analysis algorithm[4] and applied the above model into high-speed cutting technology [5]. Li Yan proposed a method to evaluate cutting tools through grey relation decision-making [6]. Kuiwei Zhang improved the above approaches by combining analytic hierarchy process and grey correlation method [7].

Those studies which mentioned above have provided some methods for evaluating the cutting tool. However, there are still remaining some problems in the study: Initially, there is no scientific method to select the evaluation indicators, and the indicator systems proposed divorce theory from practice. Secondly, the method was used separately, which cannot take the advantages of the various evaluation methods.

This paper proposed a method to build the evaluation indicator system by using Theory of The Solution of Inventive Problems, assigned the weights of the indicators with AHP and solved the evaluation model with FCE. In the end, a case study was given to demonstrate the specific application of this method.

2. Theoretical Foundation

*2.1.TRIZ.*TRIZ, which is a Russian acronym for the Theory of Inventive Problem Solving, is originally proposed in 1946 when Altshuller, who is a mechanical engineer, studied patents in the Russian Navy [8]. This method solves technical problems. It offers innovative product structures by employing a knowledge base, which is based on the analyses of approximately 2.5 million patents in mechanical design [9].

The TRIZ methodology claims that, innovative problem contains one contradiction at least. Analyzing and solving contradiction are the driving force to promote the development of things, and they are also the key steps to solve the problem.

The application of TRIZ to solve problem is generally like this: first of all, analyze the problem. In this step, the specific problem should be abstracted and converted into standard problem model of TRIZ theory. Then, the standard problem model is transformed into the standard solution model by the methods and tools in TRIZ. Finally, embody the standard solution model into specific solutions according to the actual conditions. During the transformation of the standard problem model into the standard solution model, there are three specific methods: First, engineers can find out the contradiction and solve it with the corresponding conflict resolution theory. Second, when the problem is distinct but it is unknown how to solve it, the knowledge base is a very useful tool in the model. Third, the model predicts the evolution direction of the system by technology system evolution theory, which can inspire the designer [10].In addition, the results may be unsatisfactory when the method is used just for one time, so testing the method repeatedly is recommended. The method is shown in FIGURE 1.

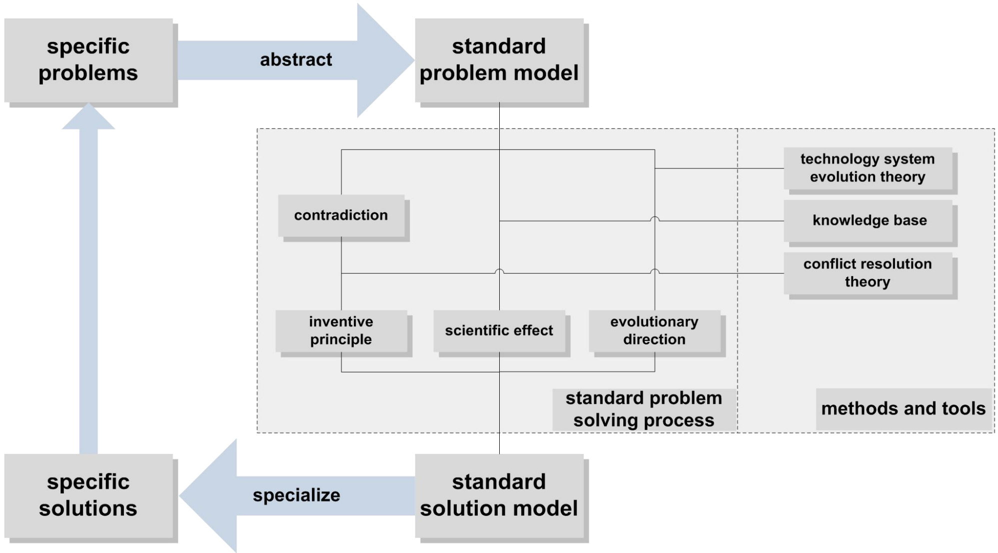

FIGURE 1: The method of solving problem by TRIZ

Technical Contradiction Matrix is the most widely used tool of TRIZ. Technical contradiction means that the behaviors can lead an improvement to a certain aspect of the system while other aspects are deteriorating. Technical contradiction is often shown as a conflict between two subsystems in the system [11]. After identified the significance of contradictions, Altshuller went on to classify them into 39 parameters and 40 inventive principles that are repeatedly used in patented solutions. To display the possible technical contradiction combinations, he produced a 39 *39 matrix and put the 40 inventive principles in the matrix according to their frequency of utilization. This matrix is called the Technical Contradiction Matrix [12].

Engineers can use contradiction matrix to solve innovation problem in the design process. The usage of contradiction matrix is as follows. Find the improving parameter (IP) in the first column and the avoiding degradation parameter (ADP) in the first row. And the proposed invention principles are found at the intersection of the row and column of the two parameters as shown in FIGURE2. The proposed invention principles inspire the designers to generate innovative thinking and solve the contradiction.

	1	2	……	Avoiding Degradation Parameter	……	39
1						
2						
……						
Improving Parameter				**Proposed Invention Principle**		
……						
39						

FIGURE 2: Usage of Technical Contradiction Matrix

2.2. Comprehensive Evaluation. With the development of science and technology, people's view on things become more and more comprehensive. To deal with this problem, comprehensive evaluation method is proposed, which is a method which evaluates several units by multiple indicators. It is known as multivariate comprehensive evaluation method or comprehensive evaluation method in short. It is a new emerging, multidisciplinary edge crossing research field. The basic idea is evaluating things according to an indicator, which is transformed from several indicators so as to it reflects a comprehensive situation [13].

There are a lot of comprehensive evaluation methods, such as analytic hierarchy process, principal component analysis, data envelopment analysis. In addition, some emerging disciplines develop rapidly, such as fuzzy mathematics, neural network, grey system theory. These disciplines are introduced into this field, forming a new comprehensive evaluation method. For different evaluation methods, the basic steps are similar. They are shown as follows. Firstly, analyze the object of evaluation and establish evaluation indicator system, next determine the weights of indicators, then build the evaluation model, and finally analyze the results of evaluation [14].

In recent years, researchers in domestic and abroad have done a lot of researches on the comprehensive evaluation method. However, there are still some problems. This paper mainly considers the following two points: First, the evaluation methods are often used individually, and research on the application of integrated evaluation method is rare. Second, there is a gap between theory and practice, mainly in the process of indicator selection.

2.2.1.Analytic Hierarchy Process. AHP, which is a method proposed by Saaty in the nineteen seventies, compares and sorts the alternative proposals, when dealing with the complex decision problem [15].

AHP is one of the most widely used comprehensive evaluation methods, especially in the selection of multi criteria evaluation. It can reflect the contradictions of system expressly and guide the designers directly [16]. AHP methodizes and hierarchizes the problem by analyzing the factors and their correlation contained in complex systems. The main idea is demonstrated as follows. Decompose, analyze, compare, and synthetize. It is showed as follows. First it constructs a hierarchy structure model, and then carries out an inter-comparison between the elements in each level, obtains the relative important degree of comparative scale and establish judgment matrix. And then calculate the eigenvector corresponding to the maximum eigen value, which is the relative importance of each factor to the upper level factor. Instead of the traditional artificial weighting method, the weights are set up in a more scientific way [17].

2.2.2. Fuzzy Comprehensive Evaluation Method. In the objective world, it is difficult to describe something, whose definition is not clear, by a simple mathematical method. In order to solve this problem, I. A. Zaden, an American scholar, established the fuzzy set theory in the 60s of this century, which has been widely used in various fields [18]. FCE is an application of fuzzy set theory, which can provide some comprehensive evaluation methods for actual problems. More specifically, FCE is a method based on the fuzzy set theory, which can turn some blurred and indistinct factors into quantitative factors, and evaluate objects from multiple indicators according to the grade of membership. It is an excellent tool deal with the vagueness and uncertainty in practical problem.

3.The Proposed Approach

This paper analyzed the currently existing cutting tools evaluation model and selects the appropriate evaluation indicators with TRIZ, established the indicators system, built and solves the model through combining APH and FCE. TRIZ is used to remove the gap between theory and practice in the research of comprehensive evaluation method. The combining of AHP and FCE can utilize their respective advantages: AHP is used to determine the weights, it is more scientific and easier to be operated and the mathematical model based on FCE can deal with the vagueness and uncertainty in cutting tools selection. The solving flow path is shown asFIGURE3.

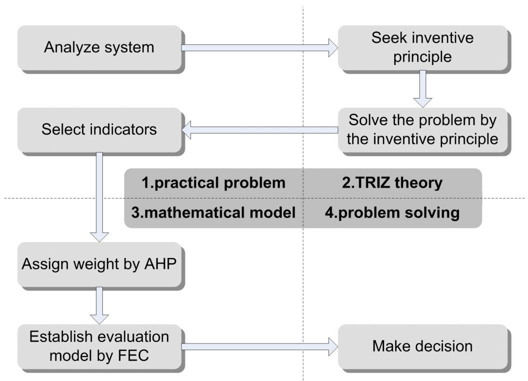

FIGURE3:Problem solving flow path

3.1. Analyze System. To analyze the system, the production range and batch of the company should be explicated. The scale and technical level are also important factors, which determine the level of the collection, organization and analysis of the data. In addition, the mainly users crowd of the system needs to be clarified, which decides the complexity of the utilization and reliability of the information.

The specific situation of this factory is shown as follows. The main production object is turbine, so the range of the component size and batch is quite wide, and the product stages of the factory differ greatly, which range from the development of new products to volume-produce of mature products. Moreover, the number of cutting tools in this factory is too large to analyze and measure, but there is some information of the cutting tools in the ERP system. Additionally,the process designers are the mainly evaluators of the cutting tools.

Judging from the above analysis of the cutting tools evaluation system, it gets the following conclusions.Evaluation indicators should guarantee the objectivity and reliability of the result and reduce the complexityto measure. In addition, the system should have the ability to deal with various situations, such asdifferentbatches and production stages.

The model describes the system using the following technical factors shown in TABLE 1.After finding the improving parametersin the first column, the avoiding degradation parametersin the first row, the proposed invention principle can be found at the intersection of the row and column of the two parameters in the contradiction matrix.

TABLE1: Technical factors

No.	Inventive Principles
24	operating efficiency
26	time wasting
32	adaptability
33	compatibility and connectivity
34	utilization convenience
35	reliability
36	ease maintenance
47	difficulty of measurement
48	accuracy of measurement

Seek for the common technical parameters mentioned before, the following inventive principleswere chosen to guide the establishment of the indicator system.

Extraction: Extract the indicators whichare hard to be measured or have little influence on the evaluation result, so the indicators which are easier to be measured and more critical are selected.

Combination: Although different indicators have different influence on the result, but some indicators which have the same dimension, function and importancecan be combined to reduce the complexity of the indicator system.

Dynamic property: It is reasonable to adjust each indicator and their weightsto evaluate the cutting tools exactly in each different production situation.

*3.2 Select Indicators by TRIZ.*The indicators should be selected by the inventive principle which mentioned above.

In the currentresearches, cutting tools evaluation model includes many factors, such as: function parameter, motion parameter, manufacture parameter, installation parameters, surface treatment, heat treatment, usability, economic [19]. Although these indicators are reasonable, there still exist some problems: They are difficult to be measured, the application range is limited and the adaptability is poor. This paper establishedan indicator system according to the following methods with the help of TRIZ.

When establishing the first level indicators, the dynamic property principle is used. In the experimental and developing stage, the key point is the quality of the products and whether the cutting tools can be used, anddesigners don’t care much about the time, cost, environmental effectiveness and operability. After starting mass production, a company should take into account the efficiency, economy and environment, etc. Applying the dynamic method for the assignment of the weightsof the first grade indicators can lead to a more practical result. Therefore, machining quality, machining requirement and machining influence are selected as the first level indicators.

When establishing the second level indicators of machining quality, the extraction principle is used.For instance, in the traditional evaluation of the cutting tools’ material, designers should take the hardness, strength, toughness, heat resistance, thermophysical characteristic, thermal shock resistance, cohesiveness resistance, chemical stability and so on into account [20]. However, in the actual evaluation process, it is difficult to measure and analyzeall above indicators. On the other hand, the influence of the various indicators of machining process is very complex,sothere is noreliable and general method whichevaluates cutting tools materials with these indicators. Therefore, the modelextractedthe ISO standard classificationto evaluate the cutting tools materials. The cutting tools materials which match the workpiece material classification, can meet the requirements of processing in all aspects,including the physical and chemical properties. In addition, the indictors are easy to obtain, which can be directly looked up in the ERP system, so it's suitable to evaluate the cutting tools materials with the ISO standard classificationin the actual process.

When establishing the second level indicators of machining requirement, the combination principle is used. The indictors,which are used to evaluate the process efficiency, include many factors, such as cuttingtime, tools changing time and so on.They can be added together and use the sum as the evaluation indicator of efficiency.

So in the end,the modelchose the machiningquality, machining requirement and machining influence as the first level evaluation indicators, and chose the material of blade, shape of blade, groove of blade, fillet radius, total time, total cost, greenness and agreeableness as the second level evaluation indicators, as shown in FIGURE4.

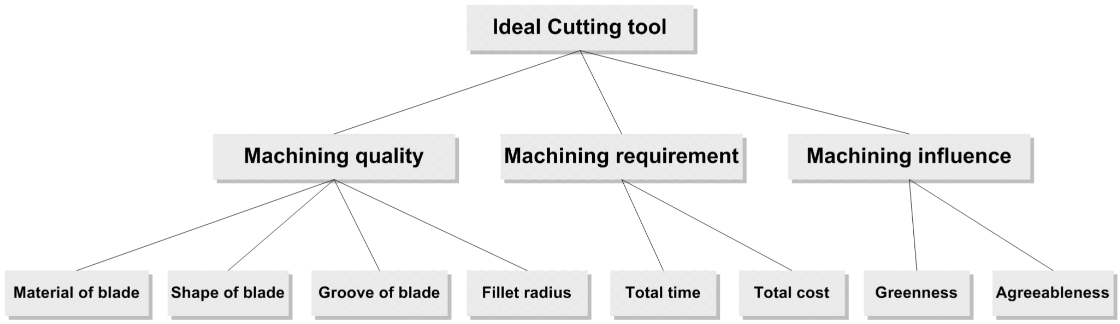

FIGURE4: The indicator system of cutting tools evaluation system

These evaluation indicators adequately consider the inventive principle. The establishment of these indicators takesnot only the objectivity and accuracy of the evaluation, but also the operability and computational simplicity of the measurement into account.And the evaluation system becomes adaptive in the actual situation,so it can give practical guidance indifferent stages of production.

*3.3. Assign Weights by AHP.*Weights of the cutting tools evaluation indicators can be assigned by the following steps. Establish the judgment matrix.Compare the indicators with each other, which belong to the same indicator of the higher lever.

The judgment matrix is an n*n matrix, and n stands for the number of indicators. The established matrix is expressed as:

A=

Here, a_{ij} stands for the comparison numberof element i to element j with respect to each criterion. The 9-pointscale, shown in TABLE 2, can be used to decide on which element ismore important and by how much.

TABLE 2:AHP pairwise comparison scale

Intensity	Intensity	Explanation
1	Equal	Two activities contribute equally to the object
3	Moderate	Two activities contribute equally to the object
5	Strong	Two activities contribute equally to the object
7	Strong	Dominance of the demonstrated in practice
9	Extreme	Evidence favoring one over another of highest possible order of affirmation
2,4,6,8	Intermediate	When compromise is needed
Reciprocals of the above numbers		For inverse comparison

Then check the consistency of the established matrix: Figure out the coincidence indicator using the following formula:

(1)

Here, is the maximum eigenvalue of the matrix, and n is the order of the matrix. Then look up the random index(R_I) in TABLE 3, and figure out the consistency ratio using the following formula:

(2)

TABLE 3: Random index

N	1	2	3	4	5	……
R_I	0	0	0.52	0.89	1.12	……

When C_R<0.1, the judgment matrix is accepted.

Next,rank the indicators in single level: Considering the accuracy and the complexity of the operation, we select the feature vector method.The weight vector can be calculated by the following formula:

(3)

Here, N is one of the eigenvalues of the matrix, and W is the eigenvectors corresponding to the eigenvalues n, which is alsothe weights vector.

After the weights of the indicators which are relative to the higher level are obtained, multiply each layer weights together from bottom to top, and the result is the total weights.

3.3. Establish Evaluation Model by FCE. After the weightsareobtained, the model establishes evaluation model and get the evaluation result by FCE by the following steps.

Firstly, the model should determine the remark set, which can be divided into five grades: V=(excellent, good, general, bad, very bad), and the corresponding value scale: E=(100,80,60,40,20).

Then experts are invited to grade the same indicator, and establish the fuzzy matrix using the membership degree formula:

(4)

Here, c_{ij} is the number of experts who grade the j remarkon theindicator i.And c is the total number of the experts. The fuzzy matrix is expressed as:

F=

Next the result of the fuzzy comprehensive evaluation can be obtained by using the formula:

(5)

Here,W is the weight vector, which should be normalized to satisfy the following equation:

(6)

Finally, the priority of each cutting tool can be calculated by the formula:

(7)

The cutting tool with larger value of N is preferred.Then cutting tools should besortedby Nand process designers can select the cutting tools reasonably according to the rank.

4. CASE STUDY

A batch of shaft parts of material 1Cr11Mo1NiWVNbN need to be semi-finished now. And there are two cutting tools are available after chosen by the cutting tools select system. They are: DNMG150608-NF4 produced in

Germany and DNMG150608-DF produced in China. Because the production belongs to the experimental stage, the quantity is small but the follow-up experiment depends on this experiment data, that is to say, the experiment should be accomplished as soon as possible.

4.1 Assign the Weights of the Indicators by AHP. As referred by the preceding part of the paper, designers selected machining quality, machining requirements and machining influence as the first level indicators, and selected the other 8 indicators such as material of the blade, shape of the blade as the second level indicators. After discussing by the process designers, the following judgment matrixesare obtained:
The judgment matrix of first level is:

A_1=

The judgment matrixesof second level are:

A_{21}=,

A_{22}=, A_{23}=

Using the formula(3), the weightsare acquired:

W_{A1}=(0.9161,0.3715,0.1506),

W_{A21}=(0.8578,0.4744,0.1732,0.0959),

W_{A22}=(0.9806,0.1961),

W_{A23}=(0.3162, 0.9487).

Then check the consistency, the check results are shown in TABLE 4.

TABLE 4: Check results of the consistency

Index	A_1	A_{21}	A_{22}	A_{23}
λ_{max}	3.0385	4.0104	2	2
C_I	0.01925	0.00346	0	0
R_I	0.52	0.89	0	0
C_R	0.03701	0.00389	0	0

It can be seen from the table, each index of C_R values is less than 0.1, so the indicators are consistent. Then the indicator weights of each layer were multiplied to get the total weights, the results are shown in TABLE 5

TABLE 5: Weight of each index

Index	Weight
Material of blade	0.78583
Shape of blade	0.43459
Groove of blade	0.15866
Fillet radius	0.08785
Total time	0.36429
Total cost	0.07285
Greenness	0.04761
Agreeableness	0.14287

We normalize the results and express them in a vector form:

W=(0.37517, 0.20748, 0.07574, 0.04194, 0.17392, 0.03478, 0.02273, 0.06821)

*4.2. Establish the Cutting Tools Evaluation Model by FCE.*Inviting several experts to mark the two cutting tools, we get the fuzzy comprehensive evaluation matrixes as follows.

F_1=

F_2=

According to the weight vector W, as figured out by the preceding part of the text, using the formula(5) and normalizing the computation, The results of comprehensive fuzzy evaluation can be obtained:

S_1=(0.343,0.259,0.280,0.098,0.020)

S_2=(0.238,0.294,0.349,0.119,0.000)

Finally, we can use the formula(7) to figure out the priority of the two cutting tools respectively: N_1=76.14, N_2=73.02.
Apparently, $N_1>N_2$, so DNMG150608-NF4 is more suitable as the cutting tool for the machining.

In order to verify the rationality of the results, some experts and process designers in the factory were invited to select the two cutting tools mentioned above based on their knowledge. And the result is shown in FIGURE 5. On the whole, the majority of them chose DNMG150608-NF4, and a few of them chose the DNMG150608-DF. After further analysis it can be found that the people, who selected DNMG150608-DF, are mostly process designers rather than the experts. To capture the reason for their decision, the people who chose DNMG150608-DF were interviewed. Their statements showed that they chose DNMG150608 – DF mainly because of its relatively lower price.

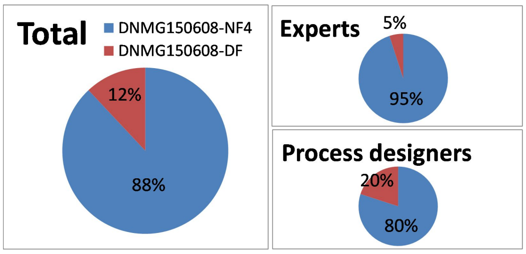

FIGURE5:The select result of the experts and process designers

The experimental stage, however, focuses on the processing quality and the cost should be a secondary consideration. In summary, according to the present situation, DNMG150608 - NF4 is a better choice, which is same as the result gotten by the evaluation model. So the proposed method is feasible, which can be used in the practical selection process.

CONCLUSION

This paper proposed anevaluation model of cutting tools which is based on the combination of TRIZ, AHP and FCE. A case was used to check the rationality of the proposed model.The research result demonstrated that the indicators chosen by TRIZ are scientific and reasonable, which reduced the difficulty of evaluating on the basic of guaranteeing the reliability and accuracy of the result. And it can also make different evaluation schemes in order to adapt to different enterprise scales and production stages. This method was made clearly and scientifically to the user by obtaining the relative importance of each indicator and calculating the weights by AHP. Furthermore,FCE solved the vagueness and uncertainty in the process. To summarize, establishing the cutting tools evaluation model by TRIZ eliminated the disconnection between theory and practice.The disadvantage, which is inevitable when applying only one method, wasavoided by combining AHP and FCE,The furtherresearch will continue to test the model in practical situationsand strengthen TRIZ by utilization of other tools such as QFD and so on.

Acknowledgments
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