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The Optimizing Strategy of Systematic Process Innovation based on QFD TRIZ and AHP

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Abstract: Process design is often associated with the compromises of conflicting process parameters, which means a rising cost and a loss of quality. Innovation in process system can create great value. The rapid development of technology and commercial environment suggests that innovative process design needs the support of a systematic innovation strategy. The strategy combining inventive tools is proposed to support process innovation. Firstly, analyze the process system according to constraints, and employ Quality Function Deployment (QFD) to obtain process requirements. In this way, the conflicts of process system can be found accurately, then analyze these conflicts comprehensively, and creatively solve these process problems with the help of the Russian Theory of Inventive Problem Solving (TRIZ), and acquire more feasible solutions or inspiration through the proposed approach. After that, use Analytic Hierarchy Process (AHP) to select the best feasible alternative under multiple evaluating standards. In this approach, both the efficiency and maneuverability of applying Inventive tools to solve process problems are improved. Finally, the performance of the proposed strategy is illustrated and validated by the example of grinding process system.

Keywords: Process Innovation, TRIZ, AHP, QFD

1 Introduction

According to the research of U.S. National Productivity Survey Committee, process technology contributed 57% to the productivity in the last century. Process also plays an important role between design and production. On the other hand, process design has objectives and constraints, and even a simple process requires a trade-off among many factors. The great value created by process and the rapidly changing modern marketplace drives companies to seek competitiveness in process development in terms of innovation, high quality, and speed to market. However, previous research on process innovation design was not enough compared with the research on product innovation. Therefore, it is crucial to pay attention to the research on process innovation.

Most previous work on process innovation in the manufacturing industry was based on an economic perspective. Stobaugh (1998) argued that increased competition in the industry has propelled innovation throughout history. Albach (1996) in the European Community Innovation Survey I (CIS I) concluded that cost and financial factors were the primary concerns for innovations in the 1990s. While these studies focused on economic issue, a number of publications have addressed innovation in the manufacturing industry from an environmental perspective. These studies suggest that process efficiency improvement and the use of new technology are among the most promising fields of research concerning innovation in process innovation (Dijkema, 2004; Korevaar, 2007; Patel, 2009). Combining the economic and technological perspectives, one would then ask: what factors encourage and hinder process innovation? Or more broadly, is there any scientific method to encourage process innovation? So far, a study that can answer these questions is still needed. Exploring the answers to this question will provide the industrial community with some insights into how process innovation in the manufacturing industry can be stimulated.

There are some answers that have been generated to the research question on process innovation in manufacturing industry.

First, as far as process efficiency is concerned, R&D and innovation have not been a top most objective for manufacturing firms. Second, the creative theory which is widely applied in product innovation hasn't been

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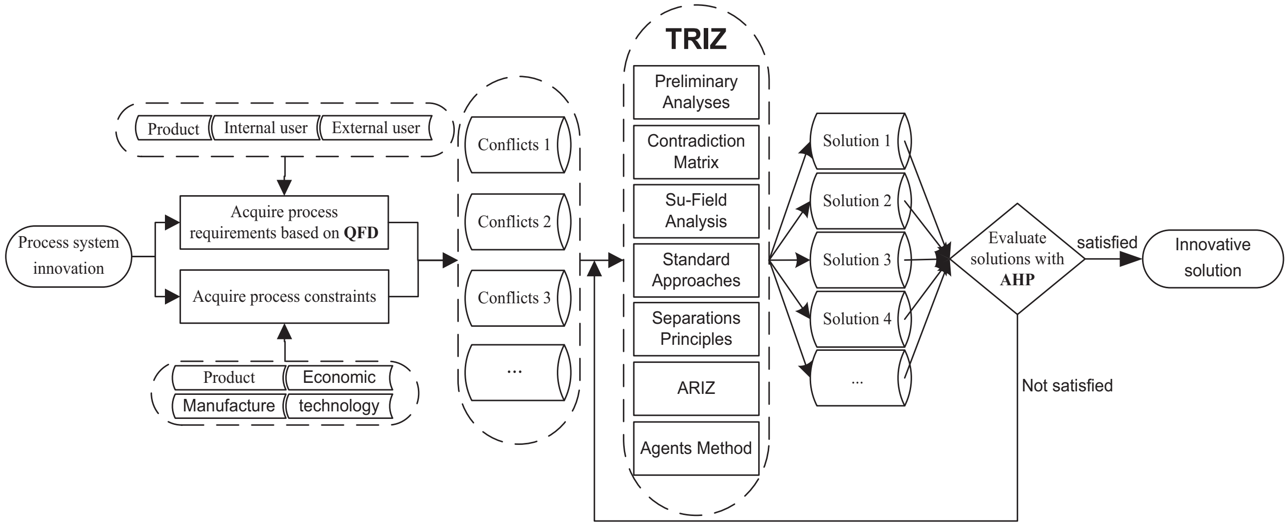

Fig. 1: The strategy of process innovation.

researched in the field of manufacturing process. Third, manufacturing efficiency improvement is a desirable and possible reward, especially in the case of improving existing processes. While improving existing processes is related to operational performance, developing new processes is a strategic innovation, or of strategic importance. For developing new processes, specific synthetic pathways are considered in the first place for its importance to firms' long-term development [1].

Process innovation usually means the change of technology, which involves new design, process technology, equipment and management model. At present, some researchers have applied innovative methods to process design. Scholars of Sichuan University proposed a strategy of process innovation design: Combining process elements, process engineers use the TRIZ method to guide process innovation, and solve the conflicts of the process system.

Since the process design in the early design stage plays a critical role which determines the manufacture of product, it is extremely important to build a systematic approach of process design. For a process engineer, when he/she tries to solve a process innovative problem, he/she usually faces a systematic incompatibility or technical conflicts. As the process engineer changes certain parameters of the system in his/her thorny design problem, it might affect other parameters badly, because numerous factors which interact with each other have an impact on process conflicts. Traditionally, the process engineer always compromises with this kind of contradictory situations and restricts him on performing innovative design tasks. The practice of using trade-off parameters as a tool for systematic innovation in the process design has only recently emerged from TRIZ. Numerous researchers have applied the concept of process design trade-offs to help acknowledge and manage process conflicting performance parameters, and find the creative solution of process system.

TRIZ is a theory which can effectively solve technological conflicts with creative ideas. There are lots of conflicts in the process system, so it is appropriate to apply TRIZ into process innovation design. Process engineers need to establish conflict models, when applying TRIZ. Consequently, analyzing process requirements and constraints, which are the source of the process conflicts, is inevitable [2]. However, if one wants to solve a process problem, especially in a complex process system, it is necessary to learn about all demands, not only users' demands but also the demand of engineers, designers, workers and managers. And QFD (Quality Function Deployment) can be an effective tool to analyze the requirements. In addition, AHP can be used to select the most inventive process solutions.

According to the above, this paper proposed an optimizing strategy of process innovation. QFD, AHP and TRIZ are applied as an integrated methodology for generating and selecting of an appropriate process system solution. Firstly, the QFD is applied to turn the process requirements into technical characteristics. Meanwhile, lots of process conflicts can be found, considering the constraints of process system. In this case, TRIZ is applied, for example, engineers can use the contradiction matrix which is one of effective tools of TRIZ to break up the complex design problem into incentive principles, and several alternative innovative solutions are achieved. After that, with the purpose of finding the best solution, the AHP is conducted by decomposing the structure of decision process into a hierarchical sequence which determines the relative importance of each alternative process innovations through pairwise comparisons. The common design parameters for selecting a suitable process system include productivity, safety and environment, quality, flexibility, and cost. If engineers are not satisfied with the achieved solution, it is needed to solve the process problem again with TRIZ or other innovative theory. The integrated approach is shown as Fig. 1.

2 Methods Explanation

2.1 Evaluate the process system based on requirements and constraints

Process requirements and constraints exist simultaneously [3], which usually generate lots of process conflicts, for example the contradiction between precision and speed, and the contradiction between heat dissipation and system complexity, etc.

It is necessary to evaluate the requirements and constraints of process system [4], if engineers want to find out the process conflicts with nothing missed. The first thing, engineer need to do is to find out the exact parameters of process requirement rather than a general description. And, QFD (Quality function deployment) can be an effective tool to do that. Secondly, constrains of process system have to be considered comprehensively, which come from cost, technology and resource. etc. The proposed approach incorporates the parameters of process requirement and constraints.

2.1.1 Obtain Process Requirements with QFD

Generally, process requirements mainly stem from three important sources which are shown as below:

1) Process requirements based on the information of products. The engineering drawing contains lots of process requirements, so comprehensively analysing the information of drawings is very important [6]. In cooperative atmosphere, process engineers engage in the whole cycle of product development, and can capture the process information comprehensively. Besides, engineers can acquire some details about process requirements from process design documents, because they convey lots of information which includes header information (e.g. name, number, materials, etc.), structure, size, tolerance, surface roughness, heat treatment and other engineering requirements. Process design documents serve to define the design and they ensure that the design components fit together. They are useful in communicating ideas and plans to other engineers involved in the design, to external regulatory agencies, to equipment vendors and to construction contractors.

2) Process requirements based on the external users. The ultimate goal of process innovation is to meet the requirements of external users [7]. External users are seriously concerned about quality, function, price, environmental protection, energy saving, service and man-machine engineering, etc.

3) Process requirements based on the internal users. Process engineers also need to consider the process demands of internal users, such as workers and production department [8], etc. Workers want comfortable working environment and a reduction of working fatigue. On the other hand, production department requires short time, low cost, less consumption and easy management, etc. They can also obtain more information about process requirements with the assistance of QFD (Quality Function Deployment).

However, the above information is not enough for process engineers. All participants including users, engineers and managers, etc. propose their ideas about requirements for planning and designing the process system. In order to acquire the comprehensive process requirements, process engineers should consider carefully, such as: market, technology and the source of process requirements: product, external users and internal users. With the help of QFD, the general description can be transformed into specific parameters of process requirement [9].

QFD (Quality Function Deployment) can turn the process demands into process design specifications, process characteristics of components, and process control requirements, by establishing the relation matrices about them (Fig.2), and prioritize each process characteristic while simultaneously setting development targets for process system. Beginning with the initial matrix, commonly termed the house of quality, depicted in Figure 2, the QFD methodology focuses on the most important process attributes. These are composed all of process participators' wants and musts.

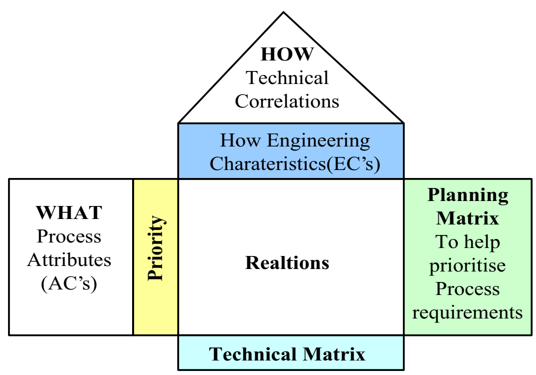

Fig. 2: The House of Quality.

Once you have prioritized the attributes and qualities, QFD deploys them to the appropriate organizational function for action, as shown in Figure 3. In this way, the deployment of process participators' needs into process characteristics can be smoothly accomplished.

2.1.2 Acquiring Process Constraints

Process constraints have a negative effect on productivity and process system. Process constraints mainly involve economic constraints, manufacturing constraints,

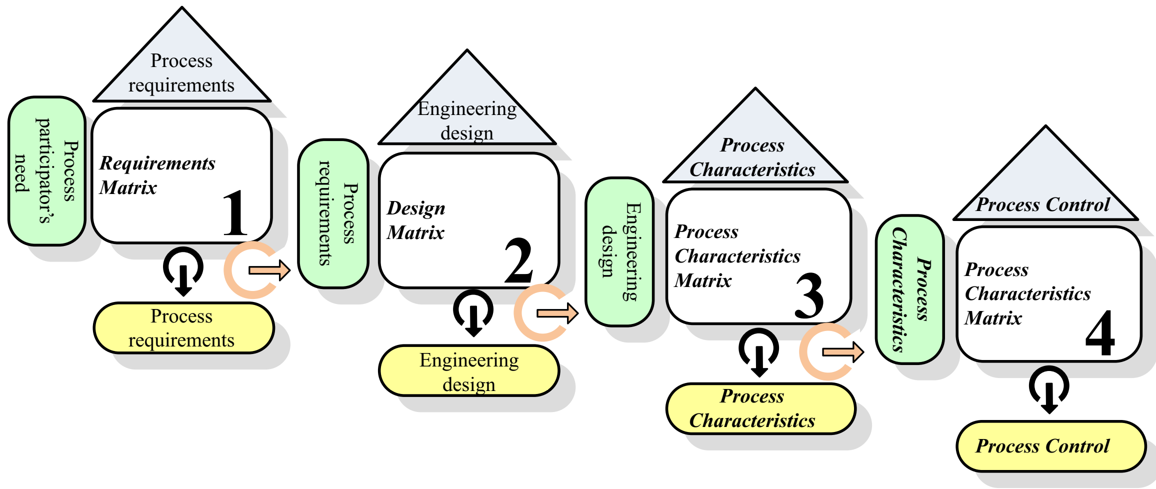

Fig. 3: Waterfall relationship of QFD matrices.

production pattern constraints, technical constraints and so on [10]. For each system, process constraints play different roles.

1) Economic constraints. Low cost creates more profits. It is worth noting that economic constraints include not only short-term profits, but also development of strategic value.

2) Manufacturing constraints. Manufacturing environment imposes restrictions on component's attributes, such as structure, size, precision, etc. Constraints involve four categories: (A) Raw material constraint. Raw material has a great effect on manufacturing cost and productivity of components. (B) Resource constraint. The equipment used to manufacture products includes machine tools, cutting tools and fixtures, etc. (C) Machine constraint. This kind of constraints includes cutting, cooling, scraps discharge and adjacent Machining method, etc. (D) Testing restriction. When processing components with complex geometry or high precision, process engineers should consider the constraints of measuring and testing method.

3) Constraints of the production mode. The mode of production of each product is different from one another. There are also several feasible processing methods for choice, according to production batch, part feature and process requirements.

4) Constraints of technology. Technical engineers are a crucial asset for an enterprise. The technological level largely depends on process engineers.

Once, engineers find out the characteristics of process requirement and the specific constraints of process system, it is much easier to analyze the process system comprehensively for engineers, and then they can find conflicts in process system with nothing missed.

2.2 Solve the CoreProcess Conflict with TRIZ

Since the engineers find these problems exciting in the process system. It is reasonable that an approach should be developed address them. According to the search of other scholars in this field, it is appropriate to apply innovative tools to solve process problems. Recently researcher in Sichuan University has already applied TRIZ into process innovation. And it turned out to be an effective tool for process engineers to find creative solutions.

2.2.1 Introduction to TRIZ

TRIZ is a human-oriented knowledge-based systematic methodology of inventive problem solving which was established by Altshuller. It can solve technical problems and offers innovative solutions by employing a knowledge base built from the analyses of approximately 2.5 million patents, primarily on mechanical design. The core of TRIZ consists of 40 contradiction principles, and the matrix; other tools are auxiliary to assisting design engineers in constructing the problem model and analyzing it. Below, however, is a brief overview of the most popular TRIZ heuristics and instruments [11].

1) Preliminary Analyses can avoid trade-off solutions of problems containing contradictions and can help clarify important information about the technique and constraints of forthcoming solutions.

2) The contradiction matrix consists of technical contradictions between the characteristics to be improved and the characteristics that can be adversely affected. It also has a few inventive principles in each cell that may help resolve the contradictions. The contradiction means that a worsening engineering parameter and an improving parameter exist simultaneously.

3) Separations principles help resolve the general physical contradictions between the opposite characteristics of a single subsystem. Substance-Field (Su-Field) Analysis is a modeling approach based on a symbolic language that can record transformations of technical systems and technological processes.

4) The standard approaches to technical problems (Standards, for short) are based on the observation that many inventive technical problems from various fields of engineering are solved by the same generic approaches. The Standards contain typical classes of inventive problems and typical recommendations on their solutions, which usually can be presented in terms of Su-Field Analysis.

5) Algorithm for inventive problem solving (ARIZ in its Russian acronym) is a set of sequential logical procedures for eliminating the contradictions causing the problem. ARIZ is considered as one of the most powerful and elegant instruments of TRIZ. It includes the process of problem reformulation and reinterpretation until the precise definition is achieved, and the logical and disciplined process of solving the problem with iterative use of most of the TRIZ instruments. It is very "solution neutral"; it removes preconceived solutions from the problem statement [12].

6) Agents Method is a graphical-logical procedure for implementing forward, backward, or bidirectional steps between the initial and desirable situations when they can, respectively, be presented as the correct statement of a problem and the Ideal Final Result.

These instruments represent a system for handling different steps during problem solving. It is important to remember that these heuristics and instruments are "for thinking" and not tools to be used "instead of thinking". Usually, when engineers solve a conflict with TRIZ, they need to turn the specific process conflict into a general conflict model, and then obtain the general solution of this conflict model and turn it into a specific solution combined with practical conditions, and evaluate this creative concept in the end [13].

Altshuller's early work on patents resulted in classifying inventive solutions into five levels, ranging from trivial improvement to scientific breakthroughs. Although there is potential to structure the creative process around trade-off contradictions, only the technical contradiction solution system and physical contradiction solution system are introduced here.

2.2.2 Contradiction Solution System of TRIZ

With the matrix, engineers can identify the most possible process innovative solutions in the 40 common principles.

There are 39 engineering parameters including the weight of object, the dimension of object, the force of object, and so forth. The matrix is a 39-39 matrix, which contains the several most likely principles for solving design problems involving the 1482 most common contradiction types. The basic process of using TRIZ is as the following statement: For using TRIZ in the innovative design problem solving, firstly the process engineer needs to find out the corresponding contradictions for his/her problem at hand. Next, the process engineer matches the meaning of each contradiction with two appropriate parameters from 39 engineering parameters defined in the matrix. The process engineer can find the inventive principles for solving the engineering innovative design problem from the matrix when he confirms the parameters of contradiction for a process system [14].

Basically, the contradiction matrix can help process design engineers to realize the conflict of the process system, and obtain the feasible inventive principles through the patent database.

2.2.3 Physical Contradiction Solution System of TRIZ

After long-term study, scholars discovered a further level of abstraction from the technical contradictions as well as process contradictions. These scholars found that, in many cases, the technical contradiction could be presented as two extremes of one feature, which he called a physical contradiction. More formally, a physical contradiction requires mutually exclusive states as they relate to a function, performance or a component. For example, typical physical contradictions includes: "movable vs. stationary"; "fast vs. slow"; "big vs. small"; "hot vs. cold", etc. The relationship between the technical and physical contradictions can be described like that technical contradiction between parameter A and B has further abstracted to present the contradiction in terms of common variable parameter C, which represents the physical contradiction. Altshuller found that by defining the contradiction around one parameter with mutually exclusive states the correlation operators used to detect a solution could be more generic and there are four separation principles (Table.1) used to help resolve this type of contradiction. The separation principles can be summarized as follows:

Table 1: Separation principles

1	separation of opposite requirements in space
2	separation upon condition
3	separation within a whole and its parts
4	separation of opposite requirements in time

Taking the ship for example, the technical contradictions are 'speed and carrying capacity', and look for another common parameter displaying mutually exclusive states. Such a parameter in this example might be the cross sectional area of the body of a ship. A small cross sectional area is required for speed, but for carrying capacity, a larger cross sectional area is required [15]. The four innovation principles would then be considered, and in this case, disintegrate the body of ship, then 'catamaran with two parallel hulls that are held in place by a single deck' could be considered as the possible option for bigger carrying capacity and higher speed.

2.3 Find the Best Solution with AHP

There are usually several process innovation solutions, it is necessary for engineers to evaluate these solutions and find the most creative one among them. The most creative one can solve the key conflict which has greater negative effects on the process system than other conflicts, and considerably improve the efficiency of process system. In order to promote the process system greatly, engineers need to find the best process innovation solutions in these alternatives with the help of AHP (The analytic hierarchy process).

2.3.1 Introduction to AHP

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions. Rather than prescribing a "correct" decision, the AHP helps process engineers to find one that best suits their goal and their understanding of the process problem. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative process solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can be related to any aspect of the decision problem tangible or intangible, carefully measured or roughly estimated, well or poorly understood.

Once the hierarchy is built, the process engineers systematically evaluate its various elements by comparing them with each other, and with respect to their impact on an element above them in the hierarchy. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the process problem [16]. A numerical weight or priority is derived for each process element of the hierarchy, allowing diverse and incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques.

In one of important step, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

The procedure for using the AHP to select the best process solution can be summarized as follows. Model the process problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. For example, when calculating the weight of each element in the hierarchy, engineers might think low cost take precedence over short time, short time over environmental protection and so on. Synthesize these judgments to yield a set of overall priorities for the hierarchy. Check the consistency of the judgments. Come to a final decision based on the results of this process.

2.3.2 Construct the Hierarchy and Assign Weight by AHP

Analytical Hierarchy Process (AHP) can be used to analyzing the process system qualitatively and quantitatively. Using the AHP method involves mathematical synthesis of judgments about the problem on hand, which could help engineers to find the best process solutions among many alternatives systematically [17].

When engineers use AHP to select the best solution, they need to build the hierarchy (Figure. 4). The topmost level in the hierarchical structure for the evaluation problem is the goal of achieving the best process system design. The second levels are a set of carefully chosen criteria and sub-criteria, respectively. The last level comprises available alternatives. Usually, the evaluation criterion of process innovation mainly include: T (time), Q (quality), C (cost), R (resource consumption) and E (environmental impact), etc.

The procedure for using the AHP method can be summarized as follows:

Step 1. Decomposing.

Engineers need to model the problem as a hierarchical structure which contains decision goal, alternatives for reaching it, and the criteria for evaluating these alternatives. For example, the goal is to find the best process innovation in alternative process solutions. The criteria for evaluating process conflict contains time, cost, quality, resource consumption and environment.

Step 2. Weighing.

The essence of the AHP is human judgments, which can be used in performing the evaluations, rather than the underlying information. Therefore, it's important to accurately calculate the weight of each criteria. In order to calculate the weight among the elements of the hierarchy [18], Engineers need to make a series of judgments based on the comparative matrix, and synthesize these judgments to a set of overall priorities for the hierarchy. Then check the consistency of the judgments.

So engineers need to establish the judgment matrix and compare the criteria with the others, which belong to the same criterion of the higher lever.

The established $n*n$ matrix is shown as follows, and n stands for the number of criteria.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{11} \\ \vdots & \ddots & \vdots \\ r_{11} & \cdots & r_{11} \end{bmatrix} \tag{1}$$

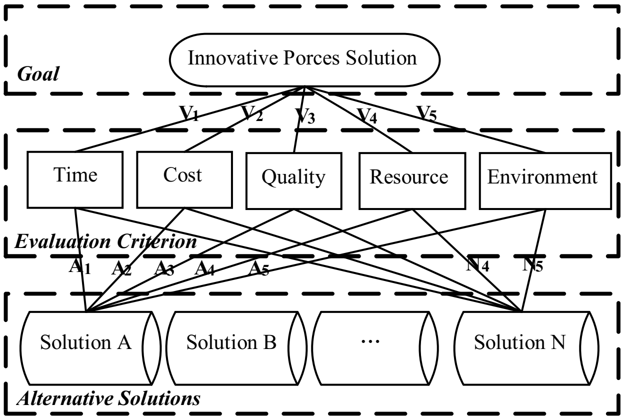

Fig. 4: The Hierarchical Structure of Process Solutions.

After that engineers check the consistency of the established $n*n$ matrix, and work out the coincidence criterion. The $\lambda_{\max}$ is the maximum eigenvalue of the matrix, and n is the order of the matrix.

$$C_i = \frac{\lambda_{\max} - n}{n-1} \tag{2}$$

Then consider the random index (R_I), and figure out the consistency ratio, and the judgment matrix is up to the mustard, if $C_R < 0.1$.

$$C_R = \frac{C_i}{R_i} \tag{3}$$

Next, rank the criteria into single level. Take the accuracy and the complexity of operation into consideration, select the feature vector method. The weight vector can be calculated by the following formula.

$$(A - n_i) \cdot W = 0 \tag{4}$$

The above formula, N is one of the eigenvalues of the matrix, W represents the eigenvectors of matrix A corresponding to the eigenvalues n, which is the weight vector.

After the weight of the criteria which is relative to the higher level is obtained, multiply each layer weight together from bottom to top, and the result is the total weight [19].

Then if we set V_m represent the weight of criterion to goal: short time (V_1), low cost (V_2), good quality (V_3), low consumption (V_4), environmental friendliness (V_5). Then we would have $A_m, B_m \dots N_m$ represent the scores of process solution to criterion (Table 2).

Table 2: Weight

	1	2	3	4	5	$\sum$
V_m	V_1	V_2	V_3	V_4	V_5	1
A_m	A_1	A_2	A_3	A_4	A_5	
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
N_m	N_1	N_2	N_3	N_4	N_5	

Note: The sum of the weight is 1. For example: $\sum V_m = 1$.

Step 3. Evaluating.
Calculate the index: $S_A, S_B, \dots, S_N$.

$$S_A = \sum A_m \cdot V_m \tag{5}$$

$$S_B = \sum B_m \cdot V_m \tag{6}$$

$$\dots$$

$$S_C = \sum C_m \cdot V_m \tag{7}$$

Step 4. Selecting.
Then we can draw a conclusion on the problem based on the conflict index. Comparing the index $S_A, S_B \dots S_N$, the most inventive process solution is the one with the largest index.

3 Discussion: Grinding System Apply Process Innovation Strategy

Since process design is a highly empirical activity, in order to solve the process conflict effectively, It is needed to establish a strategy of process innovation design, namely, acquire the constraints and requirements of the process system, then analyze the process conflicts combining with these requirements and constraints, then solve these conflicts with TRIZ, finally apply AHP evaluating these solutions to select the most creative process solution. The case of grinding blade illustrates how to apply this process innovation strategy solving conflicts in process system [20].

The blade surface of cutting tool has an important influence on its durability and performance. In Many Cases, for example, after long time works, worker needs to grind the blade of milling-tool which may get dull. Because of the complexity of blade, and considering the cost of grinding system (Figure 5), dry grinding is widely used in traditional grinding process, instead of pouring cooling fluid, which will limit the vision of the worker and increase the cost of grinder. However, the quality of blade is instable, when machining the blade of tools in traditional dry grinding way, because dry grinding will generate lots of heat which causes surface hardening and deforms the blade of tool. This paper tries to solve the process conflicts in this grinding system with the process innovation strategy which was discussed above.

3.1 Evaluate the Grinding Machine System Based on Requirements and Constraints

Firstly, engineers need to find the requirements of the process system with the help of QFD. The established house of Quality is shown as figure 6. From the house of quality and other information about the grinding system, engineers can easily find the process requirements as follows. Take away the heat generated by the friction effectively. Reduce the difficulty of operation and retaining precision.

After that, it is needed for engineers to analyze the constraints of this grinding system. The constraints of this grinding system mainly come from economic constraints, manufacturing constraints, production constraints and constraints of technology.

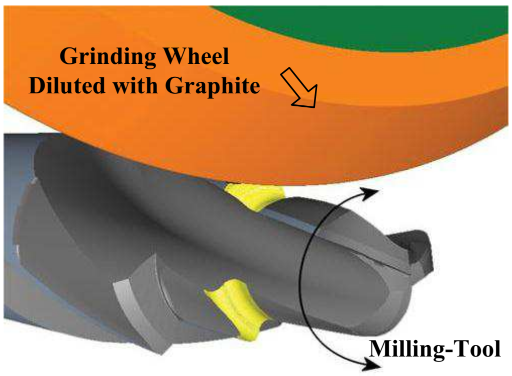

Fig. 5: Process Innovation in Grinding System.

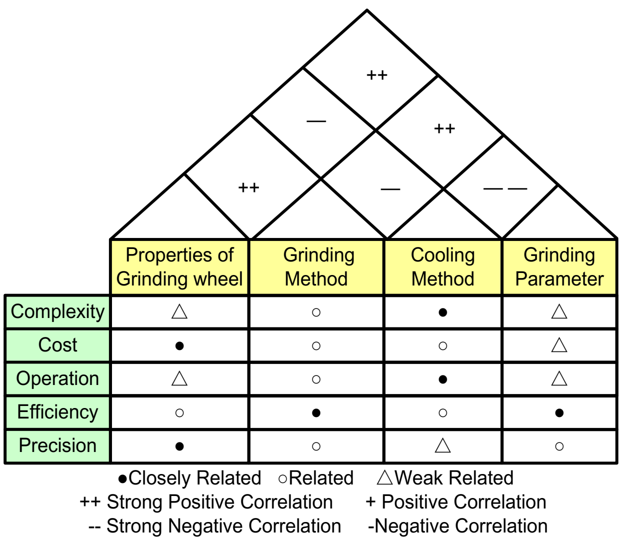

Fig. 6: The House of Quality of grinding sysytem.

1) Economic constraints. It is absolutely essential for this system to keep cost down. High cost of the machine or use cost will force company to change the failed cutting tool. Low cost means the simplicity of the grinding system and the grinding consumables.

2) Manufacturing constraints. The high temperature of grinding environment imposes restrictions on grinding material's attribute, such as heat resistance, structure, size, precision, etc. Since the grinding is an empirical process. The visual field of worker can't be affected by the cooling medium.

3) Constraints of the mode of production. This cutter grinding system belongs to small scale production, therefore, production mode has to be flexible.

4) Constraints of technology. The grinding system has to be not too complicated to operate for workers.

Then it's much easier for engineers to evaluate the grinding system, and draw a conclusion that there are two conflicts in this process system.

3.2 Solve Process Conflicts with TRIZ

Engineers want to use TRIZ to solve the conflicts in the process system, there are some principles they need to refer.

Firstly, express the process conflict in a standardized way. In the finish machining process, what needed to be improved is the high temperature caused by the absence of cooling medium. However, pouring cooling medium will increase the complexity of the process system (Table.3).

Table 3: Conflicts in Process System

High Temperature	Vs	Loss of Precision
Taking away the heat Generated by the friction effectively	Vs	Cooling system will Increase the cost and the difficulty of operation

Secondly, combining the 39 parameters of contradiction table, process engineers can obtain a new description about this process problem (Table 4).

Table 4: The New Description of Problem

Improved parameter: 31	Object-generated harmful factors
Deteriorated parameter: 36	Device complexity

Thirdly, engineers can obtain the corresponding innovation principles (01, 19, 31) with the contradiction matrix (Table.5) which tells you the 40 principles have been used most frequently to solve a problem that involves a particular contradiction.

Then comparing the 40 inventive principles which are the innovation tools of TRIZ, engineers will be inspired by these three innovation principles (Table 6).

Finally, Engineers can draw a conclusion about the final specific solutions considering the innovation principles we obtained above. In this specific case, there are two possible creative process solutions.

Solution one, add lubricant into the grinding wheel in advance. Because the grinding wheel is porous, engineers can use oil to dilute solid lubricant such as graphite and molybdenum dioxide, and then infiltrate into grinding wheel [21]. In practice Cutting oil which evaporates easily acts as thinner, and graphite powder acts as lubricant, and then they seep into the grinding wheel. Lubricant can reduce the heat generated by the friction of

Table 5: Contradiction Matrix of Grinding System

Worsening Feature \ Worsening Feature		Weight of moving object	Weight of statiionary	⋮	Device complexity	⋮
		1	2	…	36	…
Weight of moving object	1	*	–	…	26 30 36 34	…
Weight of statiionary	2	–	*	…	1 10 26 39	…
…	…	…	…	…	…	…
Object-affected harmful	31	19 22 15 39	35 22 1 39	–	1 19 31	…
…	…	…	…	…	…	…

Table 6: Principles and Meanings

Inventive Principles	Meanings
01 Segmentation	Divide an object into independent parts.
19 Periodic action	Instead of continuous action, use periodic or pulsating actions
31 Porous materials	Make an object porous or add porous elements (inserts, coatings, etc.)

grinding. At the same time the evaporating cutting oil takes away the heat which was generated in grinding process. This solution creatively solves the problem of heat dissipation without increasing the complexity of grinding system.

Solution two, add the gas-liquid mixture cooling system to the grinding system. It's an effective method for a process system which generates lots of heat to add a cooling system. In some body's view, it seems that cooling liquid is the best medium, which possesses the advantage of low cost and efficiency [22]. However, cooling liquid has a negative effect on the operation of the worker by limiting his visual field. If we change from the liquid to gas-liquid mixture as the cooling medium, we can neutralize the negative effect on worker's visual field. On the other hand, the mixture of gas-liquid just mildly reduces the efficiency of cooling.

3.3 Compare Two Process Innovations with AHP

Engineers model this evaluation as a hierarchical structure. The decision goal is to select the most inventive process solution, the alternatives for reaching it, and the evaluating criteria including quality, cost, efficiency and environment.

Engineers judge the comparative matrix pairs of criteria, and synthesize these judgments to yield a set of overall priorities for the hierarchy. Then check the consistency of the judgments. For example, when calculating the weight of each element in the hierarchy, engineers decide the quality take precedence over cost, cost over efficiency, efficiency over environmental protection. Then engineers set V_m to represent the weight of criterion to the goal: quality (V_1), low cost (V_2), efficiency (V_3), environmental friendliness (V_4).

As referred by the preceding part of the paper, we select machining quality, machining requirements and machining influence as the first level criterion, and select the other 8 criteria such as material of the blade, shape of the blade and so on as the second level criterion. After discussing by the process designers, we got the following judgment matrix:

The judgment matrix of first level:

$$A = \begin{bmatrix} 1 & 2 & 5 & 8 \\ 1/2 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 2 \\ 1/8 & 1/5 & 1/2 & 1 \end{bmatrix} \tag{8}$$

Using the square root method, we can acquire the weight:

$$W_A = (0.8578, 0.4744, 0.1732, 0.0959)$$

Then check the consistency, the check results are shown in Tab7.

Table 7

Index	**A**
$\lambda_{\max}$	4.0104
C_I	0.00346
R_I	0.89
C_R	0.00389

It can be seen from the table, the index of C_R values is less than 0.1, so the criteria are consistent, and the matrix is acceptable. Then we get the weight of each criterion relative to the total target. The results are shown in Tab.8.

Table 8: Weight of each index

index	**weight**
Quality	0.4286
Low Cost	0.2857
Efficiency	0.1714
Environmental Friendly	0.1143

Then we would have A_m, B_m, which respectively represent the scores of process solution corresponding to the criterion. (Table 9)

Calculate the satisfaction index: $S_A, S_B \dots S_N$.

$$\begin{aligned} S_A &= \sum A_m \cdot V_m \\ &= 0.4286*68+0.2857*80+0.1714*76+0.1143*75 \\ &= 73.6285 \end{aligned} \tag{9}$$

$$S_B = \sum B_m \cdot V_m$$

Table 9: Weight

	1 Quality	2 Cost	3 Efficiency	4 Environment
V_m	0.4286	0.2857	0.1714	0.1143
A_m	68	80	76	75
B_m	72	70	85	90

$$= 0.4286 * 72 + 0.2857 * 70 + 0.1714 * 85 + 0.1143 * 90$$
$$= 75.695 \quad (10)$$

Then engineers can draw a conclusion on the evaluation based on the above index. By comparing the "satisfaction index" S_A, S_B, engineers find the most inventive process solution is "add the gas-liquid mixture cooling system to the grinding process system".

4 Conclusions

Process innovation has a significant impact on manufacturing industry. Currently, process innovation design in most industries is still based on the experience of designers and engineers. The essence of this design process is for engineers to acquire and analyze process requirements, and to gain innovative design solution. In order to assist them in solving process problems effectively, an optimizing strategy is established. To guarantee applying TRIZ solve process problem, it is essential to co-operate with other existing or newly developed methods. Process problem can be effectively solved by a strategy which combining QFD, TRIZ and AHP in a scientific way. It has been shown how these methods are used in the strategy of process innovation. In this paper, a strategy of process innovation integrated AHP/QFD/TRIZ is proposed, which is composed of process requirements analysis, system assessment and conflicts resolving. The process innovation of grinding system is presented to illustrate the effectiveness of the proposed method.

The strategy can be summarized as below: Analyze the process according to constraints and requirements which obtain by QFD, then process engineers analyze the conflicts of the process system comprehensively, and solve the process problem with the help of TRIZ. Finally, evaluate these solutions and find the best solution with the assistance of AHP. In this way, the maneuverability of using Inventive tools to solve process problems is improved. Future studies will focus on how to apply TRIZ solving the process conflicts more efficiently.

We also propose a point for future researchers and engineers to consider on process innovation based on above research. While continuing to emphasize the improvement in existing processes, manufacturing industry should consider how to develop the next generation processing method. Therefore, policymakers should develop policy incentives to facilitate the do these researches, while firms should consider adding external costs to develop a new process.

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