

Ershi Qi
Jiang Shen
Runliang Dou *Editors*

International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings

Core Areas of Industrial Engineering

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Ershi Qi · Jiang Shen · Runliang Dou
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Chapter 1

A Study on Improvement Design Based on TRIZ and Extension Method

Fong-gong Wu, Jung-fu Lee, Chang-tzuoh Wu, Ming-tang Wang
and Shi-liang Luo

Abstract This research focuses on developing an approach to innovative design problems based on the TRIZ and extension method. The proposed innovative design procedure combines the Su-Field modeling procedure, contradiction matrix and extension method to improve the efficiency and extent of concept evolutions. The extensibility of matter-element can be used to exchange the descriptions of design problems and solutions into creative fields. In this research, we will introduce the TRIZ contradiction matrix and concept extension of matter-element into symbolic developments to derive out more creative solutions. This study proposes a flexible and extensible innovative design approach with the help of extension method. The bicycle design examples are adopted to explain and verify the feasibility of the proposed approach. The case study successfully demonstrates that the proposed approach is feasible and efficient.

Keywords Bicycle · Contradiction matrix · Extension theory · Matter-element · Su-field

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1.1 Introduction

TRIZ is TIPS (Theory of Inventive Problem Solving) Russian synonym word, it means whether it is the methods of question to answer, Savransky (2002) think that TRIZ method is an answer based on human knowledge invents the question systems approach (Altshuller 2000). Altshuller, the father of TRIZ, has explained the deduction course innovated and invented in detail. Before cold war era between east and west, the research of TRIZ has been the state secret as Soviet Union. But TRIZ method is wide for western countries gradually know after the disintegration of the Soviet Union, and becomes the method that the extremely authoritative innovative problem solving. In the design process of innovation, limitation of designer's knowledge field, habitual thinking course, is the obstacle appeared in innovation procedure, especially using the open thinking methods. The TRIZ method can assists the designer in the concept development stage to expand to the knowledge domain that oneself is not skillful at, and has provided a systematic design procedure to define the design problem more distinct and get the innovative idea in design processes.

The designers' abilities of innovation and problem solving play a key role in the research abilities of enterprises. Thus, developing the suitable innovative method become the most urgent need. Su-Field analysis, one of the major tools which the TRIZ method deducts, is a useful tool for identifying problems in a technical system and finding innovative solution to these identified problems. Using Su-Field analysis method can analyze and improve the function of the technological system. In the relevant research of the Su-field method, Terninko (2000) introduced the operating procedures of Su-field analysis model in detail. Some design examples successfully demonstrate that the Su-field analysis model and corresponding 76 standards solution by (Terninko 2000; Terninko et al. 2000). Mao et al. (2007) proposed that the 76 standard solutions can be summarized into seven general principles with graphic demonstrations and examples (Mao et al. 2007).

Most of the researcher, while using the Su-Field method to analysis effect relation between the system inner components, thought that the Su-Field analysis was still worth conducting the research. This research tries to introduce extensive into the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. Besides, contradiction matrix has also been used to modify the new concept. Through this research, we will try to build an explicit and feasible intelligent innovation processes and evaluation method progressively. The feasibility will also be verified through patents.

1.2 Extension Su-Field Analysis Method

Matter-element and extension method, a powerful tool to systematically analyze concrete or intangible products, has been developed by W. Cai in 1983. Extension Theory is a course to study the extensibility, extent rules, performing procedure of matter and try to employ to resolve contradictory problems.

The extension method was derived from the extension theory that involves the matter-element theory and extension mathematics. The major research subject of extension theory is incompatible problem in the real world. Its applications and research have already extended to each field, including business, management, engineering, economics, sociology, strategy, etc. (Wang and Zhao 1998; Cai 1994; Cai et al. 1997).

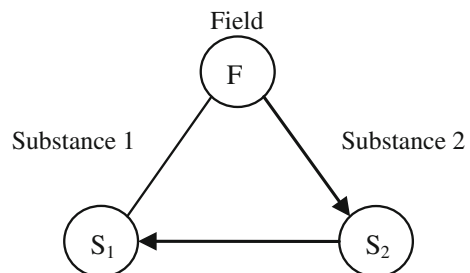
1.2.1 Symbolic System of Su-Field Model

According to TRIZ, the rationale of creating a Su-Field model is that a system, with the ultimate objective to achieve a function, normally consists of two substances and a field. The term S_1 is used to represent an object that needs to be manipulated. The term S_2 is a tool to act upon S_1 . The term field (F) includes the fields of physics (that is, electromagnetism, gravity, strong and weak nuclear interactions). A field provides some flow of energy, information, force, interaction, or reaction to perform an effect. Altshuller graphically represent a Su-field model as a triangle. This is a simple and ingenious way to explain a technical system. (See Fig. 1.1.)

Other possible states are: The effect needed has not taken place, caused harmful effect and required effects are insufficient. Besides, in technological conflict, the connecting effects are: 1. conflict between two subsystems in a system; 2. set up useful effect in a certain subsystem and lead to harmful effect in another subsystem; 3. dispel the harmful effect in a certain subsystem, cause the damage on the useful effect of another subsystem. 4. strengthen the useful function or reduce the harmful effect, cause unacceptable complication in system or another subsystem.

Usually, we focus on the components needed to be improved or with valueless function. Therefore, a fast and simple model will offer different thinking directions to a designer.

Fig. 1.1 A. Basic Su-field model (Terninko, 2000)



1.2.2 Extensive Procedures

This research will employ matter-element analysis and extension theory repeatedly; try to integrate “extension of matter-element” with the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. The stages are divided into to carry on,

- (1) *First stage*: The extension method can help people resolve problems separately by decomposing them, recombining the problems, and then searching for the feasible solutions, assist the Su-field model to extend and deduce concepts widely.
- (2) *Second stage*: While using the Su-Field method to realize innovative design, expansibility of matter-element can give extending design based on the advised solution providing by 76 standard solutions. Through the transformation, designers can conceive of other substituting matter-element models effectively and quickly to obtain various innovative design plans (Yan and Liu 2003; Yang and He 1999; Yang 1998).

The components, any of its characteristics can be changed, and the subsystem can be a component of a complete Su-Field. To solve a problem, the missing component is introduced to the incomplete Su-Field to make it complete. Even though the Su-field model is complete, model should be improved and modified while the connections between substances and field are harmful or insufficient. In addition, while dealing with more complicated design problem, Su-field model can be expanded to construct the various, multiple Su-Field triangles according to the scale of the question.

Obviously, by introducing the concept of matter-element and matter-element with multi-characteristics and regarding a substance of Su-field model as a matter-element, it will assist the creative thinking and innovation for problem solving. Matter-element and matter-element with multi-characteristics are defined as follows,

matter-element

$$R = (N(t), c, v(t)) \quad (1.1)$$

matter-element with multi-characteristics

$$R(t) = \begin{bmatrix} N(t) & c_1 & v_1(t) \\ & c_2 & v_2(t) \\ & \vdots & \vdots \\ & c_n & v_n(t) \end{bmatrix} = (N(t), C, V(t)) \quad (1.2)$$

Based on the divergence of matter-element, matter-element $R_0 (N_0, c_0, v_0)$ can be diverged from one or two of N_0, c_0, v_0 to synthesizing different matter-elements, to build an extending tree. Extending tree is a method for matter to extend outwards to provide multi-orientated, organizational and structural considerations.

An event, the interaction of matters, is described as event-element. Basic elements for an event-element are constructed by verb (d), name of verb characteristic (b) and u, the corresponding measure about (b).

Event-element

$$I(t) = (d(t), b, u(t)) \quad (1.3)$$

Multi-dimensional event-element

$$I(t) = (d(t), B, U(t)) \quad (1.4)$$

There may be different relations among a certain matter, event and other matters, events; there is interaction between these relations, influence each other. The corresponding matter-element, event-element and other matter-elements, event-elements can be used to describe these relationships and interactions. Relationship-element, a n-dimensional matrix, is form by relationship name $s(t)$, characteristics $a_1, a_2, \dots, a_n$ and corresponding measure values $w_1(t), w_2(t), \dots, w_n(t)$:

$$Q(t) = \begin{bmatrix} s(t) & a_1 & w_1(t) \\ & a_2 & w_2(t) \\ & \vdots & \vdots \\ & a_n & w_n(t) \end{bmatrix} = (s(t), A, W(t)) \quad (1.5)$$

The extensible properties of matter-element, event-element and relationship-element, comprising: divergence, expansibility, relevance and implication. While solving design problems based on Su-field model, diversity and creativity, the advantages of “extenics” method will be imported by implementing the extensibility of matter-element, event-element and relationship-element. Thus, the solution will not be limited by standard solutions but be inspired (Lian and Zhang 1995; Zhao 1998; Zhao 2000).

1.3 Introducing Contradiction Matrix into Su-Field

While we effort to improve one system characteristic and degrade another one, contradiction often arises. The contradiction matrix has been introduced in TRIZ to solve a technical contradiction design problems. In this study, three important elements of Su-field model (subject S, field F and relationships) have been tried to correspond to the TRIZ contradiction matrix. As the Su-field model built, the elements needed to be improved are also identified. For the substances S, field F or states which needed to be modified, the corresponding engineering parameters can be determined by reference to the 39 engineering parameters. A technical conflict problem can be solved in two steps by using the contradiction matrix table (Table 1.1). At first, we analyze the attributes of the problem and determine the

Table 1.1 Partial cells of contradiction matrix

Worsening engineering parameters		9	10	11	12	
Improving engineering parameters		... Speed	Force	Tension/pressure	Shape	...
9	Speed		13.28 15.19	06.18 38.40	35.15 18.34	
10	Force	13.28 15.12		18.21 11	10.35 40.34	
11	Tension/ pressure	06.35/36	36.35/21		35.04/15.10	
12	Shape	35.15 34.18	35.10 37.40	34.15 10.14		
13	Stability of object	33.15 28.18	10.35 21.16	2.35 40		
14	Strength	8.13 26.14	10.18 3.14	10.3 18.40		
	...					

parameter “feature to improve” in the columns and “undesired result” in the rows. Then, we attempt to resolve the conflict problem by using three or four recommend inventive principles that are listed in the intersecting cell. The inventive principles can be used to facilitate the development of useful “concepts of solution” (Ideation International Inc. 1999).

1.4 Illustrative Design Case

In this research, the proposed invention procedure is used to expand a design case “manpower drive vehicles”. A traditional bicycle uses a chain for transferring the pedal actuated driving force from the pedal crankshaft to the rear wheel. After using period of time, the chain-link is prone to come off the ratchet and slip gears. In addition, the long skirt also has the risk that is sullied or rolled into chain link. Thus, “How to eliminate the use of the chain, but without affecting the function of transmission” will be the design problem.

1.4.1 List Su-Field Model Related to Design Problem

The initial Su-field model is constructed according to operation situation and function of the traditional bicycle. Su-field model of the traditional bicycle can be illustrated as follows. It is essential that the present Su-field model should be conformed to the design problem. It should be avoided illustrating a Su-field

model that is irrelevant to the design problem. According to the traditional bicycle and biked processes, Su-field model can be constructed as Fig. 1.2a. S_1 represents the chain, S_2 represents front gear set. This description of Su-field model is that the front gear set (S_2) transmits pedal force (F_p) to the chain (S_1).

In order to prevent the inconvenience of the use of chain, the chain (S_1) is considered as the component that should be replaced. After eliminating it, this Su-field model becomes incomplete. Then, refer to 1st transformation rule, introduce a substance component (represent with S'_1 here, in order to avoid confuse with the original material S_1) to fill up the vacancy of model, make it keep function that transmission. Similarly, the front gear set (S_2) should support the pedal force (F_p) to the substance (S'_1). After performing transformation, Su-field model is illustrated as Fig. 1.2b.

1.4.2 Extensive Procedures of Innovation Design

The following steps are to transfer Su-field model to design prototype:

- (1) *Survey the entity component correlated to S'_1 .* Exclude chain, we search for the replaceable subject by using the divergence of matter-element.
- (2) *Use extending tree method to build the transformation model:* A matter refers to multi-characteristics, a characteristic also mapped by matters.
- (3) *Transform the transmission device into a general model by the divergence tree of matter-element extension method.* The extension of matter-element, can be expressed as,

$$\begin{aligned}
 R_1 &= (N, c_1, v_n) \\
 &= (\text{transmission device, flexible mechanism, chain}) \\
 &= (\text{transmission device, flexible mechanism, belt}) \\
 &= (\text{transmission device, flexible mechanism, rope}) \dots \text{etc.}
 \end{aligned}$$

$$\begin{aligned}
 R_2 &= (N, c_2, v_n) \\
 &= (\text{transmission device, rigid mechanism, gear set}) \\
 &= (\text{transmission device, rigid mechanism, linkage}) \dots \text{etc.}
 \end{aligned}$$

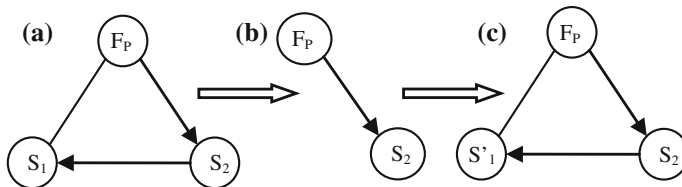


Fig. 1.2 **a** Su-field model of the traditional bicycle, **b** Incomplete model, **c** Add new substance to complete Su-field model

The extension of event-element,

$$I = \begin{bmatrix} \text{bike} & \text{type} & \text{rotation} \\ & \text{transmission device} & \text{chain} \\ & \text{force source} & \text{pedal} \\ & \vdots & \vdots \end{bmatrix}$$

The extension of relationship-element

$$Q = \begin{bmatrix} \text{Transmission} & \text{Front gear set} & \text{Chain} \\ & \text{Ratchet and slip gears} & \text{Chain} \\ & \text{Drive method} & \text{Rotation} \\ & \text{Bad effect} & \text{Come off rear gear} \\ & \text{Structure} & \dots \\ & \text{Safety degree} & \text{Poor} \\ & \text{Disadvantages} & \text{Sully} \\ & \vdots & \vdots \end{bmatrix}$$

$= (s, A, W)$

- (4) *Through the transformation, devises the new extensible model, and found the new concept:* Once the extending tree set up, the matter-element obtained from the 1st level of extending tree should be evaluated whether it meets the demand of the new Su-field model or not. If the components cannot meet the design demands, design processes should proceed with the help of performing extension of event-element or relationship-element. Relatively, a new concept has occurred that we try to let the event “bike” to be carried out by other flexible transmission device such as belt or belt gear. The similar idea has been put into practice as the patents US2007/0228688 A1 and US2011/0241307 A1. Based on original Su-field model and new concept ideas, a new Su-field model has been constructed as shown in Fig. 1.3a. The belt transmission device is slippery under the heavy load. Association between the subjects S_2 and S_1 as “simultaneously has relatedness and distress factors”, resolve their troubled association, by the standard solution 1.2.1 “useful and harmful effects exist in a system, if S_1 and S_2 is not necessary to direct contact, a new subject S_3 can be introduced to eliminate the distress factors as shown in Fig. 1.3b”.
- (5) Nevertheless, easy to be worn is the flaw of “flexible transmission device”. We consider making the “rigid transmission device” plays the major role of bicycle devices and then, design problem becomes “How to transform the flexible device into a rigid device?” Repeat matter-element extending program. Transform the flexible device into a new general model by the