Identifying an Innovative Su-Field Modeling Design Processes

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Abstract**—**TRIZ is the Russian acronymic synonym of (Theory of Inventive Problem Solving). It is a systematic method for providing valid suggestions to meet the requirements of inventive steps. Su-Field analytic method, deduced from TRIZ method, is one of the inventive problem solving tools that can be used to analyze and improve the efficacy of the technological system. By possessing a symbolic system and transformation rules, the Su-Field analysis model can assist designers to diagnose and solve most design problems. This study proposes an innovative design and problem-solving process, based on Su-Field modeling method integrated with extension of matter-element.

This research tries to integrating "extension of matter-element" with the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. We make use of extensibility of matter-element to exchange the descriptions of design problems and solutions into creative fields. The concrete result includes,

1. Evaluate the differences and benefits between Su-Field modeling procedure and matter-element modeling procedure.
2. Assess possibility and advantage to combine construction of symbolic system in Su-Field model and the transformation and extension of matter-elements.
3. Introducing concept extension of matter-element into symbolic developments to derive out more creative solutions.
4. An innovative design case, stapleless stapler, successfully demonstrates that the proposed design process is feasible and efficient.

Keywords**—**TRIZ, Su-Field, Matter-Element, Extension theory.

I. Introduction

THROUGH creative education, the compatriots' abilities of innovation and problem solving will be increased so that the management and research abilities of enterprises will also be improved. Possessed innovation ability, no matter engaged in any trade and office, can all promote working efficiency and innovative pattern. Thus, develop the suitable innovative method become the most urgent need. TRIZ, providing the guidance to invention, is such a systematic method to meet demand.

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 knows after the disintegration of the Soviet Union, and become the method that the extremely authoritative innovative problem solving. TRIZ is TIPS (Theory of Inventive Problem Solving) Russian synonym word, it means whether it is the methods of question to answer, Savransky (2000) think TRIZ method is that a answer based on human knowledge invents the question systems approach, Altshuller (the father of TRIZ)[3] have explained the deduction course innovated and invented in detail. Hsiao (1999) point out that the engineers still adopt Brainstorming method to create new idea although lack of systematic procedure, limitation of engineers' knowledge base, engineer's psychological obstacle and so on are the shortcomings of Brainstorming method. 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.

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Massachusetts Institute of Technology economic Professor Thurow in its work" The Future of Capitalism "once mentioned that this is the artificial intelligence industry time, the technological development can support enterprise's long-term competitive advantage of the business circles. No matter which kind of industry, if can't research and develop low cost, high quality and concurrently innovative products to maintain their competitive advantage, will compete finally the intense market elimination.[23] Therefore the question of maintaining the innovative skills of enterprises, increasing productivity etc. becomes the main factor that needs to overcome in order to keep enterprise's competitiveness. The appearance of TRIZ method can aim at these factors, provides vividly systematic solution.

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.[16] Using Su-Field analysis method can analyze and improve the function of the technological system. Altshuller and his colleagues, the researchers of TRIZ, graphically represent a Su-Field model as a triangle. 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. Both substances can be as simple as a single element or as complicated as a big system with many components, which can also be explained by individual Su-Field models. The States of substances can be typical physical forms (e.g., gas, liquid and solid), interim or composite forms (e.g., aerosol, power, porous). The field is the needed energy to enable the interaction between the substances. Likewise, the field can refer to a broad range of energy, including mechanism, chemistry, physics, acoustics, optics and radiations.[16]

By this grade inspection way, possibly related to "common problem models classification", the problems which existed in present systems can be identified and the innovative solutions will also be found to improve the systems. Once a technical system is simplified into a Su-Field model, its potential problems can be identified through analyzing undesired interactions resulted from the model. Based on their intensive research of a huge number of patents, Genrich Altshuller and his colleagues identified 76 standard solutions to fixing problematic Su-Field models. Although Su-Field analysis provides a simple means to model systems and reveal their problems, the more than 70 standard solutions may make users rather confused and overwhelmed in their searching for answers from these many possible solutions. In addition, the standard solutions also caused the possible answers to be restricted to lose the creativity and extent.[16]

In order to avoid the possible restriction on creative problem solving procedure, extension of matter-element based on concept model has been introduced in this paper to improve the efficiency and extent of concept evolutions. Extenics brings out the basic element—matter-element. A matter-element can be combined with the other matter-elements to form a new one, or be decomposed into a few new matter-elements; new matter-elements contain qualities that former matter-elements do not have. The probability is called extensibility of mater-element. The extension of matter-element provides another way of resolving contradictions. We make use of extensibility of matter-element to exchange the descriptions of design problems and solutions into creative fields.

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 "extension of matter-element" into the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. Mainly divides into two stages to carry on,

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.

II. INNOVATIVE PROBLEM-SOLVING METHOD

Savransky (2000) who studies TRIZ method think TRIZ method is that a systematic method for inventive problem solving based on human knowledge. Altshuller in detail explained the innovation and the invention deductive process of TRIZ method. Hsiao (1999) pointed out that the engineers still adopt Brainstorming method to create new idea although lack of systematic procedure, limitation of engineers' knowledge base, engineer's psychological obstacle and so on are the shortcomings of Brainstorming method. The TRIZ experts believed that the creation is not only a precise science, is precisely one kind of system structure, designer who even if does not have the creativity, may also be engaged in the invention and creation using TRIZ.

Though how authoritative and powerful TRIZ method is, there is not any theory method that can declare that have no time perfectly, TRIZ method is no exception. This design method, providing advised solution by reorganized the huge information database; there are suitable discussion spaces. So, the improvement and studies about TRIZ method, a lot of experts are lasting and in process.

A. TRIZ and Su-field Analysis Model

Liu and Chen (2001) proposed that one also can make use of innovative rule of TRIZ to improve the project characteristic of the system or solve the engineering problems while under such condition that the systematic contradiction information is unknown. The rules, the more often to be used for solving the innovative problem, indicate to be the higher grade rules. Thus, it would be possible of success of solving problem while adopt the higher grade rules. Leon-Rovira and Aguayo(1998) proposed that the relationships between the technical parameters in QFD house of quality tables can be solved with the matrix table of the contradiction to find out the contradiction parameters of the engineering problems correctly.

The experts and scholars propose the suggestion to various questions of TRIZ method, and also combine other design methods to improve TRIZ. The Invention Machine Corporation exactly combines TRIZ method, value engineering, trimming techniques with artificial intelligence into the computer aided innovation software to assist designers to operate conceptual design. Kaplan utilizes the simple example to explain the applications of TRIZ on engineer, mathematics, medicine and other courses field. Recently, relevant literatures such as the improvement about TRIZ method and case study, issued successively. For example, Mann and Domb (1999) employed the research of applying 40 innovative rules to commerce and management, and Mann (1999) studied on the application of 40 innovative rules in bionic science and technology. Mann (2002) further discussed the hit rate of the contradictory table.

The experts familiar with TRIZ will use the Su-field analysis method to analyze the effect relation between the components within system, but often employed contradiction matrix method instead of Su-field method while innovating and designing actually. 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, Domb and Miller(2000). Grace, Slocum and Clapp summarized a real industrial problem solving experience using the algorithm, ARIZ - 85C. and mentioned the algorithm of using Su-field method in ARIZ. Ko (2006) presented an eco-innovative problem-solving design process based on utilizing TRIZ Su-field model and 76 standard solutions. The design case study successfully demonstrate that the proposed process is a feasible eco-innovative process. Mao (2007) proposed that the 76 standard solutions can be summarized/condensed into seven general principles with graphic demonstrations and examples.

B. Matter-Element and Extension Method

Matter-element and extension method, a powerful tool to systematically analyze no matter 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 contradictive 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. The expression make qualitative and quantitative analysis mixed, describing the real world further and visually, providing another way of resolving contradictions. Its applications and the research expand to each domain, includes: trade, economics, sociology, management, engineering, strategy, etc. [25-31]

On the basis of extension method, the results of concept design research are described as follows:

1. A study on the extensible expression method of concept design knowledge: Based on the concept design of typical product, analyze and sum up profound knowledge and innovative thinking rules in the concept design process, utilizing matter-element and event-element, describe formalization to the function, principle, layout structure in conceptual design, construct corresponding models of matter-element and event-element.[29] Profound knowledge of design can be described by using extending tree or corresponding extension methods. Relatively, function and function relationship can also be described by extension analysis of function and corresponding connotation. Therefore, the systematic diagrams of functions will be constructed to providing an integrated model to complete the conceptual function design.
2. Construct the rhombus thinking model of the conceptual design process: Set up function decomposing and synthesis multistage rhombus thinking model. Started from a certain main function matter-element, along different branches separated into different sub-function matter-elements to have a variety of alternative routes so as to realize extending thinking of function creative design. Then, according to criteria such as the feasibility, quality, true or false, compatibility, etc. to evaluate the extension results and select qualified few matter-elements, thus realize the convergent thinking process.[19]
3. Transformation of function matter-element and event-element: Replacement, decomposition, addition/ deletion and expansion/contraction are four basic methods for the matter-element transformation. Overall, they are conductive to exchanging or to synthesizing different matter-elements. As to incompatible matter and opposite matter, adopt transforming bridge, by adjusting main indicator according to incompatible feedbacks and using matter-element transformation to vary the compatibility. Make the incompatible question and opposite goal turn into the compatible question and mutual goal, respectively.
4. Decision-making, evaluation, redesign of concept design: Considering the constraints, prerequisite condition and compatibility of the design process, adopt extensive decision-making and referee method to evaluate the sensitivity, technology, economy and social assessment of suggestive scheme. Repeat these steps until achieving the optimal design.

Basic disciplines that extension method involves are quite comprehensive, for example: philosophy, mathematics, systematic science, intellection science, control theory, information theory, management science and technological theory. Attempt to formalize the procedure of problem solving by set up the matter-element model to develop unique logic operation method and technology.

The experts familiar with TRIZ will use the Su-field analysis method to analyze the effect relation between the components within system, but often employed contradiction matrix method instead of Su-field method while innovating and designing actually. And also has some scholars to have the negative appraisal to this method, they thought that the Su-field method is worthless, but also had some scholars saying that the Su-field method was not well enough. Therefore, in this research, we hope to improve the incomplete properties and feasibility of Su-field method by integrated with extension method, in order to provide perfect approach in each field. An innovative design case, stapleless stapler, successfully demonstrates that the proposed design process is feasible and efficient.

III. Integrating Extension Method with Su-field Model

This research tries to integrating “extension of matter-element“ with the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. We make use of extensibility of matter-element to exchange the descriptions of design problems and solutions into creative fields.

A. Symbolic System of Su-field Model[15]

A graphical model of a minimal working technique in TRIZ is called Substance-Field, or Su-Field. Su-Field Analysis is an instrument for modeling the most important parts of TS and TP (technical systems and technological processes) for the particular problem and identifying the core of a problem related to this technique. Su-Field models and Su-Field Analysis, created by G. S. Altshuller, provide a fast, simple description of subsystems and their interactions in an operation zone and period via a well-formulated model of the technique in which all subsystems, inputs, and outputs are known or can be quite easily determined. Any technique can be presented as the ordered set of Su-Fields.

As any model of nature, society, or technique, a Su-Field model has some simplifications and conditional agreements, which are described in this section. The term *substance* (S) has been used in TRIZ to refer to a material object of any level of complexity. S can be a single element or complex system. The states of substances include not only the typical physical states but also a large number of in-between and compound states as well as those stateshaving special thermal, electrical, magnetic, optical, and other characteristics. Substance is itself a hierarchical system. Altshuller and his colleagues, the researchers of TRIZ, graphically represent a Su-Field model as a triangle. 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. Both substances can be as simple as a single element or as complicated as a big system with many components, which can also be explained by individual Su-Field models. The term *field* (F) has been used in TRIZ in a very broad sense, including the fields of physics (that is, electromagnetism, gravity, strong and weak nuclear interactions). Other fields can be olfactory, chemical, acoustic fields, etc. A field provides some flow of energy, information, force, interaction, or reaction to perform an effect. The presence of a field always assumes presence of a substance, as it is a source of the field. Altshuller graphically represent a Su-field model as a triangle. This is a simple and ingenious way to explain a technical system. The minimum technical system was found to consist of a field (F) and two substances (S_1 and S_2). (See Figure 1.)

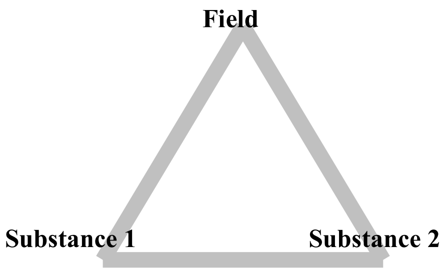

Fig 1. Basic Su-field Model

Su-Field symbols mirror relationships between the subsystems of a technique. The Su-field model supplies nine connections to describe the relationships among S_1, S_2 and F; and parts of these connection symbols are shown in Table 1. It is common practice to place the F symbol above substances for an *input* field, and below the symbols of substances for an *output* field. The most important two kinds of connections are "Useful Effect" and "Harmful Effect", as shown in Figure 2.

TABLE 1.
Symbols of connections in Su-field analysis

relationships	connection symbols
Desired Effect	→
Insufficient Effect	- - - - →
Harmful Effect	∿∿→
Field types	F_{type}
Useful Effect	**U**
Harmful Effect	**H**

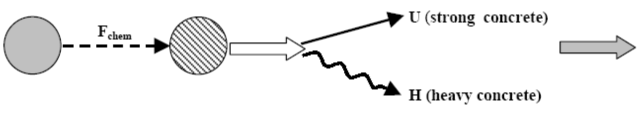

Fig 2. Symbolic representation of useful and harmful effects (Terninko, 2000)

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.

In the algorithm of TRIZ, it proposed that su-field method can be used to solve problem while ideal innovation cannot be obtained by utilizing contradiction matrix. Su-field method can be used to analysis the effects on the elements or subsystem what we are absorbing. 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.

The major implements of using Su-field model for improving system characteristics are the improvement of the useful function and elimination of harmful function. Each adjustment and revision to the Su-field model or substances denotes the systematic transition or modification. The term "Standard," introduced by G. S. Altshuller, means that a common "trick" to solve different problems results in very similar problem models. Altshuller proposed a system of 76 Standards in 5 different classes and illustrated each Standard by a few inventions. Once a system is symbolized into a Su-field model, its potential problems can be identified and the problematic Su-field may also be fixed by 76 standard solutions.

B. Matter-element Analysis and Extension Method

This research will employ matter-element analysis and extension theory repeatedly, tries to integrating "extension of matter-element" with the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. Extension theory and method are the new science, for applying to the research on conceptual design of the products and innovative design is a new field. Extension methods, a new structure of the basic research, the further studies of its application are important and necessary.

In this research, we will use the extensibility of matter-element to formalize and clarify Su-field model (substance or field) which is difficult to understand. 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. 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..

1. Definition of matter-element

A matter has many characteristics and each characteristic has corresponding value. According to matter-element theory, a matter-element is composed of the name of the characteristics and the respective measure. [2]

A matter-element can be combined with the other matter-elements to form a new one, or be decomposed into a few new matter-elements; new matter-elements contain qualities that former matter-elements do not have. The probability is call extensibility of matter-element. The extension of matter-element provides another way of resolving contradiction. Matter-element can be used to describe every matter in real world. We use and ordered triad

$$R(N,c,v) \quad (1)$$

As the basic element for describing the matter N, called matter-element, where N represents the matter; c the characteristic name; v is N measure about c. Thus, $v = c(N)$.

The extensibility of matter-element is the basis of dealing with incompatible problem. It includes divergence, expansibility, conjugate inside the matters and relativity of matter-element. Divergence is to study the possible routes of outward extension, it includes the same matter of matter-element, the same characteristics of matter-element, the measure of matter-element, the same matter and characteristics of matter-element, the same characteristics and measure of matter-element, the same matter and measure of matter-element. Extensibility studies plausibility, integration and separability of matter-element.

2. Transformation of matter-element

The extensibility of matter-element presents the possible ways of solving problems, including divergence, expansibility, conjugate inside the matters and relativity of matter-element. However, the transformation of matter-element is the technology for resolving contradictions. The processes of transform matter-element $R_0(N_0,c_0,v_0)$ into $R(N,c,v)$ or $R_1(N_1,c_1,v_1)$, $R_2(N_2,c_2,v_2)$, $R_n(N_n,c_n,v_n)$ are defined as the transformation of matter-element R_0, denotes as $TR_0 = R$. Replacement, decomposition, addition/deletion and expansion/ contraction are four basic methods for transformation of matter-element and to be conducive to exchanging or to synthesizing different matter-element.

Based on the divergence of matter-element, matter-element $R_0(N_0,c_0,v_0)$ can be diverged from N_0, c_0, v_0 to synthesizing different matter-elements, providing possible solutions of contradiction problems. As shown in Fig.3, general model of extending tree constructed by matter-element symbols expresses the divergence in simple way.

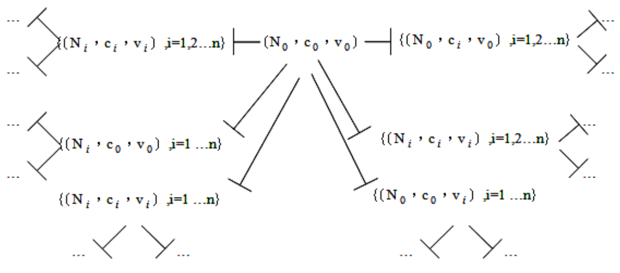

Fig.3 General model of extending tree

C. Design Analysis and Solving

This research tries to introduce "extension of matter-element" into the Su-Field modeling procedure to improve the efficiency and extent of concept evolutions. Mainly divides into two stages to carry on,

First stage: By using the extensibility of matter-element, substance or field which is difficult to understand will be formalized and clarified. 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.

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.

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. Basic properties and solving procedures of Su-field method

The incomplete Su-Fields with only one or two components can be graphically represented as shown in Fig.4. 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. Incomplete states as shown in Fig.4 picture(1), can be modified by increasing a substance and a field. Incomplete state of picture(2), can be modified by adding two substances that the S_2 is acted on S_1 through the field F. Incomplete state of picture(4), can be modified by adding intermediary substance S_2. Similarly, incomplete state of picture(3) need a field to complete the model. [8,15].

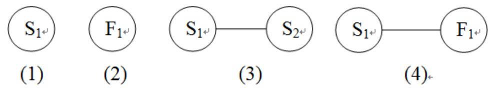

Fig. 4 Incomplete Su-field model[15].

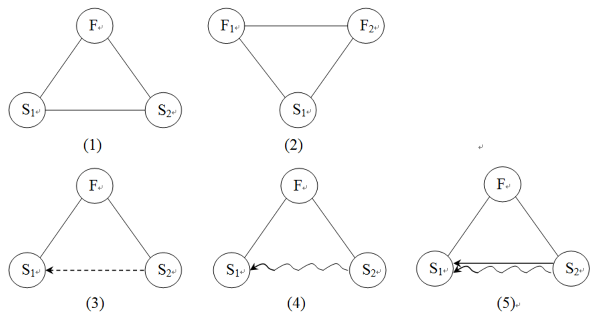

Fig. 5 Typical examples of complete Su-field model, (1) and (2) simple, (3) ineffective, (4) harmful effect, (5) harmful and desired[Terninko; Savransky]

As summarized in Fig.5, 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. [8,15]

When we mention about properties and actions of a Su-Field we mean the properties and actions of a subsystem of the technique. Savransky discussed some properties of incomplete Su-field model and also summarized the suggestions and transformation rules of problems solving. The five most important properties of Su-Fields are the following.

1. If you consider a subsystem as an incomplete Su-Field component, any of its characteristics can be changed, and the subsystem can be a component of a complete Su-Field. To modify a substance it is often necessary to use a field; and for transformation of a field it is often necessary to use a substance.
2. Differentiated action upon one Su-Field component causes differentiated transformation of other components.
3. If one Su-Field component has a specific spatial-temporal structure, then a similar structure can be created in other Su-Field components.
4. The number of fields or types of interaction between Su-Field substantial components is not limited. This number is determined by their physical properties and character of interaction.
5. Any component of any Su-Field can be a component of another Su-Field at the same time.

Such transformation rules help avoid psychological inertia during problem solving. Five basic transformations are following:

1. To solve a problem, the missing component is introduced to the incomplete Su-Field to make it complete.
2. To increase the efficiency of an existing Su-Field, its substantial component, since it is a tool, can be expanded into an independent Su-Field, connected to the initial one. (the obtained Su-Field is referred to as a chain one)
3. Problems in detection and measurement can be expanded into a Su-Field having fields at both input and output — called a “measuring” Su-Field.
4. The most efficient way to destroy harmful, unwanted, or unneeded Su-Fields is to introduce a third substantial component that is a modification of one or both substantial components composing the given Su-Field.
5. If the field F_2 is needed at the system output (with field F_1 at input), the Su-Field should be transformed using the F_1–F_2 physical transformation.

2. Integrated Extension of Matter-Element and Su-Field Model

In the works of Savransky and Fey, there are the solution procedures presented for designer to search for suitable solution. However, the procedure is often so complicated, and is probably unfavorable to practice design. Typical performing procedure of Su-field model is to use basic transformation rules to assist to change problematic Su-field model following the built initial Su-field model. Obviously, in Su-field modeling processes, adequate change or innovate components of Su-field model can effective simplify problem. This procedure is the designer’s challenge too. In this research, extension of matter-element has been introduced to assist extensive thinking so that the acceptable schemes and components can be obtained rapidly.

In addition, in general design processes, basic transformation rule 1, rule 2, rule 4 and rule 5 most often used by the designer. In performing transformation, no matter what we introduce the new component, link multiple Su-Field triangles, extend the field or make use of the intermediary matter, by integrating extension of matter-element with Su-field model, the efficiency of developing creative concept will be improved effectively. Therefore, in this article, we will try to apply and integrate extension of matter-element with Su-field modeling, the corresponding procedures and properties are presented as follows.

First of all, as for the characteristics of product concept design, such as creativity, complexity, multi-objects, multi-scheme and uncertainty of the design inference, we will use theory and method of “extenics” to set up matter-element models and knowledge extensible expressions for proceeding the divergence and transformation of matter-elements. According to the advantage of extensibility, the possible solutions for design problems based on the proposed modeling method will be extended more widely and feasibly.

Savransky proposed five most important properties of Su-fields, as stated in property 1 and property 2, a subsystem as an incomplete Su-Field component, any of its characteristics can be changed or by adding a new component to get a complete Su-field model. Relatively, different actions, which are applied to a Su-Field component, will cause transformation of other components. As proposed in basic transformation 1, to solve a problem, the missing component is introduced to the incomplete Su-field to make it complete. In basic transformation 2, in order to increase the efficiency of an existing Su-Field, its substantial component, since it is a tool, can be expanded into an independent Su-Field, connected to the initial one. (the obtained Su-Field is referred to as a chain one) As for basic transformation 4, it is advised that the most efficient way to destroy harmful, unwanted, or unneeded Su-Fields is to introduce a third substantial component that is a modification of one or both substantial components composing the given Su-Field. 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

$$R = \left(N(t), c, v(t)\right) \quad (2)$$

Matter-element with multi-characteristics

$$R(t) = \begin{bmatrix} N(t) & c_1 & v_1(t) \\ & c_2 & v_2(t) \\ & \vdots & \vdots \\ & c_n & v_n(t) \end{bmatrix} = \left(N(t), C, V(t)\right) \quad (3)$$

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 a extending tree. Extending tree is a method for matter to extend outwards to provide multi-orientated, organizational and structural considerations. As operating in Fig.3.

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

Event-element

$$I(t) = (d(t),\ b,\ u(t)) \tag{4}$$

Multi-dimensional event-element

$$I(t) = (d(t),\ B,\ U(t)) \tag{5}$$

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 $a_1, a_2, \ldots, a_n$ and corresponding measure values $w_1(t), w_2(t), \cdots, w_n(t)$:

$$Q(t) = \begin{bmatrix} s(t) & a_1 & w_1(t) \\ & a_2 & w_2(t) \\ & \vdots & \vdots \\ & a_n & w_n(t) \end{bmatrix} = (s(t), A, W(t)) \tag{6}$$

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. A patent successfully demonstrate that the proposed innovative design process is feasible and flexible.

IV. Illustrative Design Case

In this research, a design case "Stapleless stapler", is adapt to explain and verify feasibility of the proposed design procedure. Traditional staplers use metal staples to bind papers. However, metal staples have inconspicuous but serious impact to environment. Thus, it is imperious to develop a "Stapleless stapler". Design problem: "How to dispel the use of the staple under the principle of not influencing the function --binding"

A. List Su-field model related to design problem

The initial Su-field model is constructed according to operation situation and function of the traditional stapler and the course correlated to staples. Su-field model of the traditional stapler can be illustrated at least 3 types. It is essential that the present Su-field model should be conformed to the design problem. It should be avoided to illustrating a Su-field model that is irrelevant to the design problem. Inadequate model will confuse designer and make the solution procedures too complicated.

In this case, the design purpose is eco-design, tending to reduce consumption of resources. Key problem of design case which needed to be settled is "How to eliminate the use of the staple without influencing the function—binding". Among the illustrated Su-field models, the model as shown in Fig.6(a) seems to be the most suitable one. As shown in Fig.6, S_1 represents the metal staple, S_2 represents the punch of stapler, and F_{ME} represents a mechanical pressure. This description of Su-field model is that the punch (S_2) transmits mechanical pressure force (F_{ME}) to the metal staple (S_1).[15]

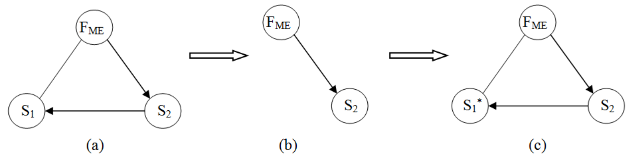

Fig.6 (a) Su-field model of the traditional stapler; (b) eliminate harmful substance S_1; (c) Add new substance to complete Su-field model

The metal staple (S_1) is considered as the material component that harmful to environment. 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 bind. Similarly, the substance S_1' should bear the mechanical pressure (F_{ME}) force by the punch (S_2) on the stapler. After performing transformation, Su-field model is illustrated as Fig.7.

B. Integrated with Extension of Matter-Element

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

1. Survey the entity component correlated to S_1^*. Besides the metal staple, we search for the replaceable subject by using the divergence of matter-element.
2. Use extending tree method to build the transformation model for staple: A matter refers to multi- characteristics, a characteristic also mapped by matters. Thus, "one matter with multi-characteristics", "one characteristic maps to multi-matters" , "one value maps to multi-matters", "one matter, one value vs. multi- characteristics", "one matter, one characteristic vs. multi-values" are the extending propositions of matter-element to resolve contradiction. The extension of matter-element, staple, can be expressed as,

R_1 = (N, c_1, v_n)
= (staple , material , plastic)
= (staple , material , rope)
= (staple , material , glue) ......etc.

R_2 = (N, c_2, v_n)
= (staple , binding method , staple binding)
= (staple , binding method , rope binding)
= (staple , binding method , glue binding)
......etc.

The extension of event-element,

I_1 = (d, b_1, u_n)
= (binding , binder , plastic)
= (binding , binder , rope)

= (binding，binder，glue) ......etc.

I_2 = (d, b_2, u_n)

= (binding，objective，papers) ...... etc.

I_3 = (d, b_3, u_n)

= (binding，tighten effect，tight) ...... etc.

I_4 = (d, b_4, u_n)

= (binding，method，rope) ...... etc.

The extension of relationship-element (relationship-element could be the binder, objective, imposer, effect, structure,etc.)

$$Q = \begin{bmatrix} \text{binding} & \text{binder} & \text{staple} \\ & \text{objective} & \text{papers} \\ & \text{imposer} & \text{punch} \\ & \text{structure} & \cdots \end{bmatrix} = (s, A, W)$$

3. 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 1^{st} level of extending tree should be evaluated whether it meets the demand of the new Su-field model or not. If the components, corresponding to matter-elements obtained from extending tree, 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 interaction “bind” to be carried out by the objective (sheets).
4. Draws out the new design problems based on the new concept and repeat the extending processes: After having this concept, we consider making the paper play the role of metal staple and then, design problem becomes “How to complete binding without using glue?” Therefore, restart the extending processes by taking a new matter “paper staple” and a new characteristic “binding method” to set up matter-element, event-element, relationship-element and extending tree. By the achievement, we obtain an idea, may consider that uses “fold-up type” the way to replace “binds”.
5. Determine the processes of using “fold-up type” to realize the proposed idea. Finally, we have to solve the key problem induced by “fold-up binding” method to complete design. The key problem becomes “How to complete “fold-up binding” the action at a time, in the stapler consecutive action.” We may observe from the traditional stapler’s operating process to describe the actions related to “field” as follows.
   a. Depresses the downward impulsive force which punch produces.
   b. Stop pressing, the resilience that the punch acts.
   c. The pulling force that the paper pulls out outward to the stapler.

   So, the new design of the stapler can refer to these three actions to avoid adding extra new components. Obviously, actions (a) and (b) which affect on traditional metal staple, has provided a new idea that transforms these actions to the formation” paper stapler” the movement and the process. Accordingly, action (c) applied to use for” fold-up” paper stapler.
6. Su-field of the new design is illustrated as Fig.7(a), the added field F_2 represents the force to fold-up paper staple and S_3 represents the sheets to be bound.

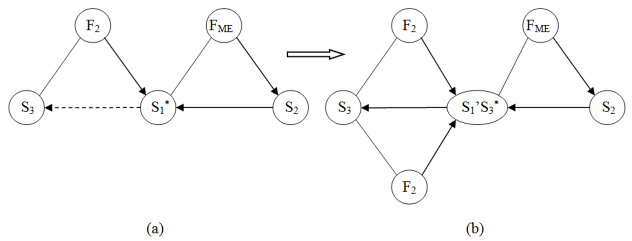

Fig.7 Su-field model of the new design

The innovative concept is that the shape of punch is designed similarly in the puncher. The impact place will have the part peeling still to leave the attachment point. The staple of new stapler is defers to the above explanation to design. The acting processes of the new stapler is,

a. Put the sheets into the punch and press downward the level arm.
b. The punch makes some arrow-shaped crevices and the arrow-shaped papers will be pulled out the sheets while the level arm is lifting up.
c. The part of arrow-shaped papers will be folded and attached to the sheets.

7. However, merely pure fold-up, the chucking power is obviously insufficient to clamp the document, but has falls off the risk. Repeat the extenics design procedures, may obtain many solutions, optimal solution should be selected to meet the design demand. A new field F_3 and substance S_3 (combined with S_1^*) are added and illustrated as Fig. 7(b).

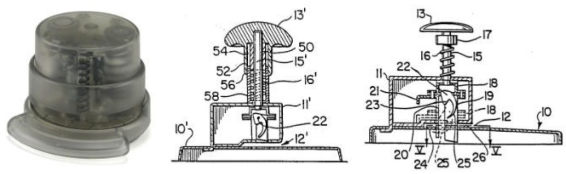

Fig.8 Prototype drawings of the stapleless stapler

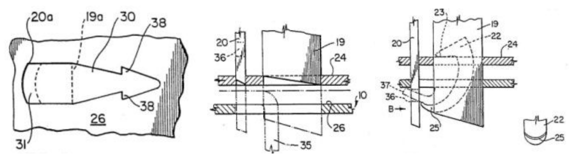

Fig.9 “stapleless stapler” schematic drawing of the fold-up process

V.CONCLUSION

Su-field analysis is able to not only model a system in a simple graphical approach and identify problems, but also offer standard solutions to improve the system. By possessing a symbolic system and transformation rules, the Su-Field analysis model can assist designers to diagnose and solve most design problems. This study proposes an innovative design and problem-solving process, based on Su-Field modeling method integrated with extension of matter-element.

In this research, we will use the extensibility of matter-element to formalize and clarify Su-field model (substance or field) which is difficult to understand. 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. 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. We make use of extensibility of matter-element to exchange the descriptions of design problems and solutions into creative fields. The concrete result includes,

1. Evaluate the differences and benefits between Su-Field modeling procedure and matter-element modeling procedure.
2. Assess possibility and advantage to combine construction of symbolic system in Su-Field model and the transformation and extension of matter-elements.
3. Introducing concept extension of matter-element into symbolic developments to derive out more creative solutions.

An innovative design case, stapleless stapler, successfully demonstrates that the proposed design process is feasible and efficient.

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