6th INTERNATIONAL MULTIDISCIPLINARY CONFERENCE

FUNCTIONAL APPROACHES IN PRELIMINARY DESIGN

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Abstract*: The Theory of Inventive Problem Solving (TRIZ) and its simplified versions have been widely recognized as a powerful systematic innovation technique that can be applied to a wide arrange of disciplines. This paper focuses on engineering design and illustrates how modeling methods already familiar to engineering designers can be adapted for use in those techniques. Specifically, the 'black-box' modeling technique, common in problem formulation and clarification in engineering design, is modified for use in TRIZ family methods. The technique, referred to as Energy, Material, System modeling, can not only serve as a substitute for substance-field modeling, but as it builds on existing knowledge in the engineering design community, removes one of the barriers to wider TRIZ adoption by not requiring designers to learn new and radically different modeling techniques.*

Keywords: *Function, Black-Box, EMS, Systematic Innovation, TRIZ*

1. INTRODUCTION

TRIZ (Altshuller, 1984) and its simplified versions (e.g. USIT - have been taught as a method that can be applied across numerous disciplines due to the generality of its collection of principles and tools. In trying generate a wider audience, most TRIZ texts use the general modeling methods and terminology developed over the years by the TRIZ community. The presentations, however, may also present a barrier to wider implementation due to the difficulty in relating TRIZ concepts typically discussed in the context of TRIZ modeling techniques to one's specific discipline.

Despite the power of TRIZ, it has not seen wide usage in the engineering design community, both in industry and in academe. This article explores ways to increase the implementation of TRIZ in the engineering design community by adapting and incorporating modeling techniques, on one hand already familiar to engineering designers, on the other hand building up TRIZ philosophy and tools from a simplified level.

2. TRIZ

TRIZ, the Russian acronym for Theory of Inventive Problem Solving, was first developed in Russia by Genrich Altshuller and is now used across the world. TRIZ is a powerful methodology for creatively solving problems in a wide range of technological (and many other nontechnological) fields. It has established knowledge bases (KBs) of technological facts with various useful indexing systems and of principles for inventive thinking and has also developed a large number of methods for problem definition, problem analysis, and solution generation. These KBs have been constructed by extracting world best solutions in science and technology, and the problem solving principles in TRIZ are at a high level of abstraction so as to be applicable to a wide range of problems.

These original analyses articulated numerous solution patterns found across patents that can be successfully applied to solve new problems. These patterns have since been synthesized into numerous methods and techniques including (1) Physical effects, (2) Laws of evolution, (3) Standard solutions, (4) Technical contradictions and the contradiction matrix, and (5) physical contradictions and the separation principles, (6) 9-windows method, (7) Substance-Field modelling, (8) Smart Little People's modelling (Zlotin – Zusman, 1999).

It provides steps that allow design teams to avoid the "psychological inertia" that tends to draw them to common, comfortable solutions when better, non-traditional ones may exist.

It is generally understood that TRIZ is based on the following scheme of problem solving. Instead of trying to solve user's specific problem directly to specific solutions staying at the concrete level, TRIZ advises to go around at a higher abstraction level using standard models which show generalized problems and their generalized solutions. The latter is based on the analysis and classification of a very large number of problems in diverse engineering fields. The general TRIZ design problem points to corresponding general TRIZ design solutions from which the design team can derive solutions for their specific design problem. The power of TRIZ, therefore, is its inherent ability to bring solutions from diverse and seemingly unrelated fields to bear on a particular design problem, yielding breakthrough solutions.

Recent works in TRIZ have added some more (referring to the above mentioned (1) – (8)) methods, including:

- Cause-Effect analysis: to model a network of cause-and-effect relationships in the problem, and to suggest a large number of smaller and more specific problems of preventing some harm or enhancing some good in the original problem. This serves in the problem definition process.
- Function and Attribute analysis: to model the functional relationships in the system (releasing the 'two-substance restriction' in the Substance-Field modeling) with some inclusion of attributes of objects. (Orloff, 2003)

3. USIT

Unified Structured Inventive Thinking (USIT) (Sickafus, 1997) is a simplified and unified version of TRIZ which has overcome the weakpoint of being too complex for those taught without clear background of overall procedure/structure for problem solving in TRIZ. All the solution generation methods in TRIZ have been reorganized into a unified hierarchical system of USIT Solution Generation Operators. On this basis, USIT has a clear procedure for creative problem solving process as shown in a flowchart and also has a clear structure, of transforming problem information stepwise into solution information. User's specific but vague problem is (1) first converted into a 'well defined problem' at the problem definition phase, then (2) further converted into the understanding of the problem system in terms of objects, attributes, functions, space, time, ideal actions, and ideal properties at the problem analysis phase, (3) modified by applying the USIT Operators into pieces of ideas of a new system in the solution generation phase, (4) constructed into conceptual solutions on the basis of user's technological background capabilities, and (5) finally implemented into user's specific solutions) in the implementation phase.

4. SUBSTANCE-FIELD ANALYSIS

A key concept in TRIZ is the modeling of all material objects (visible or invisible) as substances, and sources of energy (mechanical, chemical, nuclear, thermal, acoustic, etc.) as fields. A function (also known as substance-field) can therefore be defined as a substance,

S_1, acted upon by a field, F_1, created by a second substance, S_2. The substance-field for a complete system can be represented with the notation,

$$S_2 \xrightarrow{F_1} S_1 \tag{1}$$

where the arrow shows S_2 having a positive or desired effect on S_1 through the field F_1. Equation 1 merely presents a possible representation. The parameters S_1 and S_2 are often referred to as object and tool, respectively, where the tool is acting on the object to create the desired effect. (Klein, 2002) Models that do not have all three components (tool, object and field) are referred to as incomplete. By adding the missing element, a problem that may have been present in the system can be solved. Alternatively, if the tool has a harmful effect on the object, the straight field line would be wavy to indicate that harm is being done. Despite the appeal of the SFA model, it requires engineering designers to learn new modeling techniques, conventions and nomenclature and may therefore present a barrier to adoption. The following section will introduce black-box modeling upon which the energy-material-signals (EMS) models are based.

5. PROBLEM CLARIFICATION WITH BLACK-BOX MODELING

The following discussion of Black-box modeling is based upon the work by Pahl and Beitz (Pahl – Beitz , 1996). An analysis of engineering systems reveals that they essentially channel or convert energy, material or signals to achieve a desired outcome. Energy is manifested in various forms including, optical, nuclear, mechanical, electrical, etc. Materials represent matter. Signals represent the physical form in which information is channeled.

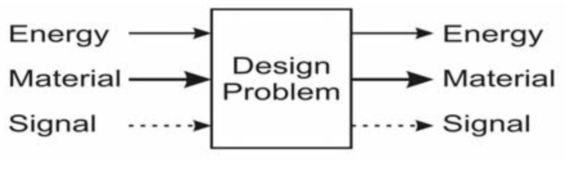

Fig. 1. Black-box model

An engineering system can therefore be initially modeled as a black-box (Fig. 1.) with energy, material and signal inputs and outputs from the system. In black box modeling, energy is represented by a thin line, material flows by a thick line, and signals by dotted lines is shown. The engineering system therefore provides the functional relationship between the inputs and the outputs.

Problem clarification involves forming a clear understanding of the problem. The overall problem represented by the black-box can be decomposed into smaller sub problems. Problem decomposition allows solutions to complex engineering design problems to be found by considering simpler sub-problems. Design teams can then focus on the subproblems critical to the success of the project first, deferring others. Sub-problems are then mapped to sub-functions for which a design is created. Combination of all the designs that achieve each of the sub-functions results in the desired system solution that achieves the overall desired function. Note that the functional decompositions and the resulting black-box diagrams are generic and do not commit the design team to any particular technological working principle. Black-box modeling of existing systems that are to be redesigned, on the other hand, decomposes the existing system into sub-systems as opposed to sub-functions. The sub-systems would then be translated to sub-functions from where the redesign process. In new product development concurrent or analogical systems might have to be dealt with.

The technique, referred to as Energy-Material-Signal (EMS) modeling, can not only serve as a substitute for substance-field analysis, but also provide the following desirable features.

1. Builds on existing knowledge within the engineering design community, thereby removing one of the barriers to widespread TRIZ adoption.
2. Applicable to both physical and technical contradiction systems.
3. Includes multiple scenarios in the same model.
4. Identifies the true problem to be solved, within the context of the overall system.
5. A separate resource list is therefore not required.
6. Includes all the features of General Function Structure (GFS).

6. RESULTS AND CONCLUSIONS

After the critical analyses of the methods and tools, incorporating the strengths of them into a complex but at the same time easy-to-learn and easy-to-use model to support the preliminary stages of design, a modified scheme (Fig. 2.) based upon TRIZ and USIT was developed. The strength of the model is that it is function oriented, problems can be solved either with a high level of knowledge of TRIZ tools, or even with less deviation from the classic German design school. This model was found to be very effective in new system design problems, because of the way the model leads the designer towards a task-independent, general understanding of the functions. The authors already have experiences on the model from student projects from education.

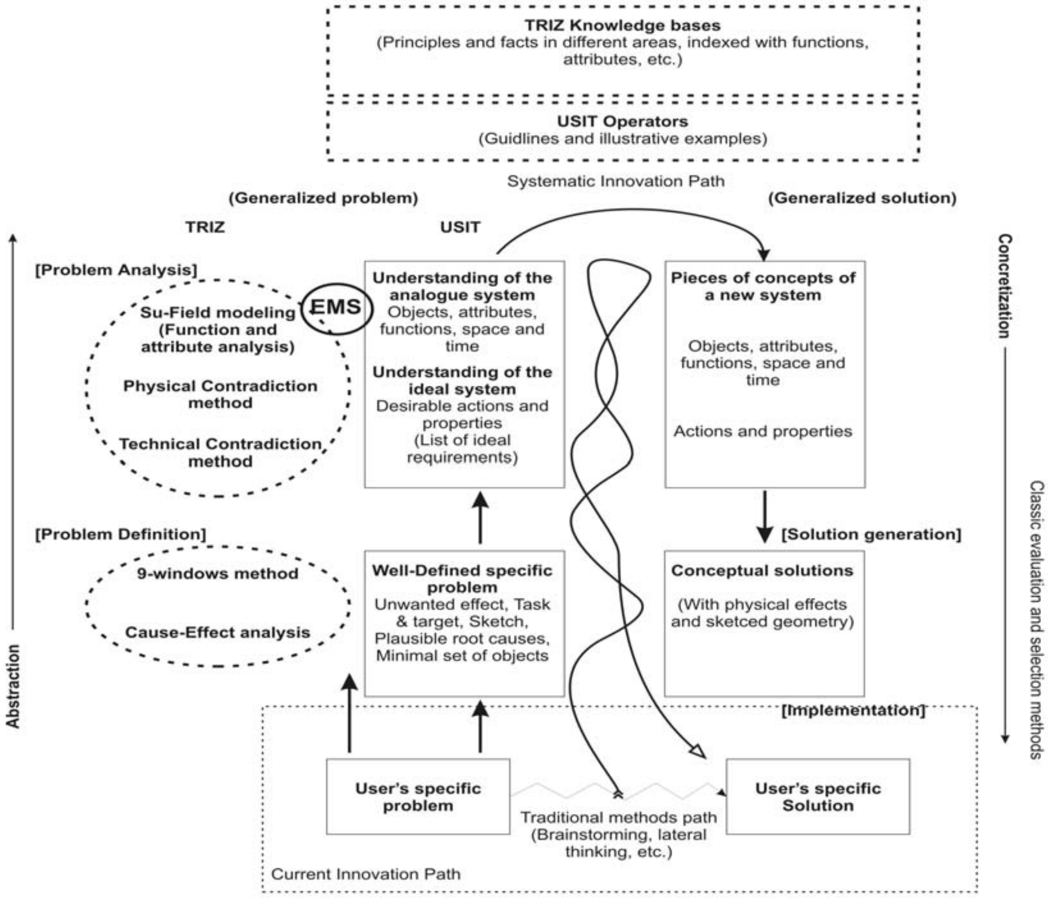

Fig. 2. The suggested method to support problem solving in preliminary design

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