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Modeling a hybrid-compact design matrix for new product innovation

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ABSTRACT

Conceptual design is a critical activity during the early phases of new product development (NPD) because most creative ideas will be generated in this process. Without creativity in design there is no potential for innovation. A complete design process for product innovation must include problem analysis and idea generation simultaneously. However, both Axiomatic Design (AD) and Theory of Solving Inventive Problems (TRIZ) techniques have their own advantages and drawbacks. There is the attribute of complementarity between AD and TRIZ in practical application. Based on AD and TRIZ, this paper presents a novel hybrid-compact design matrix by integrating problem analysis and idea generation approaches into the conceptual design stage for new product innovation. Despite the recognized importance of innovative design, there is a lack of systematic and effective design process that can cover all conceptual design activities. To address this gap, a useful and powerful hybrid model of the problem-solving is created for innovative product design, depending on the capability of AD detailed problem analysis and the expertise of TRIZ innovative idea generation. Finally, a case study of designing a new elderly rehabilitation equipment (ERE) is used to demonstrate the proposed method and the results verify the feasibility and effectiveness of the approach. This hybrid-compact design matrix can really help designers generate more creative outcomes in NPD.

1. Introduction

To face today's dynamic and competitive market environment, new product development (NPD) must not only satisfy the quality, cost and speed of production, but also ensure that products have innovative value. NPD is a key factor to obtain success in the market and conceptual design is an important phase for NPD. In order to achieve long-term survival and stable growth, companies must rise to the challenge of global competition and strengthen their product development capabilities. Only through continuous innovation in new product design can they maintain their global competitiveness all over the world. Successful companies are those that can create and dominate new markets by developing innovative products (Ulrich & Eppinger, 2000). The innovation acts an important role in the progress and growth of every company. However, companies are derived to enhance their design approaches to remain market competition and assure their survivals (Cavallucci & Lutz, 2000). As global technology competition becomes intense, an ability to solve design and technology problems expeditiously becomes critical for the innovation of enterprises and companies (Jugulum & Sefik, 1998). As such, a number of problem-solving techniques have been proposed to solve a variety of design problems. While many problem-solving tools and approaches can be found in the related works, it is important to choose the suitable methods or tools for solving design problems. Büyüközkan, Dereli, and Baykasoglu (2004) have summarized numerous approaches for NPD. A decreased set of these approaches that have been widely applied to the problem-solving processes in NPD are provided. It is probable to classify these approaches into two catalogues of problem analysis and idea generation. The tools of problem analysis include Axiomatic Design (AD), Quality Function Deployment (QFD), Failure Mode Effect Analysis (FMEA) and Total Quality Management (TQM) (Suh, 1990; Akao, 1972; Kahraman, Ertay, & Büyüközkan, 2006; Seung & Ishii, 2003; Segismundo and Miguel, 2008; Cua, McKone, & Schroeder, 2001). The tools of idea generation include Brainstorming, Heuristics, Mindmapping and TRIZ (Altshuller, 1996; Harris, 2002; Kokotovich, 2008; Sutton & Hargadon, 1996). Some of these tools have been traditionally applied to solve the related engineering and design problems.

All the above techniques and tools own different merits and disadvantages. Some techniques are particularly oriented in practice application. Nevertheless, what characters does a basic systematic problem-solving approach possess? First, it must own the capability of analyzing and constructing the problems correctly. These problems can be taken into the consideration of all the parameters involved in the design domain. Moreover, a design problem is

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usually more complicated in nature than it originally occurs. This needs a complete analysis of the problem for breaking it down into the lower fundamental level problems. After this is done, innovative ideas can be created for each of the fundamental level problems which extremely resolve the foremost problem. As mentioned earlierly, the systematization and effectiveness of developing these innovative solutions has become ultimately critical and thus the need to adopt appropriate problem-solving tools and techniques. An ideal problem-solving approach must have the good capabilities of problem analysis and idea generation. This paper attempts to integrate more effectively the Axiomatic Design (AD) and the Theory of Solving Inventive Problems (TRIZ) to fit the current requirements of design problem- solving.

1.1. Creative design approach

Designers are routinely trained to be aware of the possible solutions to particular problems, so they can recognize problem classes, retrieve matching solution approaches and then refine the details to fit a specific case. However, the design problem representations that trigger the recall of these semi-abstract solution classes will include inappropriate assumptions, and designers may focus on recent or salient solution types even when they know they are inappropriate (Purcell & Gero, 1996). What is often needed is to reformulate the contradictions and constraints in a more abstract and general form, to eliminate assumptions implicit in the designer's initial concrete formulation of the design problem. Cross (2004) argued that creative designers deliberately define tasks so that they are problematic, treating them as ill-defined and therefore harder than the same problems envisaged by novice designers. As a result, designers shake up their assumptions about what a solution will look like. Although this is valuable for provoking innovation, it is probably inappropriate for situations where minimizing novelty is desirable. However, as Kim, Jin, and Lee (2011) pointed out, there are significant individual differences in how designers approach creative problem-solving, as well as effects of the corporate design strategy. Legardeur, Boujut, and Tiger (2003) proposed an innovation development and diffusion (ID^2) tool geared towards coordinating the development of new solutions during the early phases of design projects. Sturges et al. (1993) pointed out the importance of understanding the processes which lead to innovation and to create tools which generate step changes in function in an orderly and repetitious manner.

A problem defining and analyzing method such as axiomatic design (AD) purposely forces designers to start from scratch and explore the relationship between functional requirements and physical domain (Suh, 2001). As the form and function of the design are refined in a bootstrapping manner, all contradictions and constraints must be eliminated before a greater level of detail can be approached. Since its first introduction by Suh (1990), AD has been successfully applied to computer applications (Albano & Suh, 1994) and manufacturing (Kulak & Kahraman, 2005). Bae, Lee, and Chu (2002) introduced the sequential kinematic design of a suspension system based on AD principles. Houshmand and Jamshidnezhad (2002) also provided a lean manufacturing based production system design model using AD approach. In this model organizational capabilities, technological capabilities and value stream analysis are used as the basis. Kulak and Kahraman (2005) developed fuzzy axiomatic design to use AD under fuzzy environment. And also, the method is used as an efficient tool to solve multi-criteria decision making problems. Thielman, Ge, Wub, and Parme (2005) proposed an approach based on axiomatic design methodology in order to construct a model including both quantitative and qualitative tools. Coelho and Mourão (2007) showed how AD perceived the relationships between each product and the related manufacturing processes in their paper. All above researches proved the successful application of AD in practice. AD can provide designers with a systematic problem analysis method in design process, but it cannot offer creative hints or triggers for developing innovative solutions.

On the other hand, TRIZ is a well-known methodology of idea generation. It can enhance design creativity based on resolving such pair-wise contradictions between functional requirements by identifying a new solution principle for a specific problem (Altshuller, 1988). The TRIZ method was first introduced by Altshuller (1984), who views invention as the discovery and removal of contradictions. He defines five levels of invention, where higher levels are associated with increasing degree of difficulty and increasing degree of change of an object and its environment. Altshuller's TRIZ philosophy is based on the analysis of thousands of registered patents. The insights gained from this process led to the formulation of the Theory of Solving Inventive Problems (TRIZ), which is an algorithmic approach to solving design problems (Altshuller, 1996). TRIZ has been successfully applied in many fields including product design, engineering design, manufacturing and material sciences. Tsai, Chang, and Tseng (2004) used TRIZ for concept generation to redesign a seated ball valve mechanism. Bariani, Berti, and Lucchetta (2004) adopted a "Design for Manufacture and Assembly" (DFMA) and TRIZ methods together to reduce part counts for simplifying the product structure. Cascini and Rissone (2004) attempted to use the tools of product design with the TRIZ method in the process of replacing metal parts with plastic ones. Kobayashi (2006) applied TRIZ to the design of products in cooperating sustainability and eco-efficiency related problems. Yang and Chen (2009) developed an innovative design model that integrates examples of effective energy-efficient practices in industry, the CBR method, and TRIZ tools to achieve eco-innovation. Cavallucci and Khomenko (2007) addressed the incapacity of TRIZ to face complex situations and, as a result, an extension of it has been proposed by OTSM-TRIZ theory. A case study conducted in collaboration with Thales regarding a ground-based radar design will be used to illustrate how several of their assumptions. Cavallucci, Rousselot, and Zanni (2009) presented the theoretical grounding of a new problem-oriented approach based on TRIZ and the way they translated it into generic techniques through a simple and didactic example. This approach could be led to a practical use in enterprises for network design. Houssin and Coulibaly (2011) proposed an innovative approach that aims to eliminate contradictions between productivity and safety in order to improve product performance. This approach is based on 4 steps: systemic safety integration using working situation model, taking into account the requirements of safety directives and standards, identifying the contradiction resulting from designer's choices and finally resolving these contradictions using TRIZ tools. An application case is outlined in off-set industry, to show the applicability and usefulness of the proposed approach. Houssin, Renaud, Coulibaly, Cavallucci, and Rousselot (2015) presented the results of an in depth study of the roots of both TRIZ and Case Based Reasoning (CBR) approaches, from the point of view of their philosophy and the scope of their relevant action. After several tests and investigations, the study pointed that each approach weakens the other if any of the two let the other govern its conduction.

TRIZ proposes steps which admit the designers to escape from "psychological inertia" which leads them to general, common solutions when innovative, preferable ones may appear. TRIZ is depended on patents analyses that systematize many pattern solutions from diverse principles. It has been regarded as an idea generation process which can create innovative solutions for engineering and design problems by utilizing the compressed knowledge of numerous past inventors. However, TRIZ is a tool for the innovative solutions generation, but it cannot provide