Expert Systems with Applications 36 (2009) 8302–8312

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Applying TRIZ and Fuzzy AHP to develop innovative design for automated manufacturing systems

Te-Sheng Li [a,*], Hsing-Hsin Huang [b]

[a] Department of Industrial Engineering and Management, Minghsin University of Science and Technology, 1 Hsin-Hsin Rd., Hsin-Fong, Hsinchu 30401, Taiwan, ROC
[b] Department of Mechanical Engineering, Minghsin University of Science and Technology, 1 Hsin-Hsin Rd., Hsin-Fong, Hsinchu 30401, Taiwan, ROC

ARTICLE INFO

Keywords:
TRIZ
Fuzzy analytical hierarchy process
Contradiction matrix table
Automated manufacturing system

ABSTRACT

Innovative design in the development of new product and process has become the core value in most business establishments. These innovative designs are often associated with the long-established trade-off compromises or conflicting performance parameters where speed and reliability, or quality and cost are readily acknowledged. The rate of change in technology and the commercial environment suggests that the opportunity for innovative design is accelerating, and systematic support for innovation process is needed. This study combines the Russian Theory of Inventive Problem Solving (TRIZ) and the fuzzy analytical hierarchy process (AHP) for designing the automated manufacturing systems. This study applied the contradiction matrix table, 40 innovative principles, and 39 engineering parameters to compromise the trade-off between design contradictions and engineering parameters. The design engineers can acquire more feasible solutions and inspiration through the proposed approach. However, due to vagueness and uncertainty in the decision-maker's judgment, a fuzzy AHP is employed as a decision support tool that can adequately represent qualitative and subjective assessments under the multiple criteria decision making environment. Moreover, the proposed approach can help decision makers facilitate the selection and evaluation of innovative designs in the presence of intangible attributes and uncertainty. In short, the objectives of this research are to use TRIZ to propose the automated design alternatives under the innovative design consideration, and to use a fuzzy AHP to evaluate and select the best feasible alternative under multiple criteria. A case study of designing automated connector assembly line has been used to demonstrate the applicability of the proposed approach.

1. Introduction

The rapidly changing modern marketplace drives companies to seek competitiveness in product/process development in terms of innovation, high quality, and speed to market. Since innovative design decisions in the early design stages play a critical role in deciding the product development time, it is extremely important to make a systematic approach to design decisions in the early phase of design. The concept of trade-off, or conflicting performance parameters is a core element of design where speed and reliability, or quality and cost are readily acknowledged. These engineering designs are well documented and the trade-off parameters are balanced in the design process to achieve engineering optimization for a particular application. However, the practice of using trade-off parameters as a focus for systematic innovation in the mechanical design has only recently emerged from TRIZ (the Russian acronym for the 'theory of inventive problem solving'). Numerous researchers have applied the concept of mechanical design trade-offs to help acknowledge and manage conflicting performance parameters associated with manufacturing. For a design engineer, when he/she tries to solve an innovative design problem, he/she usually faces a systematic incompatibility or conflict design problem. As the design engineer changes certain parameters of the system in his/her thorny design problem, it might affect other parameters badly. Traditionally, the design engineer always compromises with this kind of contradictory situations and restricts him on performing innovative design tasks.

The Russian Theory of Inventive Problem Solving (TRIZ) was originally proposed by Altshuller (1999). This method solves technical problems and offers innovative product structures by employing a knowledge base built from the analyses of approximately 2.5 million patents, primarily on mechanical design. TRIZ consists of three basic tools: (1) 'the system conflict resolution principles', which consists of 40 principles to effectively resolve the conflicts between customer requirements, (2) 'effect', which is a knowledge database system consisting of physical, chemical, and geometrical effects and rules for problem solving, and (3) the 'substance-field model' for modeling a technological problem in the form of 'two materials' and for deriving answers that make

* Corresponding author.
E-mail address: jeff@must.edu.tw (T.-S. Li).

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doi:10.1016/j.eswa.2008.10.025

the above interaction change in the desired direction. In this way, TRIZ shows its potential as a support tool for creating the original idea in the 'innovative design' processes.

The basic constituents of TRIZ are the contradictions, 40 inventive principles, the contradiction matrix (Domb, 1997, 1998; Zoyzen, 1997) and the laws of evolution (Petrov, 2002), the substance-field analysis modeling (Terninko, 2000), ideal final result (Domb, 1997), and substance field resources, scientific effects (Frenklach, 1998), and ARIZ (the Russian acronym for the 'algorithm of inventive problem solving') (Zlotin & Zusman, 1999). The core of TRIZ consists of 40 contradiction principles, and the matrix; other tools are auxiliary to assist design engineers in constructing the problem model and analyzing it. The TRIZ approach has applied to numerous design problem-solving such as CCD laser instrument for measuring complex 3D curved surfaces (Liu & Chen, 2001), auto-focus camera with lower response time (Jung, Bae, Suh, & Yi, 2006), CAD software integrating TRIZ into eco-design tool (Chang & Chen, 2004), integrating steering shaft lock for motorcycle (Mao, 2000), and Technology Forecasting of CCD and CMOS (Tompkins, Price, & Clapp, 2006).

The most commonly applied tool is the matrix, which is composed of contradictions and 40 principles. The contradiction means that a worsening engineering parameter (avoiding degradation parameter, ADP) and an improving parameter (IP) exist simultaneously. 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 zero to four most likely principles for solving design problems involving the 1482 most common contradiction types as shown partly in Table 1. The basic process of using TRIZ is as the following statement: For using TRIZ in the innovative design problem solving, the design engineer needs to first find the corresponding contradictions for his/her problem at hand. Next, the design engineer matches the meaning of each contradiction with two appropriate parameters from 39 engineering parameters defined in the matrix (Domb, 1997). The design engineer can find the inventive principles for solving the engineering innovative design problem from the matrix when he confirms the parameters of contradiction for an engineering system.

Analytic hierarchy process (AHP) is one of the most popular methods used commonly in industry to aid in alternatives selection. In the conventional AHP developed by Saaty (1980), the pair-wise comparisons for each level with respect to the goal of the best alternative selection are conducted using a nine-point scale. The main advantage of AHP is its inherent ability to handle intangibles, which are predominant in any decision making process like the case presented in this paper. Also, less cumbersome mathematical calculations and comprehensibility makes the AHP an ideal technique that can be employed in the evaluation process. The AHP approach determines the weights qualitatively by constructing multi-level decision structures and forms pairwise comparison matrices. In the application of AHP, the decision maker's subjective judgments are quantified by assigning the corresponding numerical values based on the relative importance of alternatives under consideration to their parent component in the decision hierarchy. The next step is to repeat the AHP procedure to obtain the relative contributions of alternatives to the accomplishment of each improvement objective. The result is a set of weights for the manufacturing system alternatives that represents their contributions to the improvement objectives and the competitive strategy of the company. Wabalickis (1988) applied AHP as stand-alone method to justify the flexible manufacturing system. Datta, Samabasivarao, Kodali, and Deshmukh (1992) presented a generic decision making model and used AHP to justify manufacturing systems. Samabasivarao and Deshmukh (1997) used AHP as an integrated tool to select and justify advanced manufacturing technologies. Byun and Lee (2004) proposed a modified TOPSIS based decision support system to select a rapid prototyping process by employing AHP to determine criteria weights. Chan, Jiang, and Tang (2000) developed the intelligent tools, such as expert systems, fuzzy systems, neural networks and AHP, based on multi-criteria decision-making technique to aid the selection of most suitable FMS design.

However, the above cited literature on the application of AHP to the selection or evaluation problem reveal that most of them employ conventional or crisp AHP, which does not address the issue of uncertainty. Fuzzy AHP is an extension of conventional AHP and employs fuzzy set theory to handle uncertainty. The main purpose of this article is to evaluate the contradiction check in the engineering design, check fuzzy judgment matrices, derive priorities from fuzzy judgment matrices, and make a final decision under group experts using fuzzy AHP. This article demonstrates the application of weighted geometric mean and arithmetic mean to aggregate the individual priorities in the fuzzy AHP to reach group consensus. All of these issues and evaluation of engineering design are illustrated with a numerical example.

The fuzzy AHP technique has been employed to develop the decision-making support tool for numerous industrial applications including FMS design and analysis (Chan et al., 2000), resources allocation enhancements (Ariel & Reich, 2003), quantitative measurement for design freedom (Wood & Agogino, 2005), and engineering design concept selection (Ullman, 2002). Furthermore, Frey, Jahangir, and Engelhardt (2000), for example, offer a more reliable calculation of decoupled designs with Axiomatic Design. Xiao, Zeng, Allen, Rosen, and Mistree (2005) apply game theory to collaborative design environments and use design capability indices to quantify some uncertainties in the outcome. Saaari and Siebery (2004) apply geometric tools to consider the quality of pairwise comparisons. Ayag (2005) integrated the simulation with fuzzy AHP method to evaluate the conceptual design alternatives in a new product development. Ayag and Ozdemir (2006) proposed fuzzy AHP and Benefit/Cost (B/C) ratio analysis to select the best machine tool under the multiple-criteria decision making environment. Jaganathan, Erinjeri, and Ker (2007) discussed three issues

Table 1
Partial cells of contradiction matrix.

IP	ADP						
	1	2	3	4	....	11	39
1							
2							
3							
4							
12						#15, #35, #10, #14	
⋮							
39							