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A hybrid approach for fuzzy multi-attribute decision making in machine tool selection with consideration of the interactions of attributes

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ABSTRACT

Global economic competition has spurred the manufacturing sector to improve and invest in modern equipment to satisfy the needs of the market. In particular, machine tool selection is the most important problem; it plays a primary role in the improvement of productivity and flexibility in the manufacturing environment and involves the imprecise, vague and uncertain information. This paper presents the hybrid approach of the fuzzy ANP (Analytic Network Process) and COPRAS-G (COmplex PRoportional ASsessment of alternatives with Grey relations) for fuzzy multi-attribute decision-making in evaluating machine tools with consideration of the interactions of the attributes. The fuzzy ANP is used to handle the imprecise, vague and uncertain information from expert judgments and model the interaction, feedback relationships and interdependence among the attributes to determine the weights of the attributes. COPRAS-G is employed to present the preference ratio of the alternatives in interval values with respect to each attribute and calculate the weighted priorities of the machine alternatives. Alternatives are ranked in ascending order by priority. As a demonstration of the proposed model, a numerical example is implemented based on the collected data and the literature. The result is then compared with the rankings provided by other methods such as TOPSIS-G, SAW-G and GRA. Moreover, a sensitivity analysis is conducted to verify the robustness of the ranking. The result highlights that the hybrid approach of the fuzzy ANP and COPRAS-G is a highly flexible tool and reaches an effective decision in machine tool selection.

1. Introduction

Due to economic restructuring, developing countries are currently investing heavily in the manufacturing sector. Many companies and factories sprang up to meet production needs for societies, especially small and medium enterprises (SME), a business form that is consistent with private economics. However, to cope with the globalization of business, the worldwide emulous economy and dramatic developments in product life, companies must invest in and improve their production facilities. The introduction of new equipment in the market is especially important. Therefore, machine tool selection is an important decision when investing in and improving the facilities and is key to the development and survival of manufacturing systems. The selection of inappropriate machines can have an influence on the overall performance of the system such as the productivity, precision, flexibility, adaptability and responsiveness. However, machine tool selection is a time-consuming and intractable problem and the largest drawback for engineers and managers due to a lack of deep knowledge, experience and technological understanding.

A manufacturing strategy taking into account the flexibility, efficiency, quality, reduced production time, increased profits, reduced production costs, increased productivity and regular maintenance services is needed for development. One of the systems that can respond to the requirement of flexible manufacturing is FMS (Flexible Manufacturing System) or FMC (Flexible Manufacturing Cell). These systems are concerned with the implementation, due to their flexibility and high efficiency, up to 90%. However, the implementation of FMS/FMC is an extremely difficult task, involving many different components such as CNC machines, transportation systems or robots, the central computer system, etc. One of the priority issues to be resolved in the first stage of production planning for FMS/FMC is the appropriate selection of CNC machines, which have the negative impact on productivity, accuracy, flexibility and the ability to respond to dynamic market demands. This has been a critical issue for many years and used to cause the acute judgment for the operation managers and manufacturing engineers. Therefore, a simple and comprehensive approach for machine selection based on expert judgments is needed.

Machine tool selection is a multi-attribute decision-making (MADM) process. In particular, the types and the number of

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machines selected depends upon many factors, including the types of jobs, the cost of the machine, expected demand and processing time (Ayağ, 2007). There are many attributes considered for decision-making process in machine tool selection, comprising the qualitative and quantitative attributes. For the qualitative attributes, quantifying the uncertain information is actually a difficult task. That is why a fuzzy MCDM (Multi-Criteria Decision-Making) method is needed to handle the imprecise, vague and uncertain information, both qualitative and quantitative (Samvedi, Jain, & Chan, 2011). The theories of fuzzy sets, grey relational analysis, and AHP/ANP are becoming increasing popular in the decision-making process because of their ability to model the uncertain information. In addition, AHP/ANP is particularly able to quantify the qualitative factors of the expert's judgments. Thus, this paper demonstrates that the integration of fuzzy ANP and COPRAS-G is a promising tool in the decision-making process.

2. Previous significant findings regarding decision making in machine tool selection

Researchers have used various methods for the decision-making process when selecting the most suitable potential machines. For example, Arslan, Catay, and Budak (2004) presented a decision support system (DSS) involving nine criteria (flexibility, productivity, adaptability, cost, reliability, precision, space, safety and environment, service and maintenance) for machine selection using the weighted average approach and a Cost/Benefit analysis. Ayağ and Özdemir (2006) presented the MADM process for machine selection based on the fuzzy AHP and Cost/Benefit analysis. The fuzzy AHP is also used by Durán and Aguilo (2008) to evaluate and justify the advanced manufacturing system. Taha and Rostam (2011) presented a DSS for machine tool selection in FMC using the fuzzy AHP and ANN (Artificial Neural Network). The inputs/outputs of fuzzy AHP are imported into ANN to predict the ranking of machine alternatives and compare with the result of fuzzy AHP. Alberti, Ciurana, Rodríguez, and Özel (2011) used ANN to design a DSS for selecting the most suitable milling machine tool involving criteria such as product dimension accuracy, process parameters, machine accuracy and cost. Dağdeviren (2008) used a combination of AHP and PROMETHEE for multi-attribute equipment selection. Then, this work was extended by Taha and Rostam (2012), who presented a hybrid method of fuzzy AHP and PROMETHEE for machine selection in FMC. The fuzzy AHP is used to calculate the weights of criteria, and PROMETHEE is utilized to predict the ranking of alternatives through the Decision-Lab software. Özgen, Tuzkaya, Tuzkaya, and Özgen (2011) built a fuzzy MCDM model for machine tool selection using a combination of the modified DELPHI method, AHP and PROMETHEE approaches with fuzzy sets theory. The integration of fuzzy AHP and fuzzy TOPSIS is used to estimate the results of the proposed model. Additionally, a sensitivity analysis is employed to show how the results changed to adapt to changes in the criteria priorities of cost-related specifications, technical specifications, operational specifications and quality-related specifications. Fuzzy AHP is also used by Önüt, Kara, and Efendigil (2008) to integrate into the fuzzy TOPSIS for evaluating the vertical CNC machining centers. Then, fuzzy TOPSIS is used as MCDM approach to evaluate the machine tools for manufacturing company by Yurdakul and İç (2009). Ertuğrul and Güneş (2007) proposed a fuzzy MCDM for selecting the most appropriate machine using fuzzy TOPSIS with the trapezoidal fuzzy numbers. İç and Yurdakul (2009) developed a DSS for machining center selection using the integration of the fuzzy AHP and fuzzy TOPSIS. Ayağ (2007) also proposed the integration of the AHP and simulation technique for the MCDM in the machine tool selection. Moreover, a strategic justification tool for the machine tool based on AHP/ANP is also proposed by Yurdakul (2004). Tsai, Cheng, Wang, and Kao (2010) proposed the MCDM approach for evaluating the machine tool from the specifications of 4-axis CNC machine tools according to expert's judgments in the field of the mold manufacturing engineering using AHP method through Expert Choice software. Samvedi et al. (2011) proposed the integration of fuzzy AHP and GRA (Grey Relational Analysis) for MCDM in machine tool selection. The model is built based on eight criteria and four alternatives for CNC machining centers. Fuzzy AHP is utilized to calculate the weight priorities of criteria and GRA is employed to rank the alternatives. Besides, sensitivity analysis is carried out to further verify their claim. Finally, the integration of fuzzy ANP and GRA for decision-making is suggested for the future research work due to interdependences of factors. Previously, Bo, Hua, Laihong, and Yadong (2008) also presented a model based on grey theory and AHP method for machine selection in networked manufacturing. The ANP is better than AHP because it contains a variety of interactions, dependences and feedback among the elements in the different levels. The fuzzy logic is integrated into the ANP to manage the vagueness, uncertainty about the expert judgments. Thus, fuzzy ANP is suggested to improve the ranking results from AHP/ANP; Ayağ and Özdemir (2011) developed such an intelligent potential approach to the decision-making process. Ayağ and Gürcan Özdemir (2012) proposed a fuzzy MCDM model based on the modified TOPSIS and fuzzy ANP for ranking the machine tool alternatives. Paramasivam, Senthil, and Ramasamy (2011) described three approaches for MADM methods, including the 'digraph and matrix approach, AHP and ANP' for the equipment selection process. Ic, Yurdakul, and Eraslan (2012) proposed a fuzzy MCDM model using the AHP for evaluating the alternatives with the criteria such as, axis size, power, spindle speed, tolerance, repeatability, cutting-tool change time, and the number of cutting tools along with other economical and commercial factors. Rao (2007) reviewed some methodologies for machine selection problem for implementing the flexible manufacturing cell. Wang, Shaw, and Chen (2000) proposed a MADM approach for machine selection in implementing an FMC, including the machine center, milling machine and robot using fuzzy sets. Besides, Balaji, Gurumurthy, and Kodali (2009) presented an MCDM model using ELECTRE III (Elimination and Choice Translating Reality) for selecting the most proper machine tool based on 20 attributes from the technical specifications. Chakraborty (2011) developed the MOORA (multi-objective optimization on the basis of ratio analysis) for decision-making process in manufacturing engineering. The applications of the most suitable selection of the industrial robot, FMS, CNC machine and machining process are implemented to show the effectiveness, flexibility, applicability and potential of the proposed method. Tavana, Momeni, Rezaeiniya, Mirhedayatian, and Rezaeiniya (2013) developed a model of a media platform using the fuzzy ANP and COPRAS-G, and Aghdaie, Hashemkhani Zolfani, and Zavadskas (2013) proposed the approach of SWARA and COPRAS-G for machine tool selection.

Previous findings realized that the applications of the AHP/ANP algorithms are very heartening and widely used in the decision-making process. The AHP/ANP archived the reasonable results in evaluating and ranking the alternatives and is applied successfully in the manufacturing environment because it simultaneously evaluates qualitative and quantitative factors (Zhou, 2012). Moreover, one of the important advantages of using the AHP/ANP is that it is capable of generating the weighted priorities of criteria and the priorities of alternatives from the pair-wise comparison matrices of expert judgments. However, the ANP, which is the extension of AHP, is better than AHP because it accounts for the interdependence, feedback relationships, and interaction between the higher-level and lower-level elements. The ANP is a MADM that coverts qualitative values to quantitative values and performs analysis