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A fuzzy approach for the selection of non-traditional sheet metal cutting processes

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ABSTRACT

This work presents a methodology for the selection and comparison of non-traditional sheet metal cutting processes as a new structure of selection by means of an expert system. The model is generated from a knowledge base acquired from diverse experts, and the use of fuzzy logic techniques. With a simple input of the parameters of a piece, the system offers the most appropriate cutting options (based on the requirements of the piece) allowing a **non-expert** user selecting the most appropriate process with emphasis on a predefined priority: finish, cost or time. The selection process consists of four base algorithms that measure the attributes of each process as a dependent indicator of the other processes, that is, a pre-selection that considers (1) the process capability to cut a material-thickness relation, (2) the speed that can be achieved with this relation, (3) the inherent complexity of the piece to be cut, and (4) the process tolerance. Results of experiments under three different approaches prove that the expert system here presented accurately prioritizes the most convenient cutting processes.

1. Introduction

Cutting processes have been under a constant change due to the increasing necessity of the industry to develop end items with optimal characteristics that make agile their introduction to the market. Sheet metal cutting is part of a group of hundreds of different processes for various applications. Within the sheet metal cutting processes are laser, plasma, oxyfuel and waterjet cutting among others, also known as *Non-Traditional Machining (NTM) processes*. These processes have continuously extended their field of application being increasingly used with thicker materials, higher cutting speeds and better cutting quality, placing them as an excellent option for cutting sheet metal. Part of the operating parameters for these processes (e.g. cutting speed, required tolerances, thicknesses and materials to be cut) overlap between one process and another in certain ranges. This could be misinterpreted if it is believed that any of the aforementioned processes can be used under the same circumstances. Frequently, the selection of a cutting process is done through a simple decision-making and it is based on the experience or previous knowledge (Manocher, 2008). However, choosing the right cutting process is a key factor for the optimization of the entire production process (Swift & Booker, 2003), it allows faster time to manufacturing and product delivery, reduces high manufacturing costs, material waste and avoids secondary operations for lack of quality.

The use of methodologies for the selection of cutting processes is a viable alternative that must consider certain limitations on the use of matrices (Dargie, Parmeshwar, & Wilson, 1982), families of schemes (Ahsby, 2005), diagrams and technical data used progressively to identify the best solution (Dieter, 1997; Halevi & Weill, 1995). Generally the result is a list of feasible processes but there is no way to quantitatively compare them, ie the user must select from the list of processes according to the prior knowledge and experience.

Multi-criteria decision making (MCDM) is a well known branch of decision making, which evaluates a finite set of alternatives on the basis of two or more criteria, choosing the best alternative from the set of candidates, or sorting the alternatives into a preference preorder (Wang & Kwong, 2014). MCDM methods support the subjective evaluation of performance criteria by decision makers (Mardani, Jusoh, & Zavadskas, 2015). In order to set the ranking of alternatives, these models typically determine the attributes, set a quantitative measure according to the relevance of the

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attribute, and then assign a score as a result of diverse procedures. Most preferred MCDM models in literature include the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and the Analytic Hierarch Process (AHP). Hybrid techniques for selecting processes often are composed of a combination of AHP–TOPSIS, and other MCDM methods such as Multicriteria Optimization and Compromise Solution (VIKOR) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Caliskan, Kursuncu, Kurbanoglu, & Guven, 2013; Jahan, Mustapha, Ismail, Sapuan, & Bahraminasab, 2011; Jagadish & Ray, 2014; Liu, Mao, Zhang, & Li, 2013).

The TOPSIS method evaluates multiple alternatives against the selected criteria assuring the nearest distance from the positive ideal solution and farthest from the negative ideal solution. Design, Engineering and Manufacturing Systems issue is a broad area in the TOPSIS publications (Behzadian, Otaghsara, Yazdani, & Ignatius, 2012). The AHP, consists of three main operations, including hierarchy construction, priority analysis, and consistency verification (Ho, 2008), and is based on the experience and knowledge of decision makers. In combination with other methodologies, TOPSIS has been used for the selection of manufacturing technologies (Tansel, 2012), in particular for the selection of NTM processes based on hybridized methods of TOPSIS and AHP (Choudhury et al., 2013; Das & Chakraborty, 2011). For addressing the problems that are marked by different conflicting interests, several Fuzzy Multiple Criteria Decision-Making (FMCDM) methods have been proposed. FMCDM approaches improve the quality of decisions by creating the development more efficient, rational and explicit (Mardani et al., 2015). FMCDM methods have addressed machine tool selection (Aya & zdemir, 2011; Önüt, Soner Kara, & Efendigil, 2008; Samvedi, Jain, & Chan, 2012), NTM process selection (Roy, Ray, & Pradhan, 2014), and other process engineering decision-making problems that involve multiple options and criteria (Tan, Aviso, Huelgas, & Promentilla, 2014).

A major limitation of MCDM tools is that they do not retain and reuse knowledge, and managers are unable to make effective use of knowledge and experience of previously completed projects to help with the prioritization of future cases (Tan, Lim, Platts, & Koay, 2006). In order to solve complex problems, in the last three decades knowledge-based systems (KBS) have been playing an important role in new decision support tools by emulating the reasoning processes of human experts. KBS are composed of two main components: a knowledge base (facts and rules about the expertise domain) and an inference engine (reasoning).

Besides being used in various decision making problems, KBS have also been implemented for process selection. In Sanchez and Nagi (2001) a review of agile manufacturing systems including KBS is presented. A "Machining Expert" was developed in Chakrabarti, Mitra, and Bhattacharyya (2007) for handling non traditional machining data. Parameters of processes were conglomerated and presented in a normalized fashion. The normalization of the available data was dealt with management information system and presented in the form of a software. Edison, Jehadeesan, and Raajenthiren (2008) developed a web-based knowledge base system for identifying the most appropriate NTM process. Input parameter requirements such as material type, shape applications, process economy and some of the process capabilities are introduced to the system. The selection is made by restricting the choice of certain NTM processes based on linguistic variables such as "good", "fair" and "poor". The development of an expert system for abrasive water jet machining (AWJM) process is presented in Vundavilli, Parappagoudar, Kodali, and Benguluri (2012). The system was developed by using fuzzy logic (FL) and a knowledge base. Three approaches were considered to predict the depth of cut in AWJM. The first approach deals with the construction of Mamdani-based fuzzy logic system. In approach 2, the data base and rule base of the FL-system are optimized, whereas in the third approach, the total FL-system is evolved automatically.

Most of the proposed KBS and MCDM methods are knowledge-intensive and require input parameters that may exceed the capabilities of non-expert users. Due to the complexity of the methods for the selection process, either by means of a MCDM, KBS or by prior knowledge on each process, there exists the need of an user-friendly tool that can emulate the behavior that an expert would have when selecting a non-traditional cutting process (eliminating the subjective judgments and keeping the experience and knowledge), a tool capable of identifying the attributes and get the most appropriate combination of attributes in conjunction with the actual requirements of the machining application.

A possible solution for designing complex systems, in which it is required to incorporate the experience of an expert or the related concepts appear uncertain, is the use of soft computing techniques such as fuzzy systems. An important advantage of fuzzy systems is their ability for handling vague information. The flexibility provided by fuzzy set theory for knowledge representation makes fuzzy rule-based systems very attractive when compared with traditional rule-based systems (Montseny & Sobrevilla, 2001).

In order to facilitate the decision-making of non-traditional sheet metal cutting processes, in this work we present an expert system based on fuzzy logic techniques. The model is generated from a knowledge base acquired from diverse experts. With a simple input of the parameters of a piece, the system offers the most appropriate cutting options allowing a **non-expert** user selecting the most appropriate process (quantitatively accurate) with emphasis on a predefined priority: finish, cost or time. The results of different experiments show that the presented system for the selection and comparison of sheet metal cutting processes, meets the requirements for its use in the selection of non-traditional cutting processes.

This work is divided into five sections. First, Section 2 presents an overview of the model. Then, Section 3, describes the base algorithms that extract and measure the attributes of each process. Section 4 presents the selection process mainly focusing on time, finish and cost. Finally results and conclusions are shown in Sections 5 and 6 respectively.

2. Selection model overview

During the final stages of design, the geometry of the piece is essentially fixed, and the material has been specifically selected, so the problem is mainly the cutting process to be used. When a new task is considered, the designer begins to question about related factors to the task he wants to answer. For example: *What processes can cut a* 10 mm *thick steel sheet? or How fast can these sheets be cut?* The first question leads to the need of information about the capability of thickness and material that the processes can cut. The second one will require more information about parameters that influence the cutting speed of the possible processes. In the context of task-based selection, this information is called *attributes*. This term refers broadly to the process, material and design characteristics that in some way must be combined to provide necessary information to evaluate whether the requirements can be met (Shercliff & Lovatt, 2001).

The proposed system combines the attributes of the process, the material and design to meet a particular criterion (priority), producing a set of selection results. There are essentially two alternative ways in which these selection results can be used, either for detection, where the choices are discarded if they cannot meet the requirements of the piece, or for ranking, where a quantitative measure allows ranking the cutting options. From simple input requirements of a piece: material, thickness and geometry (angles and perforations), the system offers a list of the most suitable