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Technical feasibility analysis of utilizing special purpose machine tools

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ABSTRACT

Special purpose machine tools (SPMs) are primarily used for performing drilling-related operations and are widely used in mass production including automotive component manufacturing. Utilization of SPM is considerably widespread; however, this technology is relatively new and expensive. The important problems facing manufacturing industries wishing to utilize this technology is feasibility analysis to decide whether a SPM can be utilised for production of the given part and if it is feasible which SPM components would be appropriate. Since the cost of utilizing SPM is high, feasibility analysis must be performed before any investment on detailed design. This paper proposes a technical feasibility analysis method which assists in deciding whether SPM is applicable for machining a given part to achieve the highest productivity. The method is based on the framework which consists of relations between the desired part properties to the characteristics of the SPM components. These relations are captured as rules and constraints in an intelligent system which is implemented in Visual Basic. Applying the proposed method to a number of industrial parts shows that it is a very useful tool in deciding when SPMs should be utilized.

1. Introduction

Increasing manufacturing competition market and rapidly changing consumer demand have led many industries to use flexible and responsiveness manufacturing systems. ElMaraghy [1] classified manufacturing systems into three major categories: Dedicated Machining Systems (DMSs), Flexible Manufacturing Systems (FMSs) and Reconfigurable Manufacturing Systems (RMSs) which have different characteristics (Table 1). DMSs are designed to produce a single part at a fixed volume over the life production time and involve dedicated machine tools which cannot be changed cost effectively to accommodate new requirements. FMSs are designed to machine a variety of undefined parts in changeable volumes and often involve General Purpose Machines (GPMs) which are typically not designed for a set defined of machining operations. Therefore, the manufacturer has to pay for unrequired capabilities and the cost of extensive efforts for meeting machine requirements. RMSs are designed to meet a specific range of machining production requirements. The capacity and functionality of RMSs, unlike DMSs and FMSs, are not fixed and may have been designed for a special purpose. Special purpose machine tool (SPM) as the major components of this type of manufacturing system can be applied to produce family parts for a specific range of volumes over the production life time. Notably, customized flexibility of SPMs makes them less expensive than GPMs [2].

These machines are designed based on current and future requirements of manufacturing systems and market demands [3,4]. Their modularity allows them to manufacture various products by applying minor changes to the machine's configuration by rearranging units and accessories [5,6]. These economic and productive machine tools are often used for drilling-related operations such as drilling, reaming and tapping which are typical hole-making operations and have large contribution to produce industrial parts [7]. Studies of modular machine tools have mainly focused on milling machines [8,9], While those performing drilling-related operations receiving less attention from researchers. The example of a SPM configuration performs drilling-related operations on the required part (Fig. 1). It consists of three working stations incorporating three machining units, a control unit, assembly components and accessories.

While many advantages may be obtained by applying SPMs for producing industrial parts, the extent of application of these machines is not proportional to the achieved benefits. Furthermore, the design and manufacturing of SPM has relatively high cost and a proper justification of utilizing SPM and related components should be made before any decision to design and manufacture one [4,6].

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Table 1
A comparison of manufacturing systems [10].

	DMS	FMS	RMS
Part mix	Single	Various	Family
Volume	Fixed	Changeable	Changeable

Clearly, this process requires appropriate and effective evaluation which necessitates substantial data analysis and identification of the major factors affecting at the correctness of analysis [11]. To do so an appropriate feasibility analysis is needed to decide whether a SPM should be used for the required production. While several studies on the design of reconfigurable machines exist systems [5,12–15], they focus on designing the configuration with feasible components; however, the technical feasibility analysis has not received much attention.

Feasibility analysis is one of the necessary steps for any engineering problem which evaluates the viability of a proposed system. This analysis facilitates enterprise decisions for a detailed system design and then its manufacture [5]. While, researchers have explored feasibility analysis in different areas of manufacturing [16–18], but few addressed SPMs. Tolouei-Rad and Zolfaghari [4] presented an economic method for feasibility analysis of utilizing SPMs. There is a need to improve feasibility analysis method; particularly from a technical point of view for SPM utilization.

To perform this analysis an expertise and experience with in depth understanding of SPMs is required. Thus, this process can be difficult and time consuming as many critical technical qualitative and quantitative factors have to be figured out and analysed prior to design and implementation. Kou et al. [19] concluded that without intelligent systems, collecting the expert knowledge needed to make final decisions would be too costly and protracted. Clearly, an intelligent system is required for manufacturing industries to successfully perform feasibility analysis and decision making of utilizing SPMs by considering part(s) specifications and SPM characteristics.

Several intelligent systems have been applied in manufacturing research. Tan et al. [20] proposed fuzzy ARTMAP (FAM) neural network model and a hybrid intelligent case-based reasoning (CBR) to assist users in manufacturing investment decision making. Culler and Burd [21] demonstrated a framework in which computer-aided process planning (CAPP) and activity based costing (ABC) are incorporated into a decision making system for documentation and cost control. Some studies applied Decision Support Systems (DSS) which majority of existing DSSs are limited to selecting machine tools and manufacturing systems by applying optimization tools [22]. Several publications reported use of expert systems for machine tool assessment to consider qualitative information [6,23]. From the above it can be concluded that there are some research about machine tools evaluation for decision making of utilizing them by using intelligent systems; yet performing feasibility analysis of utilizing SPMs by using intelligent system based on the expert and experience knowledge has not been adequately addressed.

The main objective of this paper is to present a feasibility analysis method for evaluating SPM utilization and selecting efficient SPM components for a given part to be drilled. To achieve this, the properties of part should be evaluated in conjunction with SPM component's characteristics. The paper proposes a method for feasibility analysis of utilization SPM. To do so, critical effective factors of part and SPM are determined and a feasibility analysis framework is defined. Based on the framework the relevant feasibility relations between the part and SPM components are extracted and captured as rules and constraints in a knowledge-based intelligent system. Applying the proposed method would be useful for decision making process at the preliminary stage of designing a SPM.

2. Problem formulation

To achieve the objective, critical factors of part and SPM are identified and the importance of them for performing feasibility analysis and selecting appropriate SPM components are explained. Figs. 2–4 show the framework for technical feasibility analysis for utilization of SPM. These figures clearly represent the relation between part and SPM characteristics and the important steps of technical feasibility analysis.

2.1. Part characteristics

Properties, shape, and dimensions of the workpiece, surfaces and properties of holes in each machining surface are effective factors in selecting feasible SPM components.

- *Part properties:* Part properties should be extracted from the part's design information. These items are weight, strength and machinability of the workpiece as they affect drilling performance. Weight is effective factor in selecting or designing fixture and chassis (Figs. 2 and 4). Strength is considered when selecting

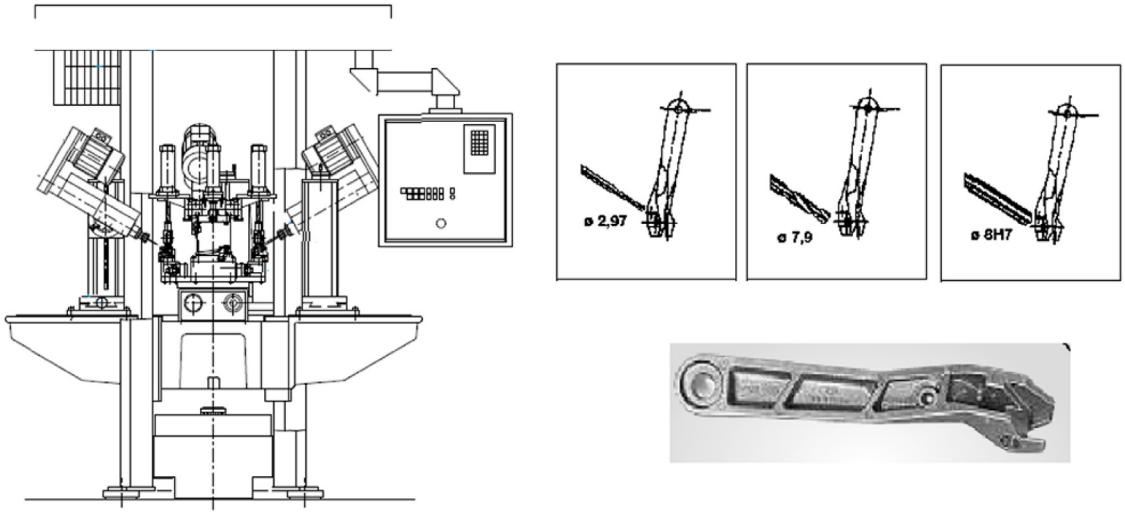

Fig. 1. SPM configuration and required working stations for producing parts with drilling-related operations [3].