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Assessment of reconfiguration schemes for Reconfigurable Manufacturing Systems based on resources and lead time

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A B S T R A C T

Reconfigurable manufacturing equipment is developed to meet the growing demand for more agile production. Agile manufacturing technology can improve the turnover of a company if it enables fast market introduction for volume production. Modular reconfiguration, defined as changing the structure of the machine, enables larger variation of products on a single manufacturing system; these solutions are called Reconfigurable Manufacturing Systems (RMS). The quality of RMS, and the required resources to bring it to reliable production, is largely determined by a swift execution of the reconfiguration process. This paper proposes a method to compare alternatives for the ways to implement reconfiguration. Three classes of reconfiguration are defined to distinguish the impact of the proposed alternatives. The procedure uses a recently introduced index method for development of RMS process modules, based on the Axiomatic Design methodology. Weighting factors are used to calculate the resources and lead time needed to implement the reconfiguration process. Application of the method leads to quick comparison of alternatives in the early stage of development. Successful execution of the method was demonstrated for the manufacturing process of a 3D measuring probe.

1. Introduction

Increasing global competition in manufacturing technology puts pressure on lead times for product design and production engineering. Quickly eroding markets, like markets for high tech systems and micro-technology, especially require tight scheduling of system development; 'being first' leads to an extended economic lifecycle, better market penetration, and higher added value for products [1]. Early market introduction will lead to higher return on investments [2]. By applying effective methods for systems engineering (or engineering design), product design, and production, the development process can be executed in parallel instead of sequentially. Modular equipment is currently under development to meet the manufacturing demand of product families rather than single products [3–7]. Reconfigurable Manufacturing Systems (RMS) reuse modular parts or 'Process Modules' as building blocks for manufacturing systems [8]. RMS are a logical addition to 'Dedicated Manufacturing Systems' (DMS), 'Adjustable Manufacturing Systems' (AMS), and 'Flexible Manufacturing Systems' (FMS). DMS are most traditional; they are applied for a long period of manufacturing without significant changes, even up to 30 years. AMS and DMS are alike, but AMS are equipped with an increased number of tools that can be changed to address a broader scope of products. FMS are computer numerically controlled systems. The computerised control system enables fast adaptations to a range of variations in production. However, the structure of the machine is determined by the mechanical system design and is not able to change afterwards. RMS fill the gap by adding a modular architecture in both mechanical design and control system [4,9,10].

Zhang and Chu [9] conducted an analytical comparison of manufacturing systems (DMS, AMS, FMS and RMS), rating given systems on 'Adaptability' and 'Reconfiguration Time' as shown in Fig. 1. The overview in Fig. 2 was obtained by combining the data in a two dimensional representation. RMS are not adapted as quickly as FMS as the change of structure comes with more overhead than the change of software. RMS score well on adaptability; changing the structure of the system adds broad possibilities for implementation of optimised process technology. However, the exact position of the RMS in the graph can vary depending on the kind of reconfiguration. The manner in which (re) configuration is performed determines how much renewal is applied in the system. A direct consequence of this discrimination is the amount of work that is required to carry the reconfiguration through. The lead time and resources needed for implementation

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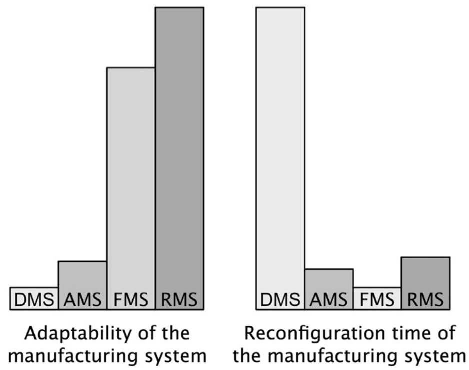

Fig. 1. Adaptability of (left) and reconfiguration. time of manufacturing systems (right).

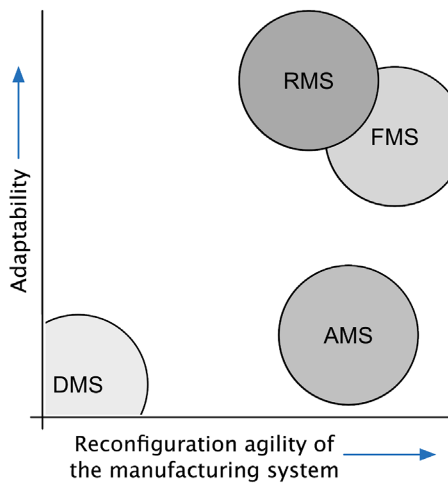

Fig. 2. Comparison of DMS, AMS, FMS and RMS. Note that the horizontal axis is reversed compared to Fig. 1.

will be lower if reconfiguration takes place with known and tested process modules. If new process modules need to be developed, lead time and reconfiguration efforts are considerably larger, but the added capability of the system may be expected to increase noticeably too. Therefore the reconfiguration 'scheme' of an RMS needs to be carefully investigated ahead to find the adjustment of the system that adequately matches production demand. Schemes refer to the systematic layout of a particular setup and how it is composed from individual (modular) process modules. A method for inventorying and quantification of risks in the reconfiguration process could help to find the right balance in optimisation on the short, the mid, or the longer term. This research tries to find such a method; the research questions of this paper are:

1. What would be a good method to inventory, quantify, and compare required resources and lead time when preparing the (re)configuration of RMS;
2. how can the method be applied as a systems engineering tool for effective comparison of alternative equipment schemes.

The paper is organised as follows: Section 2 reviews the previous work. Section 3 describes a way to index the process of (re) configuration of RMS based on the methodology of axiomatic design. Section 4 explains how resources and lead time can be calculated using a simplified version of the index method. Section 5 applies the method to a true case; the development of an RMS for the production of a 3D measurement probe. Section 6 discusses the findings and summarises the results.

2. Background

Assessment of manufacturing systems from an economic perspective is a widely investigated topic that over the years has created profound improvement of manufacturing efficiency. The increasing dynamics in manufacturing have led to increased need for changeability on the shop floor. The assessment that initially was of a pure economic nature is in modern management extended with the consideration how that valuation affects the potential strategic benefits, e.g. being able to adapt to rapidly changing product demands [11]. In this context, Section 2.1 inventories adaptability assessments that compare a range of systems (DMS, AMS, FMS, or RMS). Sections 2.2 and 2.3 respectively focus on the assessment of the adaptability of FMS and of RMS. The novelty of the presented solution here is that it not only compares different strategies for possible manufacturing solutions, being able to compare their economic strengths, but also incorporates the further development of the RMS by inventorying the need for new process modules to be developed. This brings the complexity of the reconfiguration process versus the envisioned expansion of the RMS into the equation.

2.1. *Methods for comparison of DMS, AMS, FMS, and RMS*

Since radical changes in the structure of DMS and AMS are not foreseen, methods for assessment of change of DMS and AMS are minimal in literature. A survey by Hollstein et al. [12] focusses on possibilities rather than limitations by inventorying how far existing (dedicated) manufacturing systems can be upgraded with economically feasible interventions. Michaelis and Johannesson [13] choose a comparable approach but add the principle of co-design to fit the development of new products to the opportunities and limitations of existing equipment. Zhang and Chu [11] compare the economic performance of the systems by focussing on the time needed to carry through changes. Kuzgunkaya and ElMaraghy [11] go further and compare FMS and RMS based on a combination of key parameters e.g. economic considerations, structural complexity, and responsiveness. Amico et al. [14] extends comparison on economic considerations with the theory of 'real options' to define a payoff function that can be used to compare different systems. Nassehi et al. [15] apply 'formal methods', mathematical techniques for the specification, design and verification, to check the consistency of manufacturing processes.

2.2. *Assessment of the adaptability of FMS*

Though the adaptability of FMS is of a different nature than that of RMS, related work investigates the change of a number of FMS on the shop floor, which is a similar but higher-level approach compared to the reconfiguration of RMS. Abdel-Malek and Wolf [16,17] focus on the most efficient mapping of FMS in a factory. In their approach, FMS can be moved, changed, or upgraded similarly like process modules in a RMS. This is benchmarked using KPIs to compare different alternatives and select the best option. Lotfi [18] presented a linear programming model for the optimisation of a number of objectives inter alia, financial aspects, flexibility, and group homogeneity. Yan et al. [19] use a what they call 'Life Locus Tree' that is not only modelling the birth of the FMS but also focusses on use, adaption, and expansion.

2.3. *Assessment of the adaptability of RMS*

With the start of the new millennium, assessment of the

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