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Towards practical guidelines for conversion from a fixed to a reconfigurable manufacturing automation system

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Abstract

It is generally considered to be a key requirement in the development of reconfigurable manufacturing systems, that economic feasibility is only attainable if the system is defined to be reconfigurable at the outset of its design. In this work we consider the potential exception to this requirement, in the context of a common industrial scenario where a specialized and expensive manufacturing machine or system will otherwise be rendered useless due to loss of business of the particular product being manufactured. Specific guidelines to convert from a fixed to a reconfigurable system are proposed, and evaluated through a case study.

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Keywords: Reconfigurable manufacturing systems; conversion guidelines; case study

1. Introduction

The changes in market demands witnessed in the past decades have had a significant effect on the manufacturing strategy employed. Previously, product life cycles were long and identical products were produced for the masses, resulting in the development and perfection of dedicated manufacturing lines famously pioneered by Henry Ford in

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the early 20^{th} century (e.g. [1]). In the early 1980's the concept of flexible manufacturing systems (FMS) was developed to cope with the transformation of consumer markets; shorter product life cycles and high product variety (e.g. [2]). Towards the end of the 20^{th} century, the notion of reconfigurable manufacturing systems (RMS) appeared: living and evolving systems which are designed to be reconfigurable, to be quickly adaptable to changes in product requirements, and to be able to respond to customer requirements faster and more effectively [3].

Reconfigurable manufacturing systems aim at combining the high throughput of dedicated manufacturing lines with the flexibility of FMS, with the added ability to react quickly and efficiently to changes [3]. In addition to the above, they facilitate rapid system design, rapid conversion to new models, the ability to quickly and reliably integrate technology, and the ability to cater for varying product volumes with increased product variety [4]. In [4], the authors propose a set of distinguishing features, or key characteristics, which are requirements for a truly reconfigurable manufacturing system. A system which possesses all these characteristics is considered to have a high degree of reconfigurability. Reconfiguration can be initiated by a number of factors, such as variation in product demand, the introduction of new products, or the update of system components or integration of new components for improved productivity or improved quality. In the case of reconfiguration for new products or variation in demand, the process will begin at the system (i.e. top) level and propagate downwards [5]. The six core characteristics of RMS are considered to be *modularity* of the system hardware and software sub-components; *integrability* of the various current modules as well as of potential future modules; *convertibility* of the system for application to the manufacture of different products including future products; *diagnosability* with respect to the causes of quality and reliability problems; *customization* of the system hardware and software for the specific part family under consideration; and *scalability* of the system for rapid and economical changes in production capacity [4,6].

At either the system or machine level, two types of reconfiguration are recognized. Physical reconfigurability refers to the scalability of production volume, capacity and capability which is achieved by adding, removing or repositioning machines, machine modules or material handling systems. This approach is typically costly since it involves complex machines. Logical reconfigurability is any form of reconfigurability which can be employed without physical reconfigurability to achieve better agility. This includes flexibility of machines, operations, processes, routing, scheduling, planning and programming of manufacturing systems. This approach is less costly since it is achieved through good system and software design [6]. The industry also recognizes that reconfigurable machine tools (RMTs) are essential enablers of RMS; that reconfigurable assembly lines are, at least in theory, easier to achieve than RMS because of the less stringent tolerances; and that hybrid human-machine RMS are advantageous because they make use of the flexibility which is in-built in human nature but at a relatively low cost [6,7]. The study of reconfigurability in manufacturing extends to new approaches for control (e.g. [8,9]) and strategy (e.g. [10]).

A key requirement for an RMS is considered to be that its constituent systems and components must be designed to be reconfigurable from the outset, in order to adequately meet the core system characteristics of this paradigm [4,6]. It is emphasized that one must first define the part family of products, then address the appropriate system design issues, then link these to the corresponding machine design issues, and finally address methods to reduce reconfiguration and ramp-up times. Although this approach is understandable, it may not take into account the common situation when highly specialized machines become idle or underused due to loss of business of the particular product being manufactured. In such cases, it may in fact be advantageous to carry out a conversion project rather than scrapping the machine and buying another.

The conversion of a fixed automation system to an automated RMS is not considered in the literature and is identified as a research gap. The objective and contribution of this work is to explore this possibility and approach. A provisional set of systematic guidelines are proposed, to be used to convert a fixed automation system to a reconfigurable manufacturing automation system. The problem is approached by (i) taking note of the key requirements for reconfigurable systems (as summarized above); (ii) identifying the key shortcomings in reconfigurability of a generic fixed system; (iii) developing a formal set of generic guidelines, based on (i) and (ii) above, for conversion; (iv) applying the guidelines to an industrial case study; (v) carrying out an economic analysis of the proposed system; (vi) evaluating the application of the guidelines during the case study; and (vii) evaluating the proposed system with respect to reconfigurability requirements.