Towards practical, high-level guidelines to promote company strategy for the use of reconfigurable manufacturing automation

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A B S T R A C T

Reconfigurable manufacturing systems (RMS) and more specifically reconfigurable manufacturing automation systems (RMAS) represent an industrial production paradigm that has evolved in the last twenty years, and provide a low cost solution in the presence of product variety. In spite of the potential impact of this approach to industrial competitiveness, the literature still lacks a set of structured guidelines, derived from the theory and from field studies, to promote its practical implementation in industry. In this paper some early results that contribute towards addressing this research gap are presented. A set of practical guidelines is derived and compiled from four sources: a literature review; a structured questionnaire survey on the attitude of industry to RMAS based on 55 respondents from various sectors of the manufacturing industry; unstructured interviews with the survey respondents to discuss the barriers to the implementation of RMAS; and lessons learned from three pilot industrial test cases where the feasibility of implementing a new RMAS was investigated. The portion of the work reported herein deals exclusively with high level and over-arching practical implementation aspects of RMAS, rather than detailed design and development aspects. The guidelines are validated through further feedback from industry.

1. Introduction

Globalization of the manufacturing industry and markets, as well as increasing customer demands for product variety, have meant that manufacturers have been forced to reduce production costs while at the same time to increase the agility and versatility of their production equipment. In most cases, in the industrialized world of high labour costs, the need to employ manufacturing automation can be an inevitable prerequisite for competitiveness. However, the traditional approaches to automation, such as the use of dedicated manufacturing systems (DMS, normally involving low cost and simplicity, but incongruent to variety), or of programmable or flexible manufacturing systems (CNC or FMS, suitable for product variety, but expensive and complex) are often no longer enough to safeguard company survival. The need to combine the properties of low cost, simplicity, and versatility of production equipment has led to the development of a new paradigm in the last twenty years, that of reconfigurable manufacturing systems (RMS) [1]. The main feature of a RMS is that it consists of a relatively inexpensive manufacturing line or equipment that can be set up to manufacture a particular product in a dedicated manner much like a DMS, but that can later be reconfigured, over a relatively short changeover period, to manufacture a different product. Reconfigurability is often (but not necessarily) obtained primarily through modularity, and RMS are normally used to manufacture sequentially batches of different parts that share common features.

Where a RMS is automated, it can be referred to as a reconfigurable manufacturing automation system (RMAS) (e.g. [2]). RMAS, and more generally RMS, have established a presence both in the theoretical literature (e.g. [3,4]) as well as in the field (e.g. [5,6]). However, based on our practical experience of collaborating in development projects with manufacturing companies over the last fifteen years, it appears that the development of such systems in industry, where they exist and where they are built or assembled in-house, may often be carried out on an ad hoc basis, based on engineering common sense or on company-established patterns within the respective manufacturing/automation department. The RMS mentality often may not pervade to a level where it can influence major strategy decisions of the company. A useful tool to promote the effective use of RMS would be the existence of a comprehensive set of clear and practical guidelines for the promotion or incitement of such systems, derived from both theoretical and empirical data, and addressed to both company engineering and company management as appropriate.

The objective of the work reported here is to contribute towards the compilation of this set of guidelines, and in particular to collect and

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interpret the empirical data that is needed in order to enhance the practicality of the guidelines. This work formed part of a wider project (acronym AUTOMATE [7]) which sought to investigate the use of, and the requirements for, and the problems associated with manufacturing automation in a small, geographically isolated, developed economy, taking the island nation of Malta as a case study. An empirical survey on the use of automation by manufacturing companies, which formed part of the project activities, included a number of questions directed specifically to address RMAS use in production. Further information from the respondents of this survey was obtained through industrial visits and semi-structured interviews. In parallel with this exercise, and with relevance to the present paper, three industrial test cases were analyzed in detail with a view to implementing reconfigurable solutions to manual production processes.

Malta is a sovereign, developed island state of around 400,000 people, located in the middle of the Mediterranean Sea. It is a member of the EU and of the eurozone, meaning that it can trade freely and relatively easily with the other states of the EU. It has a relatively successful and diverse manufacturing sector, a sizable proportion of which is fuelled by foreign direct investment and is export oriented [8]. These firms compete directly with other companies in the EU, in the rest of the developed world, and in the emerging / newly-industrialized states for global market share. Due to rising labour costs, Malta can no longer rely on manual production methods for competitiveness, and as such the need for contemporary production technologies (in particular of RMS and RMAS) may reflect to a large extent that in other developed countries. Thus, the empirical data collected for this work, while inevitably focused to the Maltese environment, is expected to be to a large extent also representative of companies located in other developed nations outside this environment.

2. Guidelines from the literature

The concept of reconfigurable manufacturing was introduced in the mid 1990s, with an accepted definition of a RMS being that of a system “designed for rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of its components” [3]. Thus, a RMS is a system that evolves, unlike DMS and FMS both of which in essence are static systems [1]. A RMS is characteristically developed around a part family of products (e.g. [9,10]), defined as a collection of parts that are similar either in geometric shape and size or in the processing steps required for their manufacture [11]. Six core characteristics of RMS have been identified, these being customized flexibility, convertibility, scalability, modularity, integrability, and diagnosability [3]. These characteristics do not apply solely at the system level, but they may also apply to lower level system components such as reconfigurable machines or even machine elements, and may also be applied to manpower resources or to the broader enterprise level [9].

Although the general characteristics and principles of RMS have been established, there is very little literature that provides specific guidelines to their development and construction. A guiding principle may be taken to involve the attempt to address and incorporate the various RMS characteristics listed above, with modularity being initially the property most emphasized in the general literature (e.g. [12–14]). Additional principles that would contribute to the development of cost effective RMS include the use of flexible equipment (e.g. CNC and reconfigurable machines within the system; the capability to provide alternative production routes; and the capability to respond to unpredictable events [9]. Scalability of the production system, to respond economically even to small fluctuations in production demand, is emphasized in [15,16]. The responsiveness of a RMS, which is a measure of its convertibility, is addressed in [17]. A qualitative approach for the design of RMS is given in [18], where the authors propose a three-stage process consisting of market capture, system level reconfiguration, and component level reconfiguration, through the use of IDEF0 models [19].

Extensive literature exists on the principles and benefits of product modularity (as opposed to production equipment modularity, which is central to the topic of the present paper) (e.g. [20,21]). In [22] the authors identify a number of module drivers, that they term “the driving forces for modularization within the product”, and which are then used to evaluate multiple and/or alternative technical product solutions and modular breakdown based on the extent and manner in which these drivers are satisfied. The identified product module drivers were carryover, technology evolution, planned product changes, specification variation, styling, common units, process and/or organization, separate testing, availability from supplier, service and maintenance, upgrading, and recycling. Elements from this concept can possibly be applied to the development of modular RMS or of RMAS, with the manufacturing system taking on the role of the product in the analysis.

3. AUTOMATE: relevant project elements and research methodology

3.1. Relevant project elements

The AUTOMATE project aimed at carrying out a general study on the use of automation in the manufacturing industry of a small, developed, geographically-isolated economy with a diverse manufacturing base, with a focus on the development of new RMAS, and using the Maltese industry as a case study. The elements of the project that are relevant to the present work include an extensive literature review on RMS and RMAS (discussed very briefly above); the development of a methodology for the design of RMAS; the design and development of a physical, highly reconfigurable and versatile test bed for the development of production automation solutions across multiple sub-sectors of the manufacturing industry [23]; an empirical study on the use of automation in industry and on problems encountered in this regard [24]; and the testing of the methodology and of the test bed on three detailed case studies provided by industrial partners in the project (e.g. [25]), with a view to developing general guidelines for the industry that help promote high value-added manufacturing through automation and in particular through RMAS.

The empirical study consisted of a detailed questionnaire that investigated various aspects of automation use, and that was posed to a sample of manufacturing companies located in Malta. The companies that were invited to participate in the study were selected from various national databases held by the Malta Chamber of Commerce, Enterprise and Industry; Malta Enterprise (the Government agency responsible for the promotion of foreign investment and industrial development in Malta); the national Employment and Training Corporation; and the telephone directory yellow pages. Care was taken to ensure that the sample contained companies of various sizes (less than 10 employees to 1000+) and across various sub-sectors (electronics, medical, pharmaceuticals, plastic-ware, food and beverages, chemical, glass, textile and woodwork). The selected companies were first contacted through a phone call, during which the objectives of the project were explained. Most of the contacted companies accepted to participate in the study, with the final total number of participants consisting of 70 companies. In carrying out the study the AUTOMATE researchers toured the facilities of each respondent and interviewed a top-level technical official of the company. During the structured part of this interview, the researcher filled in the questionnaire, and during an unstructured part of the interview various other relevant items of information were collected. This approach ensured that there was no danger of misinterpretation of survey questions, or of the precise meanings of technical terms (such as “RMAS” or “product family”) by the respondents. Part of the survey questionnaire was directed only at companies that already utilize automation (55 out of the 70 respondents), and a number of questions in this section inquired specifically about issues related to the use of RMAS. The results pertaining to these
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