Towards practical guidelines to promote a company strategy for reconfigurable manufacturing automation systems

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ABSTRACT

Reconfigurable manufacturing systems (RMS) and more specifically reconfigurable manufacturing automation systems (RMAS) represent a relatively recently evolved paradigm in industrial production, providing 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 not only from the theory but also 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 provisional 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 on 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.

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 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 a foregone 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

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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 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, requirements for, and 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 a reconfigurable solution to a manual production process.

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 [1]. A guiding principle may be taken to involve the attempt to address and incorporate the various RMS characteristics listed above, with modularity being the property most emphasised in the general literature (e.g. [12], [13]). 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 [14]. The responsiveness of a RMS, which is a measure of its convertibility, is addressed in [15]. A qualitative approach for the design of RMS is given in [16], 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 [17].

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. [18], [19]). In [20] 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

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 [21]; an empirical study on the use of automation in industry and on problems encountered in this regard [22]; and the testing of the methodology and of the test bed on three detailed case studies provided by industrial partners in the project [23], 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 woodworks). 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. 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 questions, based on the sub sample size of 55, are summarized in section 4.1 below.

The three industrial test cases involved companies of different sizes and that operate in different sub-sectors. The first test case was put forward by Company A (around 100 employees and producing mechanical components) and involved an investigation on the implementation of automation to the cutting of flexible diaphragms of different shapes, sizes and material properties. The second test case was put forward by Company B (around 45 employees and assembling electronic components on a sub-contractor basis) and involved an investigation on the implementation of automation to the assembly of a variety of printed circuit boards into metal casings. The third test case was put forward by Company C (around 700 employees and producing plastic components) and involved an investigation on the implementation of automation to the assembly of a part family of small plastic containers where aesthetics was of the utmost importance. Part variety was a major issue in all three of the test cases, making them prime candidates for the implementation of RMAS, and the issues and problems encountered during the analyses and investigations contributed to the setting up of the general guidelines for such implementation.

4. AUTOMATE: RELEVANT RESULTS AND INTERPRETATIONS

4.1. SURVEY QUESTION RESULTS

A summary of the response distribution to the formal questions dealing with RMAS is given in the graphs in Figure 1. In particular, 78% of manufacturing companies that employ automation on their shop floor add new products to already existing production set-ups; 73% allow for a degree of potential future product variance when implementing new production equipment; 66% always purchase production equipment with extra in-built capability to cater for possible future product variance; and 58% either reconfigure the production equipment for immediate re-use, or dismantle it for future use, at the end of life of a product. In some cases these high percentages may not stem from a general company appreciation of the benefits of building reconfigurable systems, but rather from the fact that the companies use standard purchased equipment that is inherently reconfigurable (e.g. surface mount technology equipment for assembling printed circuit boards). If companies that possess such specialized automation equipment are subtracted from the above statistics, the corresponding percentages become 60%, 62%, 55%, and 47% respectively. These figures are still high, and it can therefore be inferred that at least half of the manufacturing companies that use

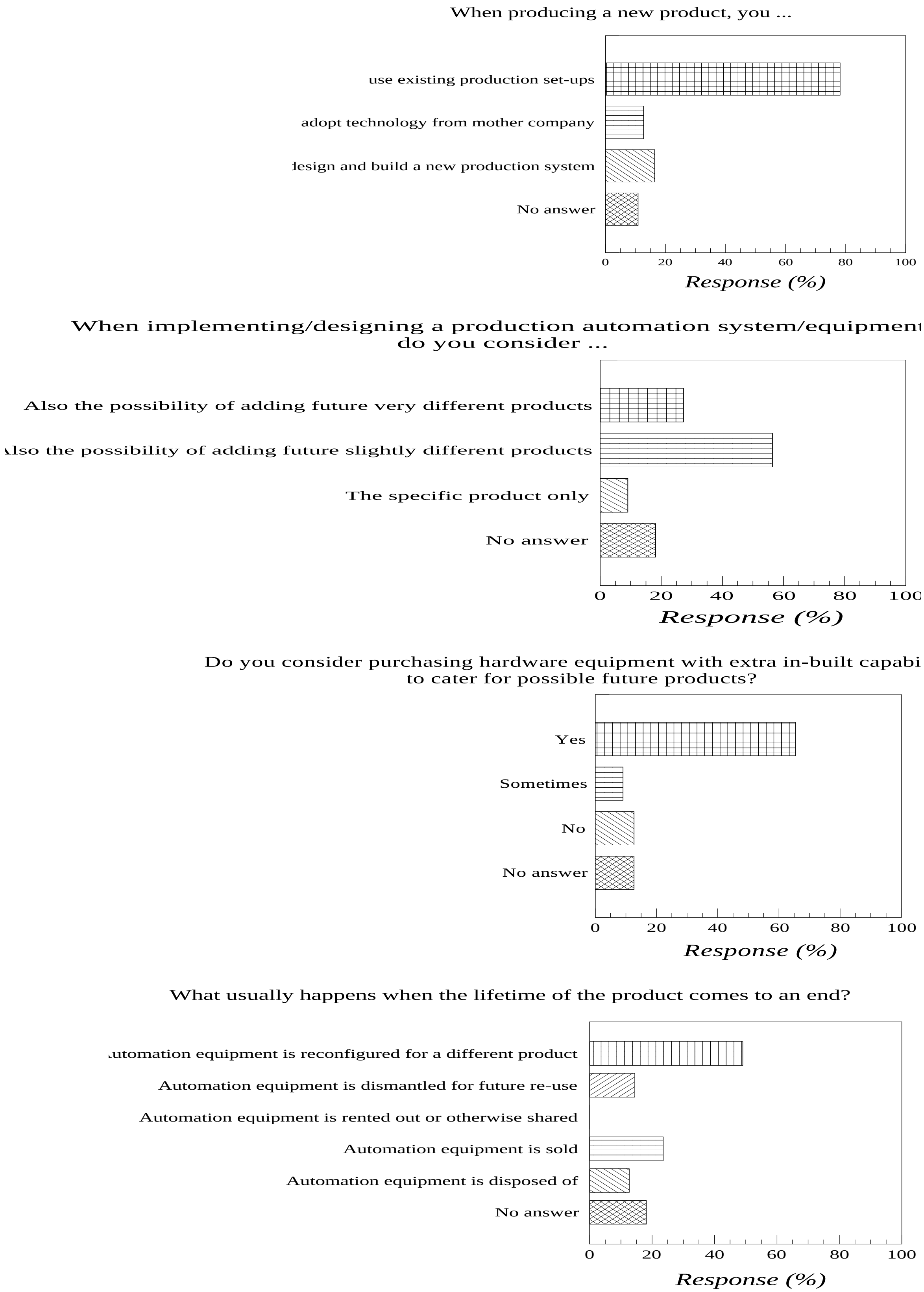

Figure 1: Response distribution to the survey questions on RMAS (multiple responses allowed where applicable)

automation already appreciate to some extent the benefits of reconfigurability and are already implementing reconfigurable automated production systems. This result must be borne in mind when analyzing the information collected from the unstructured interviews, reported in the following subsection.

4.2. RESULTS FROM UNSTRUCTURED INTERVIEWS

Many of the manufacturing companies reported that automation often cannot be justified financially due to low production volumes, or that automation is difficult to implement because of high product variety and low standardization. Many companies are uncertain as to whether they should invest in automation or not, because their demand fluctuates a lot. The time required to implement automation is also considered to be an issue by many companies. These results indicate that notwithstanding the results reported in section 4.1, many companies may not be aware of the full potential of RMAS.

Many manufacturing companies are unaware of the existence of local automation solution providers. However many companies acknowledge that more distant (i.e. foreign, in this case) suppliers at times make response times longer and are also more expensive. In general many companies prefer more established suppliers even if these are located relatively far away.

Micro companies (with less than 10 employees) often have only one person doing all the various managerial jobs including maintenance. This allows little or no time to study opportunities for improvement. Many companies (of all sizes) complain about a general lack of inter-company networking, and that there is little opportunity to share solutions within and across sectors. In some cases companies are not even aware of who their local competitors are, or of the type of manufacturing technology that their competitors are using.

4.3. SUMMARY OF INDUSTRIAL TEST CASE RESULTS

The test case put forward by Company A involved the punching of discs and of square sections, of various sizes, out of rubber, fabric, PTFE, or a sandwich made out of layers of the three materials. The punching process was carried out using a mechanical press and cutters, however all material handling was carried out manually. A major problem with automating this process is the large amount of variety involved, with over 80 different diaphragms needing to be produced. This variety did not stem wholly from an end user demand for choice, but rather and in large part from a lack of standardization of the final product. An analysis of the problem with a view to implementing a RMAS solution ultimately identified three potential modules, addressing the material handling prior to and between punching, the handling of the cutter and the punching action, and the material handling after punching. Prior to the generation of a number of alternative conceptual technical solutions, an exercise in process simplification was carried out. The company ultimately took a stepwise approach to the implementation of the solution, starting with an investment that significantly improved the productivity of the manual work while at the same time paving the way for eventual automation. The improvement involved the development and use of a reconfigurable platform on which multiple cutters could be mounted, effectively replacing many small “modules” (single cutters) by a larger, reconfigurable module that greatly reduced both the material handling requirements and the production time. A cost analysis of this partial solution showed that the payback period of the investment was of approximately two years. The problem of non-standardization remained a crucial one however, and one that it was very desirable to address prior to implementation of the full solution.

The test case put forward by Company B involved a complex assembly process that, in its current manual form, was made up of various delicate material handling and soldering steps. The company was determined to try to automate the assembly process in order to improve its competitiveness, in spite of the problems associated with a low and very volatile production volume, with significant product variety, with a set of soldering steps that required precision not only in positioning but also in time duration, and with a requirement for in-line inspection. Ultimately these problems proved to be non-surmountable hurdles for the implementation of an automated solution, since detailed technical and financial feasibility studies clearly showed an unacceptable return on the required investment. The focus then shifted to an attempt to implement relevant results from the technical automation feasibility study towards improving the manual assembly process. A modular, reconfigurable assembly jig was developed, which could accommodate the entire range of products (thus saving on jig storage space), and more significantly which cut down the number of assembly steps from twelve to seven, resulting in an average 15% reduction in assembly time. Despite its original determination to automate, the company recognized that it had achieved a more feasible and practical solution and was satisfied with the result.

The test case put forward by Company C involved significant product variety, however in this case the production volume was projected to be very high and stable. The production process involved the separate transfers of small plastic containers and of their associated lids to a pinning jig (which fastened the lid to the container), and the subsequent transfer of the assembled product out of the jig. The constituent parts arrived along separate conveyors, on which they were located randomly in terms of both position and orientation. This test case and its solution are reported in more detail in [23], and involved the use of machine vision systems (to recognize the parts and to determine their position and orientation on the conveyor belts), robots (to effect the part transfers and to re-orient the parts as required), and conveyors equipped with reconfigurable passive guiding systems (to direct the parts to the imaging and robot pick-up areas). In this case the RMAS solution was attained through the use of equipment that is inherently highly flexible, with reconfigurability being achieved through changing the active programs for the machine vision systems and the robots, the programs serving as the “modules”. The passive guides on the conveyors also served the role of (physical) modules, which could be either reconfigured or replaced as required when a changeover between different products was effected. A cost analysis of this solution showed that the payback period of the investment was of less than two years.

5. Extracted Guidelines

The knowledge gained from the field studies reported in section 4, together with the standard wisdom on RMS/RMAS, have been used to derive practical implementation guidelines for consideration by manufacturing companies that are looking to increase their competitiveness by improving their production systems with respect to modularity and reconfigurability of equipment. The guidelines are divided into two sets: those intended for the higher level management personnel of the company, and those intended for technical personnel working in the Engineering development departments of the company.

Key practical guidelines to higher level management (HLM)

HLM.1 Always push to simplify your product range, irrespective of whether you are looking to automate your production process or not.

HLM.2 When looking at a strategy for automation, or for improving the effectiveness of an assembly operation, start by designing products that are amenable to this approach. Even if you are a small sub-contractor type company, it may be possible to get involved in the product development process with a long term client by making pertinent suggestions that may make the product easier to manufacture.

HLM.3 When planning a new shop floor or production system, strive to keep open as many options for reconfigurability as possible.

HLM.4 Recognize the value of human and time investment to study opportunities for improving your production systems. If expertise and/or time are unavailable within your company, consider seeking help from outside.

HLM.5 Strive to induce a mentality within your company of internal and external networking. Expose your personnel to continuous professional development, to local and non-local technology expositions and fairs, and to other sources of knowledge on modern paradigms of competitive manufacturing.

HLM.6 Take the time to identify and to study your competitors. You should at least consider emulating your competitors’ technology, and then trying to surpass it.

Key practical guidelines to technical personnel (TP)

TP.1 When looking at ways to improve productivity and efficiency, start by seeking to simplify the current process.

TP.2 Identify your product families. When needing to manufacture different products, look for similar process steps within the product range and consider making use of reconfigurable systems to manufacture the various products on the same equipment.

TP.3 Address carefully the core characteristics of RMS. Limit flexibility to the present and anticipated future requirements, and focus on the needs for convertibility, scalability, modularity, integrability and diagnosability of the production equipment. Consider also the capability of the equipment to provide alternative production routes, and the capability to respond to unpredictable events.

TP.4 Search for the driving forces for modularization within your specific production system, and focus on satisfying these forces.

TP.5 Exploit fully the paradigm of reconfigurable manufacturing. Remember that RMS are not aimed solely at addressing product variety, but also at other changeable factors such as varying production volumes.

TP.6 Consider reconfigurability at all levels of your production system. At sub-system levels it may be worth considering the use of reconfigurable machines and/or of reconfigurable machine elements.

TP.7 The use of inherently flexible items of equipment such as robots or machine vision systems can have a major bearing on the reconfigurability of your overall system.

TP.8 When automating a manufacturing process, consider using used/demonstrational equipment to reduce the initial investment costs.

TP.9 When seeking advice or equipment for an automation project, start by considering the capabilities of suppliers that are closer to you geographically.

TP.10 An improved manual system, often exploiting modularity and reconfigurability, can result from a “failed” automation feasibility exercise, and can still have a significantly positive effect on costs and competitiveness. Learn to recognize when NOT to automate, and to follow through on, rather than to discard, the results of negative feasibility studies.

6. CONCLUSION

This work has reported on an empirical study on the use of RMAS in production, and has sought to combine the results of this study with theoretical aspects concerning such systems, in order to extract a set of high level guidelines for their promotion that are easy to understand and practical to apply in the field. The empirical study has been carried out in the environment of a small, geographically separate, developed economy that has an established and diverse manufacturing base. The derived guidelines, therefore, are in the first instance applicable to economies of this nature, however many of the guidelines are expected to be generally applicable to companies operating in developed regions where the labour costs are high. The empirical study indicates that many manufacturing companies already recognize the benefits of RMAS and are employing systems of this type, however that the potential of such systems may not yet be exploited to the full.

ACKNOWLEDGEMENTS

This work is funded under the Maltese National Research and Innovation Programme through the Malta Council for Science and Technology. The research team would also like to thank all those companies that have participated in this study.

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