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Reconfigurable Manufacturing Potential in Small and Medium Enterprises with Low Volume and High Variety

Pre-design evaluation of RMS

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Abstract

Global competition forces companies to respond to fast changing market conditions by introducing new and innovative products rapidly and more often at competitive prices. Meeting these challenges sets strict requirements in order to cope with the variety of products during both ramp-up and production. The Reconfigurable Manufacturing System meets these challenges of high variety by adapting to the capacity and functionality needed when needed. Thus, implementing reconfigurable manufacturing affects the performance during both ramp-up and production. Still, the evaluation of the reconfigurable manufacturing potential has only received limited attention even though it is highly related to justifying its investment. One practical case based example of investigating the potential in reconfigurable manufacturing has though been carried out in high volume manufacturing. However, quantifying and investigating the potential in reconfigurable manufacturing for low volume manufacturing has to our knowledge not been carried out. Thus, the purpose of this paper is to measure the potential of reconfigurable manufacturing in low volume industry, carried out by use of a case-study in Danish industry. Thus, this paper presents an approach for decision support that can be applied by low volume manufacturing companies.

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Keywords: Reconfigurable manufacturing; Reconfigurability; Reconfigurability potential

1. Introduction

Today's global market, forces manufacturers to cope with the challenges of short product lifecycles, uncertainty in product demand, rapid adaption to new technologies but still provide an increasing variety, while still being cost efficient [1]. These interlinked challenges require manufacturers to find solutions to operate efficiently in the ever-changing environment by rapid adaption of resources [1]. To accommodate these challenges, the reconfigurable manufacturing concept has emerged in an attempt to achieve changeable functionality and scalable capacity focusing on families of products and parts [1, 2]. Bearing in mind a low volume and high variety environment the reconfigurable manufacturing concept deals with the issue of excess flexibility, low production rate, and low return on investments [2]. Though Small and Medium Enterprises (SMEs) have not gained much attention in academia in regards to the reconfigurable manufacturing concept [3], Reconfigurable Manufacturing Systems (RMS) are not reserved large enterprises with high volume. In fact, Brunoe et al. [3] conclude that RMS can be very beneficial for SMEs. However, SMEs with low volume and high variety diverge from large enterprises in terms of the system level of which the company will benefit from implementing reconfigurability [3]. Moreover, SMEs with low volume and high variety are required to focus on the time used for reconfiguration because the reconfiguration frequency will most likely increase compared to large enterprises with high volume [3]. These conclusions thereby change the expectations of where to

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identify the potential of RMS in SMEs with low volume and high variety compared high volume large enterprises.

1.1. Literature review

In general, implementing an RMS is motivated by the economic benefits that can be obtained by increasing reuse and reusability and reducing the excess capacity and/or excess functionality present in other types of manufacturing systems as the Flexible Manufacturing System (FMS) or the Dedicated Manufacturing Line (DML) [4]. To accomplish such benefits RMSs are marked by three main characteristics (i.e. dedicated flexibility, convertibility, and scalability) and three supporting characteristics (i.e. modularity, integrability, and diagnosability) [5].

- Dedicated flexibility limited to one family
- Convertibility, easy change of functionality[5]
- Scalability, ability to change capacity [5]
- Modularity, modular functions
- Integrability, interfaces for rapid integration
- Diagnosability, easy diagnostics

The responsiveness of a reconfigurable system enables rapid launch of new products on existing equipment and to react rapidly and cost-effectively to market and product changes [5]. These changes include changes in product demand, current products, and introduction of new products [5]. Thus, the RMS meets many of the challenges that manufacturing companies face in the 21st century [5]. Nevertheless, many practical and theoretical problems are encountered during the design and adaptation of RMSs and RMSs are still challenged by barriers affecting the implementation [6, 7]. Many open questions remain and numerous challenges represent important areas of research [4]. Evaluation of the RMS's potential has only got limited attention, even though this initial measure is among the most important, justifying the investment and thereby the implementation [8, 9]. ElMaraghy [4] mentions in 2006 the need for lifecycle economic justification for different paradigms including RMS. In 2007 Kuzgunkaya and ElMaraghy [10] presented a fuzzy multi-objective mixed integer optimization model to evaluate the RMS investments. In 2004, Abdi and Labib [8] applied a Fuzzy Analytical Hierarchy Processing (FAHP) model to highlight the importance of manufacturing capacity and functionality for the feasibility of an RMS design during reconfiguration processes. Comparable to that contribution Singh et al. [11] utilized in 2007 a fuzzy logic based AHP model to evaluate three different manufacturing systems based on convertibility. Likewise, Amico et al. [12] and Bruccoleri et al. [13] compared in 2006 three different manufacturing systems by means of Net Present Value. On a theoretical basis Bruccoleri et al. are defining under what kind of market characteristics one manufacturing system is preferable to another. Amico et al. [12] also deals with investment decisions calculating cash flows for three different manufacturing system, i.e. DML, FMS, and RMS, which are also the manufacturing systems applied in all of the above papers comparing these systems to different scenarios.

Depending on the scope, the above-mentioned papers apply several different criteria to economically justify the selection of manufacturing system alternatives based on anticipated cost and conceptual choices. It can be argued that these approaches, which represent some advanced pre-design support tools, are rather time-consuming and difficult to apply in most SMEs, in particular in the case of low volume and high variety. This is due to the fact that the aforementioned methods are most applied to the system level, in terms of different concepts on production line-level. Moreover, the methods are widely concerned with selecting the most feasible system alternative based on an economic evaluation, while in the case of SMEs competing on high variety offerings, the strategic ability to launch new products and variety is an additional important parameter. Thus, the contributions mentioned above are challenged by complexity in practical use identifying the potential of RMS since the focus is an economical comparison of different manufacturing systems rather than a practical evaluation. Bearing this in mind Andersen et al. [14] apply an easily apprehensible method possible to utilize in companies without in-depth knowledge within the field of RMS, using information and data that is readily available. However, this contribution takes its outset in a high volume environment and thereby in the distinguishing features of the reconfigurable system compared to the dedicated system. Contrarily, this paper takes its outset in identifying the potential of RMSs in an SME with low volume and high variety, which implies an important difference compared to large enterprises. The motivation for using RMS in large enterprises will often be the benefits of sharing capacity across lines. However, the notion of production lines is not directly comparable for the production systems of the treated SMEs. Due to low volume, continuous production is not always possible and hence the production system is typically arranged into function layouts, where multiple routings occur through the same process stations, and thereby creating numerous of production lines with large changeover time. Having this mind, this paper expects the benefits of RMS to be situated elsewhere for SMEs with low volume and high variety.

1.2. Research question

The reason why we have not seen any evaluation of the potential of RMSs in low volume environments may be the limited work done embracing RMSs in SMEs with low volume and high variety in general. Furthermore, as mentioned, the advantages of RMSs do not seem to have gained ground in general industry yet [7, 9]. An important step in breaking this barrier is an easily applicable approach to determine the potential of RMS suited the intended companies. Based on these considerations, the research question is formulated as follows: *How can reconfigurable manufacturing systems address today's challenges of SMEs with low volume and high variety and how can the potential be identified and measured?*

2. Methodology

In order to address this research question, a case study in a SME is conducted. The case company manufactures earthmoving machinery with an annual sales volume of approximately 450 machines, which makes them among the smallest suppliers in the market. However, they are still able to compete on customizability and product quality. On the manufacturing facilities, they produces approximately 2000 self-produced part-numbers for each machine. Thereby, the company is currently struggling with time-consuming changeovers as an effect of the high number of different manufacturing equipment (e.g. fixtures) applied to cope with the high variety of components manufactured on few stations due to low volume. Therefore, they wish to introduce reconfigurability in their production in order to accommodate variety efficiently and improve internal operations.

SMEs with low volume and high variety like the case company are required to focus on the time used for reconfiguration because the reconfiguration most likely will occur more frequently compared large enterprises with high volume [3]. Thus, reducing the time spent on reconfiguration and introduction of new parts/products requires attention. This can be met by applying platforming principles, which opens for modularization and standardisation, e.g. modularization and standardisation of production equipment [15]. Additionally, one of the key findings in Brunoe et al. is that implementing reconfigurable equipment on station level in SMEs with low volume and high variety might imply a significant potential, as variety and part/product introductions thus could be handled much more efficiently [3]. However, to reduce the number of changeovers and the time spent on changeovers in SMEs with low volume and high variety future part groups must be based on commonality that allows reconfiguration of equipment (i.e. machines, handling equipment, fixtures etc.) across a much larger part variety. This entails an overall framework of generating families of parts and production equipment to capture and utilize commonality, which facilitates the opportunity for reconfiguration of equipment across such part variety [16]. Thereby, it is believed that narrowing the attention to the equipment that drives the variety will allow for evaluation of the RMS potential. As mentioned, this can be met by means of production platforms. The process of creating such production platforms has been conducted in parallel to the preparation of identifying the potential in RMS in the said context. Thereby, production platforms are consequently perceived as means to cope with equipment variety and thereby a means to attain reconfigurability. The case study has been conducted over a period of 20 weeks, where data primarily has been gathered through action research and interviews. In addition, the authors engaged in the process of developing modular production platforms. To sum up this process, the following activities where undertaken, inspired by [17]:

1. Define focus area
1.1. Related system level targeted
1.2. Overall intended production tasks and functionalities in the system targeted
1.3. Main relationships to superior level systems
2. Define functional elements
2.1. Functional and related solution structure of system resources
3. Define the platform scope through a domain analysis
3.1. Relate the functional reasoning to product attributes using the 5 whys iterative interrogative technique
3.2. Create balanced application domains for the platforms based on common product attributes that has significant influence on the system design
4. Modularisation, conceptualisation and platform development
4.1. Define platform modules based on modular driver considurations [18]
5. Document the platform
5.1. Create an architectural descriptions of the platform in accordance with ISO 42010 [19]

Hence, the measuring of the potential in RMS takes its outset in standardization and modularization and thereby reduction of the equipment that drives the variety within or across part groups since it has a major influence on the reconfiguration process in terms of both handling part/product variety and introducing new parts/products. After addressing the influence of reconfigurability through a case study, the potential of RMS can be measured by outlining the potential reduction of equipment variety and next measure the influence on case findings.

3. Case Study

During the last years, the company has introduced various new products and variants to the market. The annual production volume is relatively low (less than hundred for the vast majority due to customization). Therefore, producing large batch sizes implies large stocks but reduction of the batch sizes to single piece flow is at the same time undesirable because of long changeover times.

The frequency of changeovers is high (i.e. several times a day) which naturally leads to many and time-consuming changeovers (future reconfigurations). To reduce the number of changeovers and the time spent on changeovers in companies like the case company future part groups must be based on commonalities that allow reconfiguration of equipment (i.e. machines, handling equipment, fixtures etc.) across a much larger part variety. By reconfiguring production equipment (e.g. fixtures) instead of replacing it (current changeover approach) each time a change between components occur changeover time and time spent on retrieving different equipment could be significantly reduced. Furthermore, reconfigurable production equipment entails reducing the current amount of unique equipment, which reduces the need for storing capacity.

By preparing equipment for future part introduction within part groups time and resource usage for introducing these new parts can be reduced. There is an immediate great potential in predicting the future functional range for fixtures and handling equipment as the evolution of the products that is produced in this industry have not changed much through decades.

By extending the scope of production equipment functionality to accommodate larger part variety the investments in this equipment could also be reduced since it would involve a greater degree of equipment reuse. Introducing reconfigurability in companies like the case company falls back onto equipment variety, which implies to modularize and standardize equipment across larger part variety. The influence of RMSs addressed above are in line with the findings presented by Brunoe et al. [3] and Jonsson et al. [20] where both contributions describes that equipment variety is a barrier for more efficient handling of variety and new part introduction.

4. Results

The first step in identifying the potential in RMSs in the case is thereby to compare the existing equipment variety and the expected equipment variety necessary to handle the variety of components manufactured. Much of the equipment serves the same purpose but realized by means of different techniques. However, in many cases there is no justification of the high number of solutions chosen over the years.

The production platforms that scope the modularization and standardization effort is a result of production core elements (i.e. functional means that constitute the basic elements of a line, cell, station etc.) and grouped parts, both presented in Table 1. The classification of parts is a result of fundamental part and production characteristics (e.g. part geometry and welding accessibility) that strongly influences the design of the production system equipment. The core production elements presented are derived from the functionality needed to manufacture the concerned part groups. These generic core production elements consist of platforms, which are physical process solutions that constitute the production system. A breakdown of these production platforms reveals the redundant equipment variety on different levels of detail.

Table 1: Production Platforms formed to cope with the variety in equipment

	Core production elements				
	CE1: Manual welding	CE2: Robot welding	CE3: Machi-ning	CE4: Fixation	CE5: Handling
Part group 1 Part group 2 Part group 3	FB-Platform, IPHT-Platform	FB-Platform	FB-Platform	FI-Platform, S-Platform	L-Platform

Each of the production platforms consists of various modules, e.g. FB-platform (Table 1) consists of Fixture Base Modules (Table 2). Though each platform consists of numerous modules, only modules that represents equipment that drives the variety is presented in Table 2, because it is within these modules redundant equipment variety are identified. By means of modularization and standardization, equipment variety is expected to be dramatically reduced by pushing the functional variability towards the product interface (see Table 2). Modularization and standardization is critically important analysing possible solutions for reduction of redundant equipment and solutions suited an adequate range of parts. This is reflected in concepts that are outlined in Table 3. Drawn from the case and from generally expectations eliminating redundant production equipment and designing equipment to encompass the adequate range of parts enables the fundamentals to achieve reconfigurability in SMEs with low volume and high variety.

Table 2: Reduction of equipment variants in percentage after evaluating the potential of standardisation and modularization based on identified, potential future production platforms

Number of parts	20	10	36
	Part group 1	Part group 2	Part group 3
Fixture Base Modules	85 %	80 %	78 %
Fixture Interface Modules	91 %	83 %	73 %
Support Modules	Reduced to four principles		
Lifting Modules	75 %	67 %	67 %
Internal Process Handling Tools	0 %	0 %	33 %

Table 3: Future variants for three part groups deduced. However, some constraints exists combining module levels. The three different fixture levels represents module levels of which level one interfaces the production whereas level three interfaces the product. The three different groups mentioned under lifting modules represents part groups from Table 1

As-is	To-be
Modularization and standardization of Fixture modules	
	Product interface
59 fixture variants →	Level 3: 4 principles Level 2: 3 variants Level 1: 3 variants
	Production interface
Standardization of Lifting modules	
	Part groups
21 lifting module variants →	Group 1: 2 variants Group 2: 2 variants Group 3: 2 variants

The immediate motivation to implement RMSs in such companies is the influence on time and resource usage in terms of: 1) changeovers and retrieving of equipment, 2) storing capacity, 3) NPI, including design, manufacturing and installing equipment, and 4) Equipment investments In order to demonstrate the value of adequate equipment variety as an enabler for RMSs in SMEs with low volume and high variety the impact of adequate equipment variety on the above-mentioned bullets was investigated. The current demand situation reveals a basis for reasonable expectations that pairing part groups to dedicated work stations will fit the capacity of these work stations after considering the influence of reducing or even eliminating the time spent on changeovers and retrieving of equipment. Actually, if it is not necessary to produce more than only one part group on each work station the actual changeover and retrieving of equipment can be eliminated. The average batch size for the concerned parts is approximately 2.5 and the time spent on changeovers and retrieving equipment constitute approximately 20 % of the process time, which forms the basis for a great potential. Due to the future equipment concept's different levels of completion, the potential reduction of storage space is calculated for only one of the part groups. Modularizing the equipment has a tremendous influence on the storage space needed in the future. This is because the functional differentiation is captured in upper levels of e.g. fixtures and the reusability is thereby increased. Based on one possible concept the storage space is reduced by approximately 90 %.

Through modularization and standardization and by preparing equipment for future generations within part groups the adaption to new part variants increases the reuse and thereby sets less requirements for design, manufacture and likely installation. However, it should also be mentioned that the savings of utilizing reconfigurable fixtures is highly likely to also involve higher investments than in dedicated setups. However, regarding the product evolution track, some components has only slightly changed during the last thirty years, which actually is not uncommon for this industry. Therefore, analyses should be made regarding the trade-off between increased flexibility of fixtures and the increased associated investments costs, which currently, actually is a subject of high interest to the main author of this paper. The design and manufacture of dedicated fixtures typically amount to 10-20 % of total manufacturing cost [21]. If reconfigurable solutions for each part group is designed encompassing an adequate variety of functionality time spent on design, manufacture, and installation of equipment will be reduced tremendously. One example shows that the time spent on design, manufacturing, and installation of fixtures for six slightly varying parts is five times higher than the time spent on changeovers in one year for these six parts. Thus, the reason for reducing equipment variety is not limited to reduction of operating costs but at least as important if not more important to reduce time and resources spent on new part introduction.

5. Discussion

As indicated initially competitive market scenarios challenge industries to pursue more holistic platform strategies enabled by the capability to create descriptions of modular production platforms [15]. The creation of modular production platforms has not gained much attention in literature, however emerging concepts for holistic platforming strategies exists [15, 22]. Thus, as this paper takes its outset in production platforming it can be argued that this approach builds on an incomplete basis not easy to repeat. However, modularization and standardization across equipment variety does not necessarily require creating holistic platform strategies embracing descriptions of modular production platforms. Nevertheless, applying approaches that consider the essential concerns in platform design is more likely to create platforms that consider the following two essential questions [15] asked by Michaelis et al. [23]: What is subject to change and what is not and where is variety acceptable and where is it not? By applying production platforms to accommodate adequate variety across production equipment as an enabler for introducing RMSs it turns out to have influence on time and resource usage in terms of changeovers and retrieving of equipment, storage capacity, new part introduction, including design, manufacturing and installation of equipment, and equipment investments. However, to ensure that production equipment is capable of handling future part generations, equipment should be prepared for the evolution of the concerned products. Contrarily, it is equally important that future product generations are designed in accordance with the equipment developed to cope with exactly these future part/product introductions. Due to the product evolution tracks traditionally seen in the industry of the case-company it is assumed that the proposed modularization and standardization concepts most likely will be put into practice. It should also be mentioned that the very significant reductions of equipment variants presented is largely caused by the great potential in modularization of equipment that have been developed over time and thereby have different legacy and thereby different solutions for the same purpose. Besides the findings from the case study, the modularity that are implied by production platforming provides the opportunity to share and change functionality in different layers of production equipment. Thus, the opportunity for reconfiguring equipment for different purposes and thereby provide the possibility for not only changing functionality but also to scale the capacity arises. It is most likely that equipment capacity can be shared across part groups depending on to which extent functionality can be shared, e.g. between workstations. This can have a positive influence on lead-time. Actually, dedicated flexibility – as a consequence of introducing RMS – might naturally lead to sequential layouts with increased focus on parts or products rather than machine functionality like job shop or batch production. Such dedicated layouts focused around parts implies considering capacity needs and the ability to share functionality forming part groups so that part groups formed not causes insufficient or excess capacity. The size of part groups also have influence on the level of functionality that goes into equipment since this might influence the reconfiguration time. Thus, the time used for reconfiguration becomes crucial when designing new production equipment since an optimum between the range of variety in equipment (number of parts possible to handle in same equipment) and the reconfiguration time must be found. In contrast to large enterprises SMEs have more limited resources devoted for production engineering, and therefore have less resources for developing the production system. Additionally, SMEs are often forced to use external suppliers of general-purpose machines, which might complicate the implementation of reconfigurability in the production systems in SMEs. Another barrier towards implementing RMS could both be the rather large investment made up front and to allocate many resources of an already small department [3]. Nevertheless, these barriers towards reconfigurability should be seen as an investment that ideally will give benefits in the long term.

6. Conclusion

This paper takes its outset in identifying the potential of RMSs in an SME with low volume and high variety, which implies an important difference compared to large enterprises. The motivation for using RMS in large enterprises will often be the benefits of sharing capacity across lines. However, the production volume in SMEs is often too low for continuous production on even one line. Thus, SMEs with the said characteristics diverge from large enterprises in terms of reconfiguration frequency and the system level of which the company will benefit from implementing reconfigurability. Nevertheless, RMS can be very beneficial to SMEs with low volume and high variety, though the benefits is expected elsewhere. Implementing reconfigurable equipment on station level in SMEs with low volume and high variety can imply a significant potential, as variety and part/product introductions thus could be handled much more efficiently. This can be met by applying production platforms, which opens for modularization and standardisation and thereby for reduction of equipment variety. Such initiatives is enablers for recongurability and is found to significantly influence SMEs in the said context in regards to time and resources spent on changeovers and retrieving of equipment, storing equipment, new part introduction, including design, manufacturing and installation, and equipment investments. Thus, by deducing the production equipment that drives the variety of parts promising result was obtained and showed that the reason for reducing equipment variety is not limited to reduction of operating costs but at least as important if not more important to reduce time and resources spent on new part introduction. Applying equipment variety reduction as a measure for RMS potential is an easy applicable approach. Furthermore, finding the adequate equipment variety is also found to have great influence on SMEs with low volume and high variety regardless of whether the goal is a striving for reconfigurability. Therefore, applying production platforms to increase reuse and reusability of production equipment is not reserved this particular scope of application. Modularization and standardization across equipment variety does not necessarily require creating holistic platform strategies embracing descriptions of modular production platforms. Nevertheless, applying approaches that consider the essential concerns in platform design is more likely to set some important perspectives for reuse and reusability and reduction excess capacity and/or excess functionality present in a manufacturing system.

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