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Changeable, Agile, Reconfigurable & Virtual Production

Reconfigurable Manufacturing – An Enabler for a Production System Portfolio Approach

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Abstract

The purpose of this paper is to investigate how the development of a strategically integrated product and production system portfolio could be enabled by the concept of reconfigurable manufacturing. In previous research, several critical challenges related to developing production system portfolios have been identified, but it has not been investigated how developing a reconfigurable manufacturing concept could aid some of these. Therefore, through a multiple case study, these critical challenges have been investigated in two companies that have recently developed reconfigurable manufacturing concepts for multiple variants and generations of products. The findings reveal that the companies need to deal with several challenges in order to enable a functioning RMS. By running the project separately from the NPD project and to include several product types and production sites the company overcome several challenges.

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Keywords: Production system portfolio; changeability; reconfigurability; production development; portfolio management

1. Introduction

The need for developing product families and managing a product portfolio that meets customer needs is widely accepted as a means for handling product development in a global competitive market place with rapidly changing technologies, shorter product life cycles, and increased need for variety [1]. Production system development on the other hand is often carried out relatively close to its introduction, and the introduction of new product generations generally triggers numerous changes in production that often prescribe costly changes to the production system [2]. Therefore, adopting a long-term planning perspective to the production system development is of major importance for competitiveness and innovation. To create, visualize, and manage a production system portfolio in line with the product portfolio reveals a large potential. The results of this approach is a matching portfolio of tentative products and production systems, which allows for efficient, fast, and sustainable development [1].

However, numerous challenges have been identified in production system portfolio development, related to information management, resources, production system design mindset, equipment supply, monitoring of the environment, competences, production strategy, and development process [3]. Thus, developing production systems that enable change in accordance to the product portfolio is a main concern. The concept of the reconfigurable manufacturing system (RMS) has been described as a way to rapidly react to market opportunities and changes [4]. The RMS enables reconfigurability and adaptability on system and machine level [5], which prepares operations for new generations and updates of products, resulting in a more efficient and sustainable production system development approach. For that reason, RMS can be viewed as an enabler for strategic and integrated portfolio planning of products and production systems. Therefore, working with reconfigurable manufacturing development could potentially aid some of the critical challenges that have been previously experienced within developing integrated product and

production portfolios. This paper is based on a multiple case study, including two companies that have recently initiated the development and implementation of RMS concepts in order to handle product variations. The purpose of this paper is to describe how a production system portfolio mindset could be enabled by the RMS concept and propose further research in order to deal with the identified challenges in production system portfolio development.

2. Frame of Reference

2.1. Challenges in Production System Portfolio Management

In this approach, a company manages a portfolio of production systems in the same way as product portfolios are usually managed and planned. However, in previous research, several challenges have been identified in production system portfolio development [3].

Having a long term perspective on production development requires an ability to wisely use available information about the future plans. However, this represents a dilemma since on the one hand there is a general reluctance to release early information on e.g. upcoming product families, and on the other a tendency to use incomplete information when designing the production system [3]. The tendency to stick to incomplete information could be explained by the challenge in managing information. The effectiveness of information management needs to be based on the capability to avoid situations in which the production system development process is either being subjected to information overload or getting information too late or not at all.

Competencies in production development and operations is another critical issue in order to enable re-use and reconfiguration of production systems [6]. The challenge is both to have the right competence within the company and that the competent persons have dedicated time for development activities. Production engineers often struggle with the trade-off between working with firefighting activities in operations and long-term production system development. Thus, they are seldom dedicated for long term production system development including pre-technology development or advanced engineering (AE) activities [6].

Previous research identified that it is challenging to have a long-term view on production development and often production systems are designed according to current products, which decreases capacity utilization and increases risk and investment considerably [7]. Meanwhile, the production system concepts are strongly influenced by previous production system developments [8]. A clear production strategy supporting a long term perspective in production development is urgent since the production developers needs mandate to invest in long term solution like reconfigurable production solutions.

Another challenge in production system portfolio development is the collaboration with equipment suppliers. Collaboration with equipment suppliers in production technology development creates interdependencies and involves uncertainties and information asymmetry [9]. However, several scholars have found that a strong

collaboration between equipment suppliers and the users, i.e. the receiver of the production equipment, is positively related to the performance in acquiring and implementing production technology [10, 11] and close collaboration with suppliers is a precondition for building trust, mutual understanding, and commitment from the supplier [12].

To always be updated on relevant process innovations monitoring the external environment of the company is required. Benchmarking and networking are two critical activities that can provide new insights to the manufacturing companies.

Development of production systems is still not an area that is as prioritized as product design [8, 13]. To coordinate the production system development process and work in a structured and systematic way is important for a long term view on production system development [6, 14] and structured processes have been proposed by several scholars [15, 16]. In practice, production system development is however typically based on past experience and judgement based on experience which require numerous iterations and correction stages [17] and the production system development process is not regarded as a means to design the ultimate production system [15].

2.2 Reconfigurable manufacturing systems

RMS can be viewed as an enabler for strategic and integrated portfolio planning of products and production systems and working with reconfigurable manufacturing development could thus aid some of these critical challenges described above. The RMS was initially introduced in the 90's by Koren [4] as an intermediate manufacturing paradigm combining the high throughput of dedicated manufacturing lines and the flexibility of the flexible manufacturing systems. The RMS is designed for continuous change of capacity and functionality in accordance with product, process, and demand changes [5]. The reconfigurability of the RMS is enabled by six core characteristics; customization, convertibility, scalability, modularity, integrability, and diagnosability [18]. Convertibility and scalability refer to modifying the capacity and functionality of the system, which is accomplished through modularity, integrability, and diagnosability. The last characteristics, customization reduces the traditional trade-off between efficiency and flexibility, as it refers to machine and system flexibility being limited and customized to a specific part or product family [18]. Thus, the RMS concept entails a high degree of integration with product development, where analysis of the current and future product portfolio in the analysis of need for reconfigurability, determining product families for the design, and updating the system in accordance with new products are essential parts of its design and operation [2, 19]. The concept of co-evolution has been proposed to describe this continuous adaption of the production system and the product family [20], where the progression of product design and technological breakthroughs of manufacturing capabilities are viewed as symbiotic relationship that evolves over time [20]. Therefore, the process of developing adaptable and reconfigurable manufacturing systems is closely linked to the idea of maintaining high interrelatedness between the

product and production portfolio, where the design of the RMS and its changes are direct results of strategic portfolio planning.

3. Research Methodology

In order to further investigate how the RMS concept could aid some of the critical challenges in integrated portfolio development, two cases have been studied. Both cases represented companies that initiated the development and implementation of new manufacturing concept intended to manage future product and production system portfolios, strongly influenced by principles of reconfigurability. Case study methodology was selected due to the rather exploratory nature of the research objective, and due to the ability to gather in-depth knowledge about how the two companies approached the RMS concept, and how that potentially enabled the ability to manage and plan an integrated product and production portfolio [21]. The case studies had an embedded design, where the overall concept was studied and the embedded unit of analysis was a pilot production system design project, where the concept was realized in a production system aligned with today's product family and ready to be reconfigured to future product families. Both of the cases were selected based on theoretical sampling with the goal of extending the emergent theory [22]. Therefore, the case studies were conducted over a longer period of time with researchers present every week. Case study A was running between 2014-2016 and case study B between 2012-2016.

The case studies were conducted in collaboration with the companies and the researchers had an active role in the companies. Throughout the entire data collection, the critical challenges related to strategic portfolio planning were applied as research variables. The data was collected through participation in weekly project workshops and meetings, where follow-up questions and interviews were conducted, as well as in participant observations [21]. In both cases an on-going dialogue was held with involved key persons until rich descriptions of the single cases were achieved [21]. The analysis of data included data reduction, data displays, and conclusion drawing and verification [23]. The analysis process was iterative and of explorative nature and the within-case analysis was complemented with cross-case analysis to provide possibilities of pattern matching [21].

4. Findings

4.1. Case A

Case A is a large Danish enterprise in the water utility industry. The company is currently in a transition towards developing principles of reconfigurability in operations in order to reduce time-to-market, increase capacity utilization, and reduce uncertainty and risk related to investments during new product introduction projects. The company strives for long-term strategic development of production systems and products, as their previous approach to production development was carried out rather close to introduction, requiring frequent costly and time-consuming changes. Therefore, during the latest years, the company has conducted

inter-departmental projects aiming at developing modular product and production platforms that would enable scaling of capacity and functionality change. These projects have been conducted in cooperation between production technology specialists, product developers, production engineers, and equipment suppliers. However, the projects were not aimed at a specific product introduction or production development project, but rather as a frontrunner project that should define the approach and develop the methods for how to deal with future introduction projects. The time horizon for the implementation of the project results were expected to be more than five years. In the following, findings related to how the different portfolio challenges was dealt with in the RMS development are presented.

Portfolio challenges

In the case A, the creation of new modular concepts for production aligned with the product architecture required a large amount of information to be retrieved, processes, and managed in an appropriate way. In particular, information and data on the entire current product range and production systems were a critical source of information during the entire project. Structuring this information, both in terms of which current products that were produced on which current systems, and in terms of how historic generations of products and systems matched was carried out, where a high-level visualization of the portfolio was made. However, in regards to defining future reconfigurable production concepts, highly uncertain information and data about the future were to be collected, structured, and used which was a critical challenge that there was a general reluctance towards. An approach applied for aiding this concerned formulation of different types of uncertainties, e.g. physical appearance of product, level of expected demand, or timing of product introduction, and then stating potential outcomes.

In the case company, several projects were carried out in cooperation between product and production development with the aim of developing shared platforms. However, these projects were not directly connected to specific new product introductions, and they were limited to only a smaller part of the company's entire product application range. Rather, these projects were conducted as forerunners to actual NPD projects, aiming at developing new approaches and standards for how to deal with future product introductions and production system development projects. Therefore, the projects did not face pressure for specific deliverables related to a specific market entrance, which promoted and enabled a mindset focused on how to radically change the approach to production system development, rather than focusing on fire-fighting activities and relying on already implemented and tested solutions. However, initial analyses in the case company proved that the current dedicated production systems were highly underutilized, as they quickly became obsolete due to rapid new product introductions and generations. Therefore, a natural result of this was that focus also shifted towards how to modify existing production systems, to improve the current situation.

As the co-development project in the case company was conducted as a forerunner project to future NPD projects, the mindset of the participating employees focused largely on the

long-term radical changes to conducting development, rather than relying on current practices. However, in the initiating phases of the projects, there was a high need for articulating and communicating how the drawbacks of the previous approach to making dedicated production systems without consideration of an overall integrated portfolio, in order to align the mindset of the participating employees. Efforts were made in terms of quantifying the expected potential in regards to capacity utilization, investments, and time-to-market. Despite the fact that these expected outcomes relied heavily on a number of assumptions, they lay the foundation for formulating a new strategic approach to developing products and production systems.

When the transition towards becoming convertible and scalable in operations and co-developing products and production systems initiated in the case company, there was no systematic approach to how to conduct co-development projects. Thus, the effort and results relied heavily on having skilled project managers that were able to continuously guide the process in the right direction. In particular, there was a need for specific approaches to how to practically conduct the shared development, which was rather ad-hoc based. The involvement of equipment suppliers in the development of a reconfigurable concept was present, and consultants from the supplying company were directly involved in the co-development projects. This involvement led to consideration of radically different production system concepts that were not limited by currently applied production technologies. However, another important observation from the case company was that the involvement of production technology specialists in the development projects were an important source of information.

4.2. Case B

In case B, a large Swedish enterprise within the automotive industry was studied focused on a new product and manufacturing concept aiming for improved lead-times, increased flexibility in operation, and reduced product and development costs. In this concept the company had a long term view of its production system considering how current and future products could be assembled in a multi-product assembly system. Today's products as well as those that will be introduced between 2017 and up to 2024 were considered. The concept required a close collaboration between product design and production departments/operations. Part of the concept was tested two years ago in one of the company's Swedish sites, and the results from these tests have been implemented in the site that has been studied in this research. In practice, the new manufacturing concept implied a modularized product architecture with pre-defined assembly steps of main modules. Different enablers were identified to support the efficiency of a mixed-model/product assembly to enable management of change and variation e.g. flat assembly space to enable adding/removing assembly stations dependent on volume. On technology level several areas were investigated such as tooling/fixtures, which could be used for different products. Other examples of solutions were kitting racks that could be reconfigured for different products and a transportation solution that could be reconfigured for different

products to transport the products on the assembly line without making heavy floor investments.

Portfolio challenges

In developing the new manufacturing concept, information about future product types, that will vary a lot in both size/content and functionality, was required which implied a large challenge. All of the production sites within the company were involved in discussions about similarities and differences between the products and how they are manufactured. This included e.g. information about product and product models, size, weight, key components, today's line layout and what processes that are critical today. Based on this, the products were grouped according to their similarities.

In the pilot project that was studied where the concept was implemented in a production site only one group of the product types were included in order to step-wise test the reconfigurability ideas. One of the sites had main responsibility for this pilot project, however, it required collaboration between the sites, between the departments within the site, and within each department. This group included products of different sizes that never before had been assembled in the same line as well as both present and new products. On a detailed level, one important IT development identified is to generate information/signals of what kit is needed in a specific line station, this information system solution is today lacking.

The overall reconfiguration of the assembly line, adding or removing assembly stations concerned the overall planning. The manufacturing engineering/logistics department required competent staff in order to manage this long term view. Since this is a major rebalancing of the factory, it affects the whole production system and requires a long term development including forecasting and layout/equipment development. A lot of production engineers were involved in the development activities. Some of them were dedicated for working with production development while others also were working with operation. A need for training employees to handle an increase of models/products was identified which is an important issue to consider in a multi-product assembly system. Besides the competence development of employees an important aspect was development of products and/or manufacturing technologies that reduces the perceived complexity in assembly. The training and competence development of assemblers were identified as one of the most critical aspects in this case.

The overall concept was very much a strategic program with impact on product design, production system development as well as the interaction between them. The goal was to enable assembly of different products and new products in different plants. The mindset when designing the assembly system was not to stick to previous ideas but instead develop something radically new for the company. This newness was evident both at an overall level, i.e. by assembling a vast of different products within a common line, but also on a detailed level in terms of reconfigurable tooling and fixtures. This new production concept adopts a very long term view and is a global strategic initiative since it will in the future include the whole manufacturing network. When the case was studied, the

concept development regarding a full scale assembly line ready for reconfiguration between all product types were running.

In case A, it was a necessity to build up in-house competence about how to manage and operate a multi-product assembly system. Therefore, most of the technology development was done in-house. An exception was for material handling equipment, where suppliers were involved. To build up the internal competence and monitoring the environment, a lot of time and effort were put on investigating new technologies and processes that were coming up. New equipment that could potentially be used in the system were purchased to be a basis for experiments and elaborations made by in-house technicians. Besides testing new technology to be used in the assembly line, experiments were done with google glasses to show assembly instructions and investigated other technologies to reduce complexity from an assembler point of view. In the process to develop a multi-product assembly system the company tried to follow general checklists and processes for concept development, e.g. MRL/TRL 1-4. There was an advanced engineering (AE) development process/model within the company that was used with assessments for milestones between different TRL/MRL levels. Regarding solution development to increase flexibility and enable reconfigurability within assembly, the work followed general steps for concept development and innovative/creative processes including e.g. benchmarking and brain storming activities.

5. Analysis and Discussion

The two cases investigated in this research share the same overall goal; developing and implementing a new production concept that enables production of multiples variants in a product family as well as different product families within the same production system that is also ready for future product generations. In both cases, the product range offers a variety of different product sizes, weights, and volume characteristics, which were to be included in one assembly concept, requiring new technological solutions. In case A, the scope of the concept only covered part of the entire product range, meaning that only one producing site were involved. The complexity of the project in case B was increased by the fact that numerous producing sites were in scope. Moreover, the position in the development process differ, where case A is still in the concept development phase and case B already has conducted testing of the new concept and its technological solutions in a production relevant environment.

The findings of both cases support the previous findings [3], stating that despite that developing integrated portfolios is considered important in companies, its development is still challenging in practice. Several of the challenges mentioned in Section 2 were clearly present in the studied cases. However, the cases also suggest several ways of dealing with these challenges through the RMS concept. In Table 1, the findings related to this are summarized and further areas for research are listed accordingly.

In terms of information management, the findings suggest approaches for how to initially structure information needed for developing a reconfigurable concept. The criticality of

acquiring information on current products, production processes, and their interrelatedness in order to group products based on similarities and knowing essential processing capabilities were present in both case. In terms of looking into the future, uncertainty in information is unavoidable, but the case findings suggest that structuring this uncertain information in accordance with the impact on the production systems is one way of dealing with the dilemma.

In regards to the trade-off between fire-fighting and development work, the findings of the cases suggest that conducting a shared development project that is not specifically tied to a NPD project could benefit the transition towards integrated portfolios, and create a solid foundation for future co-development of products and production systems. Having the mandate and time to work on long-term solutions was highly influenced by this, where both cases highlight the need for conveying the goal of the efforts in order to create the right mindset in the project. However, having the right competences to work with reconfigurability both in concept design and the later utilization and planning on the shop floor requires effort in terms of training.

In the cases, equipment suppliers were involved to different extent. In case A equipment suppliers were highly involved and contributed to new perspectives and mindsets avoiding the company to stick to previous system solutions. In case B on the other hand much of the development was done in-house in order to develop the in-house knowledge and competence. There are pros and cons with both approaches; when involving equipment suppliers, you get access to new perspectives however this often requires a long term relationship between the company and the equipment supplier to secure future reconfigurations. To keep development in-house the internal competence is built up however, there is a risk to stick to the existing production system. In case B they dealt with this risk by having a cross functional development group involving several departments and several production sites.

To monitor the external environment of the company in terms of e.g. upcoming relevant process innovations, is a continuous task and could be enabled by a reconfigurable system where new innovations easily can be added during reconfiguration. The ability and competence to reuse the production concepts was in both cases enabled by the reconfigurability characteristics, meaning that the new concepts were modular and had the ability to be connected in various ways. Thus, the reconfigurable concepts secure the ability to in the future introduce new products with reduced effort and investment. Moreover, the development process differed between the cases. Case B represents a more structured approach to the production development project, where an advanced engineering development model was followed. In case A, the effort was conducted rather ad-hoc and trial-and-error based, as a first step towards becoming reconfigurable. Due to the complexity in the task, a developing process supporting RMS is however preferred [6].

Table 1. Summary of case findings

Challenges in production system portfolio	How this could be enabled by RMS concept/thoughts	Knowledge gap/propositions
Insufficient information management	Classification of product families	Identify and structure information on urgency and type of uncertainty
Lack of resources and competences	Conduct pre-development project Modular product and production concept	Transfer RMS knowledge to practice
Lack of long-term mindset and production strategy	RMS requires the company to adopt a long-term perspective	Quantification of RMS potential
Insufficient collaboration with equipment suppliers	RMS calls for a long-term collaboration both in investment projects and during reconfiguration development	Collaboration practices suitable for RMS projects
Lack of monitoring the environment	RMS enables resource-efficient inclusion of new innovations	The link between developing RMS solutions and the management of environmental factors (external information)
Lack of development process	-	A development process supporting development of RMS

6. Conclusion

The purpose of this paper was to describe how a production system portfolio mindset could be dealt with by the RMS concept and propose further research in order to deal with the challenges in production system portfolio development. Two cases have been studied that offered the opportunity to study the interaction between development of products and production systems, both in terms of their long-term strategic impact and how to develop modular and reconfigurable production platforms. The main findings of the case studies are first that by a RMS concept the companies are forced to deal with several challenges required to enable an integrated product and production system portfolio. A long term mindset is required, a good relation with equipment suppliers must be established and competence ready for reconfiguration is needed. Secondly, by running the project separately from the NPD project and to include several product types and production sites the company overcome several challenges linked to information management, resources, competence and long term mindset. Future research has been proposed e.g. to quantify the RMS potential to motivate an RMS investment, identify ways to secure a long term relationship with equipment suppliers in RMS projects, and to set up a development process supporting development of RMS.

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