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# Reconfigurable Manufacturing Systems as an Application of Mass Customisation

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**Abstract**

*Manufacturing systems are today developed as engineer to order solutions tailored to producing a specific product or a limited product mix. Such dedicated systems are not consistent with market demands for rapid product changes, product variety, and customisation, which require flexibility and responsiveness of manufacturing systems. A Reconfigurable Manufacturing System (RMS) is aimed at possess such flexibility and responsiveness and is said to be the manufacturing paradigm of tomorrow. RMS is, though, not yet fully developed. A similarity between RMS and modular product families, known from Mass Customisation (MC), is seen and based on this similarity a potential to maturing RMS further by applying MC methods and techniques is identified. Based on literature surveys this paper analyses this potential by diagnosing gabs for RMS to succeed as a MC product. For each gab MC theory holds related methods and techniques, which indicates a potential and, herby, an area of interest for further study.*

**Key words:** *Reconfiguable Manufacturing System, Configuration, Mass Customisation, Modular Product Architecture*

## 1. INTRODUCTION

The globalised and increased competition on today's market generally implies a need for rapid product change, high product variety, and customised products. As argued by [52] product variety initially increases sales but as variety keeps increasing the law of diminishing returns suggests, that the benefits do not keep pace. To counteract such an effect it is imperative to optimise external variety with respect to the internal complexity [49] which is a keystone of Mass Customisation (MC). MC aims at satisfying individual customer needs while taking advantage of mass production efficiency [38]. A key method of MC is modular product architectures/families, which has been recognised as an effective means to achieve economy of scale contemporary with increasing product variety [32] [48] and to increase reuse, reduce development risk and system complexity, and improve upgradability [43].

Regardless of MC the new demand of the market has increased manufacturing complexity and, hereby, a need of flexible and responsive manufacturing systems is emerged. In response Flexible Manufacturing Systems (FMS) evolved in the mid-nineties but due to complexity, low system output, and the high cost of general flexibility FMS fail to gain industrial acceptance [26] [44]. The trend today is towards Reconfigurable Manufacturing Systems (RMS) [44]. RMS is a modular manufacturing paradigm where manufacturing system components, controllers, machine tools, etc. is modulized [27] and the modules form a manufacturing family corresponding to the product families known in MC theory. A manufacturing system is developed as one particular module configuration tailored to the production needs of a company's product assortment. The modular approach enables reconfiguration (change, add, and remove modules) in response to market changes and RMS is, therefore, aimed at holding the capacity needed when needed [30]. RMS is identified as first priority among six grand challenges for the future manufacturing in the '*Visionary Manufacturing Challenges for 2020'* by the US National Research Council [7] and listed as one of the focus areas in European Commission Strategic Research Program for future competitive manufacturing in Europe [6].

The research effort on RMS is mainly focused on the principals of RMS and the RMS enabling technologies. This implies that aspects such as manufacturing family architecture, system configuration, etc. have received less or little attention. Based on the similarities of RMS and highly customised MC product it is the objective of this paper that RMS can be treated as a MC product and, herby, that MC methods and techniques can be applied on RMS in order to cover these areas. As a foundation for examine the objective, section 2 and 3 review MC and RMS respectively. Section 4 examines the objective by presenting the analysis, its results, and a discussion of the potential of applying MC methods and techniques. Finally section 5 draws up the conclusions.

## 2. MASS CUSTOMISATION - REVIEW

In order to differentiate companies in a highly competitive and segmented market, the concept of MC emerged in the late eighties and provided high variety and customised products at a reasonable low cost[38]. Hereby, MC is a response to an increasing market demand for product variety, product customisation, and a lowering of product lifecycle which destroy many mass production industries [17], [28], [2], and [39] through [45]. Several definitions on MC exist where a practical one is:

*"A system using information technology, flexible processes, and organisational structures to deliver a wide range of products and services that meet specific needs of individual customers at a cost near that of mass-produced items [45]."*

Based on a literature review [45] present six success factors of MC: 1) Customers' demands for variety and customisation must exist, 2) market conditions must be appropriated, 3) the value chain should be ready, 4) technology must be available, 5) products should be customisable, and 6) knowledge must be shared. [45] further identifies a number of MC implementation enablers as the methods and technologies used to achieve the success factors. The enablers can be divided into three groups [45]:

- MC process and methodologies: Agility of manufacturing, organisational coordination, customer driven design/manufacturing process, customer value definition, waste reduction, etc.
- MC enabling technologies: Advanced manufacturing technology (flexible manufacturing systems, CNC machines, CAD/Cam systems, etc) communication, and information technology
- Information translator: An efficient customer-manufacturer communication link for information transfer

The customer involvement can be incorporated at many stages in the value chain, which is treated by several authors such as [14] and [29]. Based on [39],[14], [29], and [46] Silveira et al. [45] introduce eight levels of customisation formulated from a manufacturing point of view (divided by the product decoupling point). The eight levels are [45]:

1. Standardisation: Standard products without any customisation/variation, pure standardisation [29]
2. Usage: Products can be adapted to different functions/situations in the use stages
3. Package and distribution: Fitting of products to a market segment by individual packaging
4. Additional services: Customisation of the service around a standard product
5. Additional custom work: Customised by adding additional work to a standard product in the sales situation
6. Assembly: Modules are assembled into custom products
7. Fabrication: Customer tailored products based on basic predefined designs
8. Design: Individual engineered to order products

The modular approach of RMS corresponds to a customisation level of 6 or level 7 if predefined parts need to be tailored. The remaining review is, therefore, preliminarily focused on methods related to these high customisation levels. From the list above it should be noted that a high level of customisation requires customer involvement in an early stage of the value chain. This is traditionally associated with high product cost. A means to achieve successful MC implementation is modular product design combined with postponement of product differentiation [4] and [38]. This is supported by[15] who argues that part standardisation and modularisation in form of modular product architectures is a means to achieve a high customisation level in a cost effective manner.

### 2.1 **Modular Product Architectures**

Ulrich and Eppinger [51] define product architectures as:

*"The scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact."*

Functional elements can be defined as *"the individual operations and transformations contributing to the performance"* and the chunks as *"building blocks consisting of a collection of physical elements (parts, components and subassembly which implements the product functions) which together implement the function of the product"* [51].

Based on the mapping relation between functional elements and chunks/physical elements product architectures can be more or less modular. At the one extreme modular architecture consist of "one-to-one" mappings and at the other extreme integral architectures consist of complex (many-to-one or one-to-many) mappings [51]. In the theory of domains [3] a generic description of a product design is gradual determinate by four domains: Process, function, organ, and parts. By introducing the organ domain in between the function and the part/physical domain the theory of domain varies the modularisation discussion process.

A direct mapping (modularity) makes it easy to customise a product by tailoring the module combination or by changing, adding, and removing modules of predefined products. The variety between products developed by modular product architectures is created in the assembly structure of standard modules (modules which can be reused in and across product families). Hereby, it becomes possible to achieve volume in the module production and, thereby, delivering variety and at the same time obtaining economy of scale. Modular product architectures are, furthermore, aimed at increasing reuse, reducing development risk and system complexity, and improving upgradability [43].

### *2.1.1 Modularisation*

Architecture modularity (or product modularity) is a relative property and is often stated in regard to a comparative architecture/product [51]. As stated above, modular structures are characterised by a "one-to-one" mapping between functional elements and physical elements/chunks. Another characteristic of modular structures is a well defined interaction between chunks/modules (interfaces), interactions which in general are fundamental to the primary functionality of the products [51]. This implies that modules are identified so interactions between modules are minimal but can be high within modules [50].

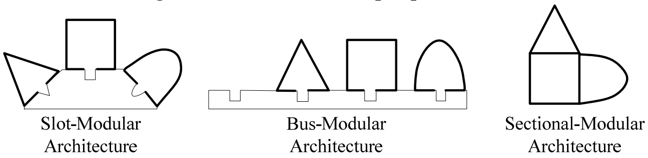


**Figure 1:** Slot, bus, and sectional architectures [51]

According to [51] modular architectures can be divided into three categories: Slot-, Bus-, and Sectional architecture, see Figure 1. [33] takes the classification further and relates each class to the life phase which benefits the most. It is, hereby, possible to relate the modularisation approach to the point of customer involvement. [12] and [11] express the various reasons for modularisation in a set of modular drivers: Carry over, technology evolution, planned product changes, technical specification, style, common unit, process and/or organisation re-use, separate testing, supplier offers black-box, service and maintenance, upgrading, and recycle.

### *2.1.2 Product architecture*

Modular product architectures can be seen as a tool to develop, maintain, and manage the product assortment and, hereby, obtaining product variety in a cost effective manner. A comprehensive work on architectures is to be found in [15] who defines architectures as:

*"An architecture is a structural description of a product assortment, a product family, or a product. The architecture is constituted by standard designs and/or design units. The architecture includes interfaces among units and interfaces with the surroundings".*

Harlou [15] distinguishes between architectures and platforms, where a platform is a subset of an architecture including only existing standard designs and their interfaces. As stated in the definition, an architecture (or platform) can be on assortment, family, and product level as shown in Figure 2.

Architectures include both design units and standard designs where design units are: *"the function, organ, part, or an encapsulation of a group of these. A design unit together constitutes a product"* [35] through [15], and standard designs are: *"design units which complies with one or more product family and the rules of re-use, documentation, and responsibility"* [15]. From the above stated definition and from the architecture approach it should be noticed, that in a modular architecture based development, the standardisation, reuse, etc. are performed at part level and not only at the higher module levels. According to [15] this approach is proven effective in industrial cases regarding R&D resources reduction, reuse of solutions, knowledge, lead time reduction, etc.

Sanchez [41] introduces process architectures which decompose the functionalities of a process into specific functions and functional activities. Related to process architectures [41] states the importance of aligning

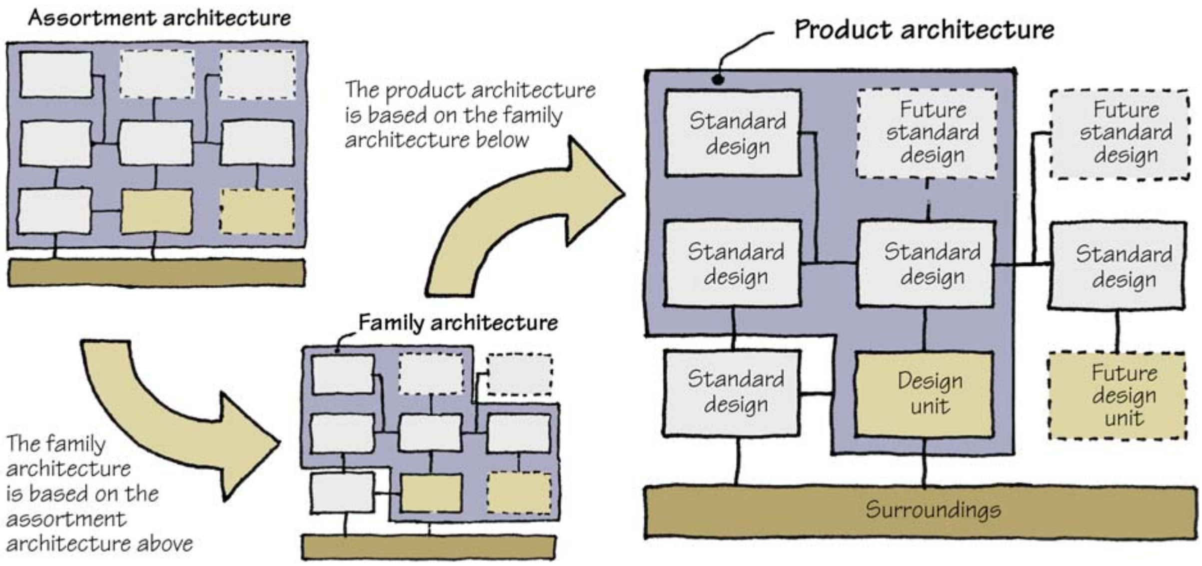


**Figure 2:** An architectures relation between assortment, family, and product [15]

product and process architectures in order to harvest the benefit of architectures. In [42] knowledge architectures are added as a third architecture. The importance of a holistic view of architecture is supported by [19] who presents a holistic decision framework of product family design and development inspired by the Concept of Design [47]. The framework consists of customer-, functional-, physical-, process-, and logistics-domains and a product portfolio, product-, process-, and supply-platform to assist the domain transformation between these domains respectively, see Figure 3.

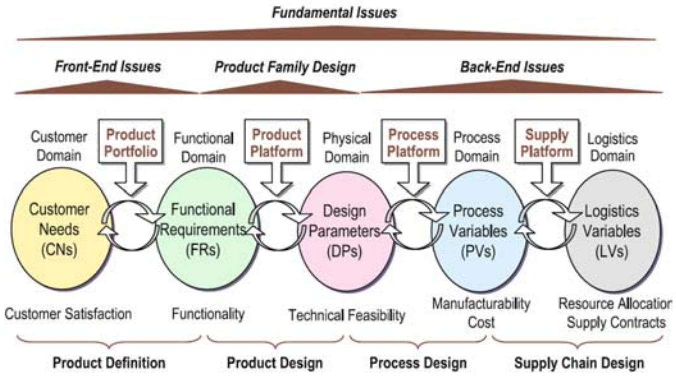


**Figure 3:** Holistic design framework covering the value chain [19]

Related to manufacturing [19] outlines the need for firms to adapt, integrate, and reconfigure more sufficient, the need of information technologies, concurrent engineering, and methodologies to describing and sharing capabilities. [19] is further outlying an expectation for further research on *"building up rigorous frameworks of reconfigurable process and process platforms, integrated management for product and process families, coordination of product and process variety, etc."* [19].

### *2.1.3 Developing modular product architectures*

Modularisation and development of modular product architectures are widely described in the literature. A consensus concerning the importance of a "customer need focus" in the development phase seams to appear. Several methods with various focuses exist. One general accepted method for modularisation of a structure is the Design Structure Matrix (DSM). In order to identify structures with limited interaction, which can be encapsulated into modules, DSM examines interfaces and interactions among system components. Modular Function Deployment (MFD)[12] is a method to identifying modules in a given product and consists of five linked tools

1. Clarify customer requirements
2. Select technical solutions
3. Generate concepts
4. Evaluate concepts
5. Improve each module

Design for Variety [10] is a domain oriented approach for modular design, where the relation between the functional, technological (organ), and physical domain must be understood and for each domain a product model must be developed and standard interfaces defined. Design for variety is closely related to Theory of Domains [15]. [53] and [1] suggest a method to identify reusable modules across product families by use of function structures (mapping of energy, material, and information connections of sub functions). A method to design product platforms regarding market segments is the Power Tower [31] and the four related methods of mapping a platform to segments (niche specific platforms, vertical platform scaling, horizontal platform scaling, and beachhead strategy). On a strategic level a number of authors [14], [29], etc. stress the importance of selecting the right point of customer involvement in order to meet the market demand. In relation to this the design rule of postponing the product decoupling point must be taken into account.

## 2.2 **Developing products based on product families**

From a modular product family a product can be derived as one specific module combination. Such a combination is called a product configuration and the design process of combining modules into one specific product is called a product configuration process. The customisation approach of MC entails customised configuration, which have to fulfil a set of customer needs. In order to achieve MC the configuration process of each individual customer product and the following generation of documents, production basis, etc. has to be simple and fast, and preferably automatic. This requires formalisation and representation of knowledge related to the entire value chain such as design, manufacturing, and supply chain knowledge. A cornerstone of MC is, therefore, to formalise knowledge and representing knowledge in a useful way [40]. One such representation is a model (such as product and process models) which applies the formalised knowledge in order to transform information inputs into useful outputs. Models are, therefore, crucial for achieving MC and the ability to formalise and modelling knowledge can be a limiting part of a platform and, hereby, the architecture. In order to handle, generate, and distribute information, MC solutions often include an information network as a part of the architecture. This is supported by [40] who argue that a successful implementation of MC must integrate all information flows in a so-called Information Cycle of Mass Customisation and by the MC success factor no. 6 - Knowledge Must be Shared [45].

### *2.2.1 Product models and configuration*

A product family usually includes a large number of possible products, which are not feasible to tread as individual product variants. Instead it is suitable to treat the product family as a whole and derive the particular product as an instance/configuration of the product family. In order to do so, a model of the product family, its components, modules, etc. is needed. Such a model is called a product family model, which describes the product family and all its possible products. The result of a configuration is according to [36] and [22] a model of the configured product (product model) from which the physical product can be produced. To secure that only legal configurations can be configured a product family model should include "restrictions about what is feasible and not feasible" [22]. [15] argues that the following four aspects are essential for modelling an architecture (and, hereby, modelling product families):

1. Organ structures: Structure and variety of a product families organs, where organs refer to the organ domain in theory of domains [3]
2. Organ interfaces: Overview or interfaces among organs
3. Visualise variety: Overview of variety from a commercial, functional, and physical point of view
4. Linking variety: Description of how commercial, functional, and physical variety are related

Furthermore, [15] emphasises the essential of gaining an overview of a company's product assortment, describing the structure of the product family, and the variety within the product family.

It is important to distinguish product family models from the product configurator. The product configurator is a software system supporting the product configuration process. A product configurator is based on the product family model and can be rule-based or constraint-based. A rule based configurator is sequential (predefined order of parameter specification) and use predefined rules (if-then logic) to determine the actual solution span whereas constraint-based systems directly derive consequences of a choice and is, hereby, random-sequential [24].

Product family modelling has been treated in the literature by several authors and a number of methods exist. [20] and [8] describe a product family by three views: Functional, technical, and structural. The functional and technical views describe the customer's functional requirements and the design parameters respectively. The structural view represents the mapping between the functional and technical view as well as describing the configuration rules. Product Family Master Plan (PFMP) [16] and [34] is a pragmatic method, which according to [15] has its origin in the object-oriented paradigm [5], system modelling (system theory, [25]), theory of technical systems [18], and theory of domains [3]. The PFMP describes a product family from the customer, engineering, and part view. The modelling formalism of PFMP consists of three types of elements (classes, attributes, and constrains) and two types of structures ("part-of" and "kind-of"). Another common modelling formalism is Object Oriented Modelling [13], often performed by use of Unified Modelling Language (UML). Object oriented modelling was originally developed for software modelling and the formalism consists of four key elements (objects, classes, attributes, and instances), which can be related to each other by generalisation connections, specialisation connections, and whole-part connections. By use of the object oriented UML modelling approach [36] and [23] presents a multiple abstraction level modelling approach supporting the business process of Engineer to Order (ETO) products. The Generic Organ Diagrams [15] is modelling architectures from a functional point of view by a block diagram of the organs and organ interfaces of a product assortment or family. A block in an organ diagram can represent an organ or a group of organs [15] and the interface among the organs is market with interface types, which according to [37] can be divided into four interface types (spatial, energy, information, and materials).

According to [21] most existing product family modelling methods focus on modelling the solution space (attributes of the product and product structure) of a configuration process and do not include important information related to the product value chain.

## 3. RECONFIGURABLE MANUFACTURING SYSTEMS

Since the time of industrialisation, manufacturing systems is traditionally developed as Dedicated Manufacturing Lines (DML). In order to produce the products at a high volume in a cost effective manner, DML is developed as a dedicated/fixed system around one specific product. DMLs are cost effective as long as demand exceeds supply and they can operate at their full capacity [27].

As introduced FMS was evolved in the mid-eighties as a response to the new markets demand for flexible and responsive manufacturing systems. FMS consists of general purpose CNC machines and other programmable automations [26], often operating in parallel. FMS aims to hold such flexibility but has never been widely adopted due to low system output [26], high complexity [44], and a high cost of general flexibility, which in most implementations only partly are used [30] [26].

RMS was introduced in the mid nineties and aims to be flexible, responsive, and less complex and costly compared to FMS [44] [27]. This also appears from the definition: *"A Reconfigurable Manufacturing System (RMS) is designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements"* [27]. The module based approach is essential for RMS and is enabled by the two RMS enabling technologies: Open-architecture modular controllers (reconfigurable controllers/software) and module machines/tools (reconfigurable hardware) [27].

RMS is based on modules, interfaces, etc. as known from modular product architectures and a manufacturing system is designed as a configuration of the modules. RMS configurations are like DML customised around the target product or product family in order to provide only the features and flexibility needed [26]. RMS, hereby, provides customised flexibility through scalability and reconfiguration instead of a general flexibility through equipment with a build in high functionality like FMS [30]. The key feature of RMS is that, unlike DMS and FMS, its capacity and functionality are not fixed [30] [9]. [27] presents a number of key characteristics of RMS:

1. Modularity: All major components have to be modular
2. Integrability: Modules are designed with interfaces for component integration
3. Customisation: The system flexibility and the control is customisable for production of a product family
4. Convertibility: Systems need to be designed to shorten conversion/setup time between batches
5. Diagnosability: Easy to tune a system to produce good quality, etc.

RMS is designed at two levels: System level (machine interfaces, link to ERP, etc) and machine level (internal machine/tool modularity, interfaces, etc.). To ensure a high level of reconfiguration, both of these system levels have to be characterised by the key characteristics of RMS [26]. In regard to the reconfigurability [30] argues that *"for a system to be reconfigurable these subsystems and their components must be designed to be reconfigurable at the outset"* [30]. This is supported by [27].

RMS is aimed at being the manufacturing paradigm of MC [9] and high expectations of the potential of RMS are illustrated by the high priority of RMS in [7] and [6]. Until now the main focus of RMS has been on the principals of RMS, basic structures, enabling technologies, etc. while minor attention is put onto the architectural aspects and system configuration process, which mainly is treated as an engineer design task. When comparing the modular structure of RMS with a modular product family a structure similarity should be noted. A further similarity is the configuration approach where a product or a manufacturing system is developed, based on needs, as one particular module combination. In RMS these needs are the production demands of the company's product assortment. Also in the purpose of applying the modular approach similarities can be seen. In both theories this approach is applied in order to create volume in manufacturing and to speed up product/manufacturing development and adjustment (add/shift/remove modules, option of parallel activities, and shorten run-in time due to module testing and easy debugging). Based on these similarities it is found relevant to analyse the opportunity of treating RMS as a MC product in order to adapt MC methods and techniques.

## 4. ANALYSIS AND RESULTS

In order to evaluate the opportunity for treating RMS as a MC product and, thereby, applying MC methods and techniques to RMS, a GAB analysis is performed to identify area of improvements for RMS to succeed as a MC product. The potential of applying MC methods and techniques is then identified by pinpointing the MC theory covering, for the gabs, comparable or partly comparable issue. The GAB analysis is performed by compare RMS and the MC success factors introduced by [45], see Table 1. From the evaluation of success factor 1 and 2 it appears, that the market demands customisation, but at the same time the market needs confidence before adapting a new technology like RMS. From the evaluation of the remaining factors, it should to be noted, that the tendencies are pointing towards RMS, but there are still a way to go. Overall the gabs related to these factors can be divided in three categories:

1. RMS technology development: In order to realise RMS, further RMS technology development is needed, both on system and machine level.
2. Platform/architectures: Standardisation and standards are needed regarding development of equipment, control algorithms, software, models, etc. This implies a need of various platforms such as development, information, configuration, ramp up (adjusting/diagnosing), supply chain, etc. In order to relate these platforms, a holistic development framework covering the entire value chain is needed. In relation to a market with many players, there is a need for standards to be open and shared in order to ensure acceptance and rapid development.
3. Modelling and knowledge formalisation: Models and modelling methods within a broad area such as product, process, self adjusting, and self diagnosing are needed. Easy modelling and model implementation are keys to gain acceptance, which demand easy to use standard methods with standard interfaces to the information network in the architecture. RMS is further challenging excising models such as forecasting, pricing, and returns of investment. This put forth a demand for such new models.

By comparing MC theory with the three categories of gabs, it appears that MC theory covers methods and techniques for comparable or partly comparable issues. These are modularisation, platforms/architectures, and product modelling respectively. In order to make a successful transferring of methods and techniques related to these areas, the scope of the methods and techniques must cover the new area of application. Consequently, the potential of applying these methods and techniques onto RMS is evaluated by conceptually hold their scope against the RMS requirements.

### 4.1 Adapting modularisation methods and techniques

An important issue in regard to RMS technology development is modularisation and interface standardisation where the Design Structure Matrix and Modular Function Deployment are found applicable in regard to the hardware components while usage on the software components of RMS is an object for further study.

### 4.2 Adapting architecture and platform methods and techniques

In category 2 a need of architecture and platforms covering the many aspects related to manufacturing appears. In order to define such platforms in a way which are relevant for the value chain and to relate these platforms, it is found reasonable that inspiration of a framework can be found in the product development framework presented by [19]. The need of standardisation and standards requires the architecture to include design rules and standards for modules and their interfaces, control issues, simulation models, product model data, in/out-put information demands, etc. These designs rules and standards must ensure achievement of the RMS characteristics at both machine and system level. In a market with many players, such standards have to be easy to use and ensure that modules can be shared. A RMS architecture have to be applicable at several levels such as the global market of manufacturing machines, tools, and technology, on a company level, and on firm level. It is found likely that a distinction similar to [15] architecture/platforms distinction is suitable for treating such levels and a deviation similar to assortment, platform, and product [15] can be useful to distinguish firm, manufacturing lines, and specific manufacturing setup respectively. The separation in standard designs and design units [15] is further found applicable in order to include special designed modules in a particular architecture (e.g. a firm).

**Table 1:** Comparison of MC success factors and RMS in order to identify gabs of applying MC methods and techniques on the configuration/reconfiguration process of RMS.

| MC success factor | Current status | Needs |
|---|---|---|
| 1) Customers' demands for variety and customisation must exist | • Manufacturing systems/equipment is today an ETO market with a high level of customisation | • Marked acceptance of the "new" way of customise and the related increase in standardisation level |
| 2) Market conditions must be appropriated | • High market demands for flexibility and responsiveness of manufacturing systems<br>• Market requires a high degree of confidence and proven reliability, performance, quality, etc. before adapting new manufacturing solutions | • The concept of RMS and its probability for a business outcome must be industrial validated by pilot projects and case-studies |
| 3) Value chain should be ready | • Focus on corporative supply chain<br>• Supply chain structures need flexibility and responsiveness<br>• No general model/platform combining the value chain like the holistic decision framework presented in [32] | • Introduction of RMS across the supply chain<br>• Extended supply platforms regarding information exchange, etc.<br>• New models for corporation, pricing, forecasting, etc.<br>• Development of a general holistic framework covering the entire value chain |
| 4) Technology must be available | • The theory of RMS is still under development both regarding machine and system level technology, but the enabling technologies exist<br>• Limited amount of formalised knowledge which is needed for systems to be flexible and responsive (self adjusting algorithms, etc.)<br>• No general design rules or common standards | • Further research on RMS on both system and machine level<br>• Formalise knowledge and develop models for use in self adjustment and diagnosing algorithms on both machine and system level<br>• Development of standards and standard interfaces for tools, machines, support systems, etc.<br>• Easy to use development platforms stating design rules, standards, etc. |
| 5) Products should be customisable | • Per definition the structure of RMS is customisable, but the customisation process is today an engineering process | • Product models and configuration systems supporting the needs of RMS |
| 6) Knowledge must be shared | • Individual system integrators, machine builders, software developers, etc. share little or no knowledge<br>• PDM and PLM tendency put data collection and sharing on the agenda | • Shared standards for virtual models, product family modelling information, control systems, signal exchange, etc.<br>• Information structures and infrastructures in and across systems and companies |

### 4.3 **Adapting product family modelling methods and techniques**

Communality in the product structure is found, which indicates a potential of transferring product family modelling methods and techniques such as PFMP and Object Oriented Modelling. It is found that most of today's MC methods focus on hardware products, which limit them in regard to the software parts of RMS. Due to an origin in software modelling it is the expectation that Object Oriented Modelling can be expanded to cover both hardware and software. The different views presented in Theory of Domain can be useful to describe the many aspects of RMS. It is found likely that a multiple abstraction level approach like[36] and [23] can be used regarding the system/machine level approach, the needs of black/grey-box modelling of unknown designs, and to introduce a multiple number of design stages in the configuration process.

Most likely RMS will be constantly modified; modules will be updated, etc. This calls for version control of the product family model and the enclosed modules and also for compatibility modelling, which is found to be a limitation of today's modelling approaches. Another limitation of the modelling approach is to balance the many related aspects of a manufacturing system in order to find the trade-off which provides the best performance. To do so in a configuration system, it is found likely that a product family model and the configuration system must support optimisation techniques. This typically requires feedback to the optimisation algorithm, which most likely can be generated as the output of a virtual manufacturing simulation.

## 5. CONCLUSION

Based on reviews of Mass Customisation (MC) and Reconfigurable Manufacturing Systems (RMS), it appears that RMS hold great similarity to modular product families known from highly customisable MC products. Such products are developed as one particular configuration of a product family, which is the approach in both MC and RMS. RMS still hold research potential. A potential to take RMS further by applying MC methods and techniques is indicated by the similarities with MC. This objective is supported by the analysis, which results in the following three focus areas for product maturing of RMS as a highly customisable MC product:

1. RMS technology need to be further development
2. RMS platforms/architectures are needed
3. Modelling and knowledge formalisation is needed

A potential of applying MC methods and techniques occur for each of the areas as a similarity between the scope of methods and techniques and the requirements of RMS.

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