

## Modularity in the design of reconfigurable manufacturing systems

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**Abstract:** According to recent results, Reconfigurable Manufacturing Systems or RMSs are the most efficient for manufacturing companies to adapt to the current market. This market is characterized by a high competitive level and very frequent and sudden variations in customer demands. Developing an RMS is not an easy task and a lot of work has been done in both academic and industrial fields to give solutions to address this issue. We can, for example, apply different methods and techniques used in the design of complex systems to design an RMS, these methods should be studied, analyzed, modified and improved if necessary before to be applied. Modularity is one of these techniques. In this paper, we will discuss how modularity could be used to develop RMS, and we will propose a standard approach based on the Design Structure Matrix to design an RMS with a modular architecture.

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### 1. INTRODUCTION

In the 21st century, manufacturing companies have to face an increasingly, unpredictable and frequent market changes caused by global competition. To remain competitive, companies must develop production systems that not only produce low-cost and high-quality products but also allow for rapid response to market and customer needs changes. The Reconfigurable Manufacturing System or RMS is a new concept or a paradigm that is born from this fact.

Dedicated Manufacturing Systems or DMSs are devoted to produce one specific product at a high rate with a low cost. Manufacturing a new product with the same system is impossible and performing any change in the production volume could not be done in small steps. For each new product or production volume change, a new production line has to be deployed. Thus, DMSs are not flexible enough to cope with the market changes (Koren & Shpitalni, 2010). Flexible manufacturing systems or FMSs can deal with the market variations, but they are not reactive enough. The range of flexibility is defined at the system installation and any modification that is not previously planned could be impossible or very expensive. Also, the products manufactured with FMS are expensive because all the components to support the flexibility are installed till the beginning and the customer has to pay for the over-flexibility. From this brief analysis, we can conclude that both DMSs and FMSs are incapable to satisfy the requirements (quality, cost and reactivity) of nowadays market. Thus, the concept of Reconfigurable Manufacturing System or RMS was introduced. This new concept could allow the production of a

product in a minimum delay and a cost-optimized and with a certain quality

Like any manufacturing system, the RMS could be considered as a complex system. It is designed to be able to adapt to its environment. During its operational life, the system will take different configurations. It will adapt and evolve, this adapting and evolving feature specifically will make it difficult to design and will introduce more complexity to the system. In our work, we aim to develop a global methodology or approach to help to design an RMS. We are looking for different techniques and methods used in the development of complex systems and trying to adapt them to design the RMS. Modularity is one of these techniques. According to Baldwin & Clark (2006), modularity or modularization from an engineering perspective helps to manage complexity. The basic idea underlying modular design is to organize a complex system (a manufacturing system for example) as a set of distinct components that can be developed independently and then plugged together.

The rest of this paper is organized as follows: In section two, we will give a brief introduction about RMSs and their features. In section three, we will introduce modularity, its definition and its benefits. In section four, we will expose the principals of modular design. In section five, we will mention some methods found in the literature on how to design modular systems; these methods could be extended and applied on RMS design. We will show how Design Structure Matrix (DSM) could be used to design a modular manufacturing system. We will conclude this paper by

summarizing the important points that we have mentioned in this paper, and also we will give some perspectives to further research work.

## 2. RECONFIGURABLE MANUFACTURING SYSTEM

In the literature, the RMS has been given many definitions, but most of them use the same keywords like rapid change, low cost, products family, etc. The RMS is designed from the outset to a rapid change in the structure (physical and logical), to quickly adjust the production capacity and functionality around a family of products in response to sudden changes in the market, or to the intrinsic changes of the system. It can be created by incorporating the core process modules which can be rearranged or replaced quickly and reliably. The reconfiguration allows adding, deleting or changing capabilities of a particular process, a control system, or the structure of the machine to adjust production functionality and capacity in response to changing market demands or technologies. This type of system will be open architecture so that it can be improved, updated and reconfigured rather than replaced (Koren, et al., 1999), (Mehrabi, et al., 2000), (Mehrabi, et al., 2002).

RMS has some key features that enable a high level of responsiveness to market needs, these features are: *customization, convertibility, scalability, modularity, Integrability, and diagnosability*. They should be integrated into the system during the earlier phases of the design process to ensure a high degree of reconfigurability (Koren & Shpitalni, 2010).

After noting the importance of RMS, the question that arises is: how to design this type of systems? Several studies have been conducted to give some solutions on how to design an RMS and several issues were addressed, such as how to design a modular and reconfigurable machine? How to choose the architecture of a production system to make its reconfiguration easy? How to group the products in families to design the production system that will support them all? etc. But a general and standard method for designing an RMS as a whole has not developed yet. Recently a general overview of methods and supportive tools to design RMS was conducted and based on that, a generic design method for RMS was proposed in (Anderson, Brunoe, Nielsen, & Rosio, 2016).

In the next sections, we will show how modularity could be used to manage the complexity of the RMS during its entire life cycle; this technique is already used in the design of complex systems.

As mentioned before in this section, modularity is a very important feature that the RMS should have, but how modularity can be achieved or how modular system can be designed? Thus, the goal of this paper is to propose a standard methodology to design a modular system. This methodology can be applied to design modular manufacturing systems including RMS. It is composed of five steps, starting by defining the system's functions and

finishing by identifying its modules. This methodology is based on the DSM (Design Structure Matrix) which is a tool to manage complexity.

## 3. MODULARITY

Modularity has been given many definitions in the literature; most of these definitions differ between them because of the perspective from which we consider modularity.

*From the design perspective:* Modularity in design is a design approach that subdivides a system into smaller parts called modules that can be independently created and then used in different systems. So, modular design is a design which functionality is partitioned into discrete, cohesive, and self-contained units with well-defined interfaces that permit substitution of such units with similar components or products from alternate sources with minimum impact on existing units.

*From the use perspective:* Holttä-Otto & de Weck, (2007) define modularity as using the same module in multiple products enabling a large variety of products while using more standard component types than if the different products did not share common modules. Also, Huang & Kusiak (1998) give the same definition: modularity is used to describe the use of standard units to create product variants. It aims at the identification of independent, standardized or interchangeable units to satisfy a variety of functions.

Other definitions for modularity could be found in the literature, and we can notice that modularity has been applied mostly to design modular products, but a manufacturing system could be considered as a complex product and all the work done on modular products could be easily extended and applied to manufacturing systems.

### 3.1. Advantages of modularity

Modularity presents many benefits which we have judged important in the design of RMS. These advantages are grouped into three families according to their impact perspective: engineering perspective, organization perspective and the economic perspective.

#### Engineering perspective

*Manage the system complexity:* The modularity makes the complex nature of the system manageable by providing an efficient division of different tasks (Baldwin & Clark, 2006), and the system's modules could be designed, produced, tested, verified and validated independently from each other. And these modules can be changed, improved and evolved without impacting the rest of the system. Also, modularity reduces the system's architecture complexity, so the system architecture appears simpler and therefore easier to manage (Holttä-Otto & de Weck, 2007).

*Improve the system reconfigurability:* The modular systems enable operational flexibility. The system's modules can be rapidly and easily configured to meet changing operational requirements, this is a very important feature of modular systems, specifically for manufacturing systems.

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