Customization Measurement in Reconfigurable Manufacturing Systems (RMS)

Jesus Vital Kombaya[a], Nadia Hamani[b] and Lyes Kermad[a]
[a]Department of Industrial Engineering, University of Paris 8, Paris, France
jkombaya-touckia@ etud.univ-paris8.fr, l.kermad@iut.univ-paris8.fr
[b]University Picardie Jules Verne, Saint Quentin, France
nadia.hamani@u-picardie.fr

Abstract

With increasing consumer demand for a greater variety of products in changing and unpredictable quantities. Manufacturing different products tailored to the needs of their clients is a real challenge that industries face today. Today's consumers are looking for products that carry part of their identity and allow them to stand out from the crowd. In this context many indicators have been proposed to evaluate the reactivity and flexibility of a production system; such as customization, scalability and convertibility of the system. Customization is one aspect of flexibility; it expresses a system's ability to produce customized products with customized functionality. This document develops a measure of customization of reconfigurable production systems. These measures do not only impact the production system but also the product design and the process design, which can therefore serve as a guide for the customization of manufactured products. A case study is presented to show the use of the proposed approach.

Keywords
Reconfigurable manufacturing system (RMS), Customization, Measure, Manufacturing flexibility.

1. Introduction
To remain competitive, companies designing complex products need to collaborate in ad hoc networks. The increasingly competitive nature of companies therefore depends on their abilities to react quickly and at the lowest cost to market fluctuations. This ability for change concerns all levels of the company. The reconfiguration of a production system makes it possible to change its production rate and product types with a minimum cost and time. It is achieved by integrating new resources (transport or processing) into the production system but also new partners. This type of organization requires the interconnection of a multitude of information systems which are de facto heterogeneous in terms of both the functions they perform and their designs (models, architectures, etc.). It is difficult to integrate, which creates problems, with regard to the exchange and sharing of product models and associated processes between the digital environments of the different partners. Reconfiguration contributes to extending the life cycle of the production system by modifying its physical, organizational and IT characteristics according to changes in the market.

A lot of work has been done on this theme, which therefore aim to assess the reconfigurability of production systems. Nevertheless, evaluation contributions based on characteristics are very little treated and even less so those that take into account customization to measure reconfigurability. According to (Koren 2007, Wiendahl, ElMaraghy et al. 2007), customization plays a central role in a reconfigurable production system because it adapts to product families and is always ready to be replaced by new product families or product variants. Evaluating the customization of reconfigurable production systems will facilitate the responsiveness of the system and increase its operational performance. The aim of this article is to propose an approach to evaluate the customization of a reconfigurable production system. In a first part, we will explain the existing approaches through a bibliographical study. In a second part, we will propose our mathematical model for the evaluation of customization. Finally, we will evaluate the configurations through an application in order to implement these developments. In this work, we define customization as a characteristic that allows a system to manage the existing variety of products and to adapt its resources to potential product changes. Examples from the industry are presented for illustration purposes.

The remainder of this document is organized as follows. Section 2 presents the state of the art and existing approaches to the measurement of RMS customization which allows us to formulate our contribution. Section 3 is about our contribution. In section 4, the approach is presented through a case study. Finally, section 5 concludes this study with a perspective.

2. Literature Review

In the section, a literature review was prepared. This includes different types of work: quantitative and qualitative. The quantitative work is based on mathematical models, axiomatic models, algorithms and decision support tools in order to be able to measure reconfigurability and its characteristics as well as possible, based on production data as well as the interactions between the subsystems. The authors begin by evaluating the characteristics and then integrate them into models in order to give a measure of reconfigurability. Some work includes decision support models to find the best configuration according to the characteristics. Work of this type is often tested in case studies to validate the results so that they can be used by industry to examine the reconfigurability of their systems and improve it to meet customer needs and remain competitive in the market. However, in spite of their importance and contributions, we still want to improve them in order to get closer to reality and to further perfect models Farid (2014) and Wang et al., (2016). Despite the diversity and richness of these articles, we note the lack of models evaluating customization, a basic characteristic of the reconfigurability of production systems. In our contribution, therefore, we need to consider joining the different types of contributions in order to have a more comprehensive model that evaluates, in an accurate and more realistic way, the customization of SPRs.

In order to measure the customization of the reconfigurability of production systems, we were interested in the mathematical models proposed by Farid, Wang and Wu. We will explain each proposal and give their limits in order to provide a solution. The idea is to propose a measure of the customization of reconfigurable production systems (SPR) according to the different customizations (operation, system and size), this allows us to simplify our calculations and have a customization closer to reality.

In this contribution A.M. Farid evaluated the customization based on production data (processes, workstations ...). This contribution is limited to evaluating the system's ability to make changes in functionality and does not take into account changes in relation to production capacity and batch sizes.

The measure of customization is given by comparing the degrees of freedom of the product (transformation and transfer) with those of the system. This formula reflects the system's utilization rate and the rate at which the system's capabilities match the actual application.

His work is more focused on the notion of degree of freedom of production (DOF). In mechanics the degree of freedom is the basic vector on which the behavior of the whole system is described and evolves. Measurements of the reconfiguration potential called degrees of freedom of production have been specifically used to calculate the production trajectories of a product line through a manufacturing system (RMS).

(Wang et al.,2016) has built a decision support tool for manufacturers to choose the best configuration for their production systems based on reconfigurability. First, the authors assessed the six key characteristics of reconfigurability. Secondly, the team then integrated the measurements of the characteristics for each configuration into the decision-support tool composed of the AHP and PROMETHEE I&II in order to classify the configurations according to the value of reconfigurability obtained at the end of PROMETHEE II.

This work is based on production data in order to evaluate the reconfigurability customization and uses mathematical models. Its measurement of customization takes into account the product and the functionalities. The calculation of this characteristic depends on the types of products, the use of machines and the impact factor of the time needed to produce a family of products.

To an extent Naiqi Wu (2005) offers flexibility in manufacturing systems for mass customization, it has limited itself to the design of a product in terms of time and cost.

Although this contribution offers a method for evaluating customization in order to measure the reconfigurability of the system, the authors have limited their vision of the system to the workstations without taking into account the handling and storage tools.

Naiqi WU (2005) worked on the flexibility of the manufacturing processes for mass customization. His work focused on a chemical manufacturing system that must be flexible to meet customers' demands. He developed a measure of flexibility in manufacturing systems for mass customization. It measures not only the material impact of the manufacturing technology but also the impact of the product design and the design process. Its measure the flexibility in manufacturing systems, describes versatility and efficiency in terms of time and cost savings. Its calculation of

flexibility in manufacturing systems depends on the PDP (point of product differentiation), the number of different products for a given type of product and the efficiency in terms of time and cost.
Yang and Li (2002) set up a system of indicators for assessing the agility of production systems in the context of mass customization. Jiao and Tseng (2004) proposed customization indicators related to product design and production processes. They used a fuzzy method to assess agility. An indicator that measures the flexibility of operations in the context of mass customization has also been proposed by Welborn (2009). In parallel to these initiatives, Blecker et al (2006) established an influence network where they grouped indicators to trace the influence of certain parameters on the value perceived by the customer. Later, Daaboul (2011) set up a method to assess the economic feasibility of mass customization. It attempted to integrate the value criterion into the economic evaluation of a given strategy. Its value chain approach (Daaboul et al., 2010) using discrete event simulation allows the scope of evaluation to be extended by integrating different actors contributing to the production of the good or service.

3. Approach proposed

Before developing the RMS personalization measure, we will analyze the functioning of the personalized products. When customers order a product according to their preferences, the product ordered contains two parts. A so-called standard part, common to other products, and a customizable part.
We introduce the measure of flexibility into our customization measure. Because we define customization as the flexibility of the system or of a machine limited to a product family according to Wang (2016). It is also to produce customized products with customized functionalities (product family, machine utilization rate). Chryssolouris et al. (2013), summarized flexibility in three main forms: Operational flexibility, product flexibility and capacity flexibility. Based on the definitions of Chryssolouris and Koren , we suggest that system customization can be linked to product, operation and PDP flexibility. According to Naiqui Wu et al. (2005), flexibility in RMS allows for time and cost efficiency and measures system performance. The proposed approach is based on the following three parameters:

1. Product flexibility (PF)
2. The flexibility of PDP (FPDP)
3. Capacity flexibility (Y)

Product flexibility allows a production system to manufacture various types of products with the same equipment. It means that the system has the ability to economically use small batch sizes to adapt to changing demand for various products. In the long run, this means that the system's equipment can be used over several product life cycles. This measure is given in the form of the following equation:

$$\mathbf{PF} = \mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{P_m}} \tag{1}$$

- FP : product flexibility
- P_m : The number of customized products a system can produce.

Some systems may have a limited number of product options, while others may produce what customers want for the same type of products. The more products a system can produce, the more flexible it is.
Capacity flexibility allows a production system to vary the production volumes of different products in order to adapt to changes in demand, in volume, while remaining cost-effective. This type of flexibility reflects the ability of the production system to contract or expand easily. Operational flexibility refers to the ability of the system to produce a set of products using different machines, storage tools, operations and sequences of operations. It results from the flexibility of processes and individual machines as well as the flexibility of the structure of the production system itself (Chryssolouris 2005; Baykasoğlu 2009).
Operation customization is the ability to perform different operations on a machine that would lead to the evaluation of machine customization. The personalization is calculated with all the operations of the product. The operations are aimed at determining the extent to which the current product range uses the capabilities of the existing production system and the number of ways in which each product can be manufactured.
This measurement is given in the form of the following equation:

$$\boldsymbol{Y} = \frac{(\boldsymbol{OP_{PT}} + \boldsymbol{OP_{PM}})}{\boldsymbol{OP_{PH}}} \tag{2}$$

- OP_{PT} : The number of operations relating to the transformations of a product family (the transformation functions). It is an instance of a work function or transformation at a workstation (machine). It gives an idea of how production capacities are used.
- OP_{PM} : The number of product operations relating to transport or transfer resources.
- OP_S : The number of system operations.

Flexibility in Product Differentiation Point (PDP) is defined by Naiqui Wu et al., (2005) as a step in the manufacturing process. Before PDP, we have standard manufacturing and after customized manufacturing. The PDP can be determined by a custom component or simply by operations involving customization. It is highly dependent on the product design and the design of the manufacturing process. It is clear that if the PDP in a manufacturing process is closer to the time when the product is sold (or point of sale), this means that it is adaptable to a type of customizable product, as we can respond to the customer's order quickly by carrying out the operations before the PDP in advance before the orders arrive. There is a way to bring the PDP closer to the point of sale, see figure 1, which consists in standardizing the components of the products. In this way, we can use as many standard and common components as possible to produce one type of product.
This is given in the form of the following equation:

$$\text{FPDP} = \frac{\boldsymbol{T}}{\boldsymbol{t}} \tag{3}$$

- t : the total and necessary time to manufacture a personalized product.
- T : the time required to manufacture the product.

Our measure of customization is the product of PDP's flexibility, products and capacity.

$$\boldsymbol{C_m} = \text{FPDP} \times \boldsymbol{PF} \times \boldsymbol{Y} \tag{4}$$

Our measurement considers the PDP, the number of products that can be customized and the functionality, which depends on the types of products, the use of the machines and the flexibility of PDP. The measure of personalization (C_m) should increase (decrease) with the PDP close (far) to the point of sale. In fact, it rises with the increase in the number of personalized products to be produced and a high equipment use rate and vice versa as shown in the figure 1.

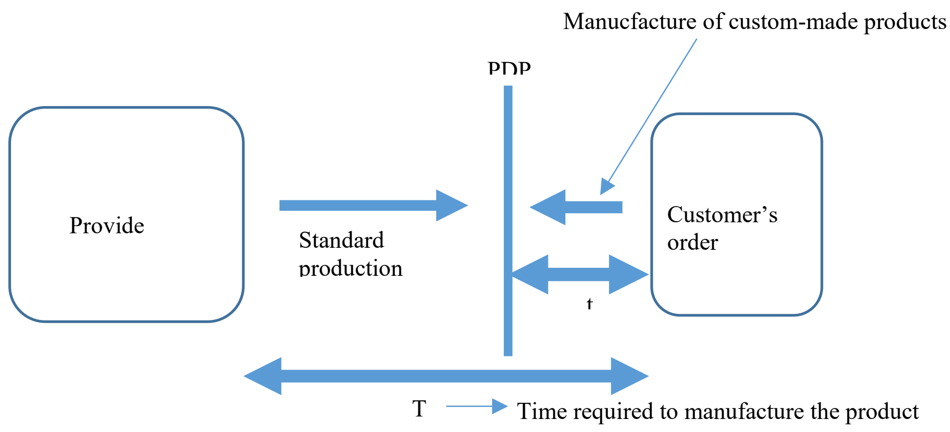

Figure 1. Flexibility in the product differentiation

If PDP's flexibility is high, the system is able to produce customized products quickly, which reflects that the system is able to adapt to changes in the product. On the other hand, according to Wang (2016), a high use of the equipment indicates a great capacity of the RMS to complete the transformation of all types of products of each family; therefore, a great capacity for customization.

4. Case studies and discussion

The DEKENZ company is semi real/semi fictitious company created in 1998 around the flexible production line of the IUT of Montreuil. DEKENZ's activity is based on the design, manufacture and marketing of mid-range pens. It has a major particularity that makes it special. In fact, every year a new team takes over and takes responsibility for the DEKENZ company.
The production system consists of two workshops: The manufacturing workshop which includes:

- Machining machines (milling machines C3000 and C4000 and lathe G2009)
- A storage magazine for MP and PF
- An injection moulding machine
- The assembly and finishing workshop comprising
- Tribofinishing
- The engraver

This company manufactures personalized pens with the following composition:
- Body: metal for Pr1 and plastic for Pr2
- head: metal for Pr1 and plastic for Pr2
- ink chamber
- Spring
- Silicone holder (for Pr2)
- Staple for the product Pr1
- Knob: metal for Pr1 and plastic for Pr2

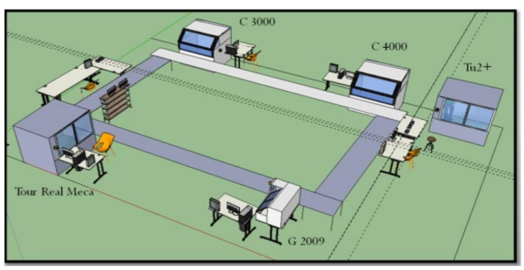

Figure 2. Description of the workshop with the different workstations

On a system consisting of nine machines, as shown in figure 3, we want to personalize pens used for different age groups.

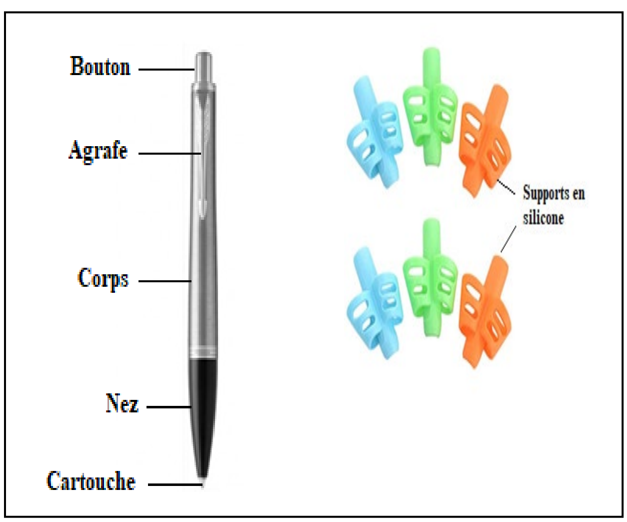

Figure 3. Description of the pen types

The products manufactured by the company are:

- Normal pens for the other age categories: A Pr1 Product Family
- Pens for children: a family of Product B: Pr 2

Each product is manufactured in 2200s and it takes 800 s to have a personalized product.

The Pr1 product follows a specific manufacturing process. Raw materials in the form of aluminum bars are loaded by operator OP1 to be cut into strips. Then they go through two types of machining: the first is turning and the second is milling to obtain the body, head, clip and pusher. Then the clip will be engraved.
All these components pass through the control station to check their measurements, then through the tribofinishing and on to the assembly where the operator adds the ink chamber and the spring.
Finally, a finished product is obtained which undergoes final inspection and will be stored.

The Pr2 product follows a well-defined manufacturing process.

The raw materials, which are polystyrene and silicone, are injected separately into the injection moulding machine to form the polystyrene body, head and pusher and the silicone support. These components will be controlled and then assembled by adding the spring and ink chamber to obtain the Pr2 finished product which will be controlled and stored.

We have put all the data in the table below:

- **Inputs**

FPDP	OPPM	OPPT	OPS	Y	FP
2.75	10	13	42	0.54	0.5

- **Outputs**

$$\boldsymbol{C_m = 0,74} \quad (5)$$

A high Cm value indicates a stronger RMS customization capability. It clearly expresses how the flexibility of the system and its capacity are able to perform different operations on the machines. Flexibility affects the measure of customization, the greater the flexibility, the stronger or greater the customization capacity is. A better way to improve the flexibility of the system is to improve the flexibility of PDP. The more flexible the system is, the more we know about the better customization capability.

5. Conclusion

By integrating process and product information, this document provides a customization indicator for reconfigurable production systems. The customization metrics defined here provide a quantitative assessment of system customization. This measure is particularly useful for quantifying the synergy of the product family, for comparing systems, and for arguing the decision regarding the plant in which a specific variant can be produced. Initial experimental results have shown the effectiveness and usefulness of this indicator to help product and assembly line designers and process planners make the right decisions to ensure optimal customization of their production system.
A case study is presented to show the successful application of the proposed approach. In developing the measurement of customization of reconfigurable production systems, we do not consider other factors of production such as production cost and batch size are not included in the evaluation process. Therefore, in future research, it is necessary to determine the actual production conditions and take into account factors such as production cost and batch size, in order to obtain evaluation results that are closer to reality.

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Biographies

Jesus Kombaya holds a master's degree in industrial computer science from University of Picardie Jules Verne in France and is currently preparing a PhD thesis at the University of Paris 8. His research work focuses on the Reconfiguration of Production Systems (RMS), in particular the design and evaluation of the reconfigurability of the production system.

Nadia Hamani is an Associate Professor at the University of Picardie Jules Verne and Head of a Master and Bachelor Program in Logistics. She is a member of the laboratory of Innovative Technology. She obtained a PhD in Industrial Engineering in 2005 at Ecole Centrale de Lille. She is co-chair of international conferences or special sessions and she authored or co-authored more than 90 scientific papers. She is involved in several research networks, projects and associations. Her research interests include sustainable supply chain and transportation, performance improvement of production and logistics systems.

Lyes Kermad is an Associate Professor at Paris 8 University. He is a member of QUARTZ laboratory. He obtained a PhD in Industrial Engineering in 1996 at University of Technology of Lille. He obtained his accreditation to supervise research in 2017. His current research areas cover manufacturing information systems and quantitative risks evaluation in the reconfiguration projects in industrial companies.