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Identification of reconfigurability enablers and weighting of reconfigurability characteristics based on a case study

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Abstract

Today manufacturing systems face a volatile demand with varying customer needs in terms of both volume and product mix ratio. The highly automated dedicated production lines can not fulfil the demand diversity which needs quick adaptation of the production system. Market fluctuations for the next years are unknown and products have shorter lifecycles. In order to specify precisely needs of factories regarding flexibility, this paper presents a methodology using a qualitative analysis and its application to a use case company. The aim is identification of current needs regarding reconfigurability of production systems and following research directions. To do so, decision makers from various fields and decision levels are identified and interviewed individually using a questionnaire. An Analytic Hierarchy Process (AHP) is also applied to identify weights of the six characteristics of reconfigurability: modularity, integrability, customization, convertibility, scalability and diagnosability; based on the experience of the interviewed decision-makers. Indeed, there is no standardized reconfigurability indicator for the assessment of a production system regarding its changeability capacity. Weighting of these characteristics is the first step before computing numerical values for each characteristic based on a mathematical model proposed in literature.

Keywords: Reconfigurable Manufacturing Systems; Reconfgurable Assembly Systems; Reconfigurability, Flexibility; Qualitative Analysis; AHP

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1. Introduction

Large-scale enterprises are nowadays aware of the need of flexibility and agility of their production lines. Decision makers recognize the importance of reconfigurability in manufacturing and assembly systems depending on the economic context and market demand. However, introducing a new paradigm in a traditional company is complex. Adding reconfigurability on a line may have a long-term return on investment and there is a lack of projects supporting this initiative.

In order to prepare a future implementation of changeability key principles, a study on the existing production paradigm of the company is conducted. The proposed method is based on the simultaneous use of a questionnaire and an AHP analysis.

Following research questions, partially based on the work of [1] guided the procedure:

a) What are the requirements for a reconfigurable production site?
b) What are the current constraints limiting changeability?
c) What are existing enablers for reconfigurability within the company?
d) How to assess reconfigurability based on a multicriteria indicator?

The aim is to support a company in the identification of adequate manufacturing paradigm towards changeability in response to market changes in terms of volume and multiproduct flexibility. This is done based on reference to reconfigurability characteristics defined in previous literature by [2]. These characteristics are used to define the current level of flexibility and reconfigurability within the company, and required changes.

2. State of the art

2.1. Reconfigurable Manufacturing Systems

Reconfigurability in production has been defined as an ability to transform the system thanks to its modular structure, composed of standardized sub-entities. This way, a Reconfigurable Manufacturing System (RMS) enables rapid production change in terms of volume or product type through structure change, as defined by [2]. On the other hand, a Dedicated Manufacturing System (DMS) provides manufacturing or assembly of a single type of manufactured item, in a fixed and predefined volume. Between these two extremes, a Flexible Manufacturing System (FMS) is a fixed system with intrinsic changeable capabilities (technological or software) to adapt to various planned and predefined product variants [3] [4].

Between these three paradigms – DMS, FMS and RMS, the most accurate has to be chosen depending on the company's external and internal factors. External factors are the economical context including customer demand and market share; internal factors are company politics, internal management, structure, implantation of plants network.

2.2. Key Characteristics of Reconfigurability

The concept of reconfigurability within production systems, studied for more than 20 years, is defined by [5], [3] and [6] as a resultant of six characteristics. They consist in enablers influencing several levels and constituents of the production system: machine tool, production cell, material handling, layout, production segment. [2] and [7] classify reconfigurability enablers into two categories: critical characteristics and characteristics allowing rapid reconfiguration. The second category is subordinate as these characteristics do not guarantee modifications in production capacity and functionality, but only have impact on the rapidity of reconfiguration.

Critical enablers are customization, which is the ability to adapt to new needs for similar products; scalability, ability to convert between volume capacities; and convertibility, ability to transform functionality of existing systems. The other characteristics identified in previous works are modularity, characteristic of the system to be divided into functional sub-entities in order to be rearranged; integrability, ability to integrate modules; and diagnosability, capacity to identify quality failures and their root causes [2].

2.3. Qualitative analysis of Reconfigurability within Production Systems

Previous studies proposed a qualitative analysis of reconfigurability within production systems. [8] carried out a survey among more than one hundred Portuguese companies aiming to diagnose perception of reconfigurability based on the definition of the six characteristics cited in last section. This work took the form of a closed-answers questionnaire. The results obtained gave insights in the level of reconfigurability of Portuguese factories today and their interpretation and understanding of the main concepts and enablers. However, the size of the sample did not let the possibility to discuss qualitatively the chosen answers and only a single person answered the questionnaire for each enterprise, which could lead to bias depending on the receptiveness regarding these concepts of the person who took part to the survey.

In their article, [1] proposed a methodology for the design of a manufacturing system based on participation of the company. The study has been conducted on a sample of companies – two Danish industries were presented in the article, and several meetings were needed to identify changeability requirements. The proposed participatory systems design methodology is mainly composed of three steps: specification of changeability requirements, determination of conceptual manufacturing paradigm, and at last manufacturing paradigm embodiment design. For this study, precise questions were submitted to experts and decision makers within the company. Questions were divided into main categories, depending on their relation with either product, production, facility or technology.

However, these approaches do not cover identification of reconfigurability limits and needs through discussion with specialists coming from various fields of a single company, and do not propose an analysis based on metrics to rate the level of reconfigurability of production lines.

3. Methodology

3.1. Reconfigurable Manufacturing Systems Design

Design of Reconfigurable Manufacturing Systems (RMS) has been recently tackled in literature with industrial applications. [7] proposed a methodology divided into the following six stages: management and planning, clarification of design task, basic design, advanced design, implementation and start-up, reconfiguration and start-up. Between each step, this method includes a back loop to the previous step.

The design methodology proposed here consists in four steps. First step is design task definition based on application of a questionnaire during interview of experts. Second step is system modelling; then a tool coupling discrete event simulation and optimization is used in the third step to assess the proposed concept for the RMS. At last, the fourth step is system reconfiguration. This article aims to handle the first stage of the proposed design methodology.

3.2. Qualitative Analysis

In the framework presented in 3.1, the first step is to define the design activity by identifying requirements concerning past, current and potentially future changes of market demand, considering product characteristics. Questions cover product, technology, as well as facility characteristics, targeting specification of needs for the reconfigurable production system. Expected outcome is a research direction to guide the choice of reconfigurability concepts and technical solutions for the production system, in order to feed a modelization of the production line.

The questionnaire partially reuses questions from the questionnaires designed by [8] and [1]. It should be used to open discussion with the interviewed person and to raise awareness on opportunities to develop reconfigurability in the factory, meaning that the discussion provoked by the questions is more important than the initial response.

3.3. Weighting of reconfigurability key characteristics through AHP

In order to assess production systems layout and equipment regarding reconfigurability, there is a need in an indicator of reconfigurability at the production segment/line level. Considering volume flexibility, the range of the covered volume in terms of number of products manufactured per year gives information on capacity of the system to adapt to volume change. It covers the range from V_{min} (minimal number of manufactured products/year) to V_{max} (maximal number of manufactured products/year). In terms of product mix, a metric can be defined as the number N_f of product families covered by the production line and the number N_{vi} of product variants within a family *i*.

Nevertheless, these values are not covering information like the time needed to change from a production system configuration to an other. Also, distinction between product variants and families is subjective depending on the industry and the company. Based on the six reconfigurability characteristics defined by [2], [9] proposes a mathematical model to compute numerical values for each characteristic, depending on the configuration of the considered production system. In a procedure of reconfigurable manufacturing system design, this enables assessment of technical solution proposals for the manufacturing system.

However, at this phase the reconfigurability indicator of the production line is composed of six values. When designing a RMS, the decision-maker needs objective non-biased comparison between numerical indicators. That is why an Analytic Hierarchy Process (AHP) is proposed. The interviewed people have to compare following characteristics two by two: modularity, integrability, customization, convertibility, scalability, diagnosability. For each pair, they are invited to define the most important criterion regarding reconfigurability of the production system and to select the relative importance on a range going from 1 (equal importance) to 9 (extreme importance). The used tool developed in Excel by [10] includes a verification for solution consistency which should be under 10% when using this scale from 1 to 9.

4. Case study

During the case study, eight experts from the studied automotive company have been interviewed. They were selected according to the diversity of their fields of expertise, such that they came from different areas: industrialization, production, logistics, and management, as well as from different plants of the company. The interviews were conducted individually.

4.1. Requirements for the RMS

The conducted interviews highlighted high expectations regarding improvements of the company's production system regarding reconfigurability.

The investigated company produces a high number of variants within each product family. Driven by external factors, the number of variants is increasing; variant mix from week to week is varying stronger, and life-cycle length of each product is decreasing. This implies a need of more reactivity and convertibility of the production system. Moreover, product volume is expected to increase in the next months and years. Some factories of the company produce already at their maximal capacity, employees also working on weekends and on night shift. In consequence, a higher scalability of manufacturing lines is required. This would enable to cover the expected production volume increase or its decrease in case of wrong forecasts. Indeed, experts consider the prognosis of future sales as complex and uncertain.

In the future, the ideal production system for this company according to the auditioned employees would be a system being able to mix different product families on the same line. In addition, as this enterprise will invest a new market to follow the energy change of the market, future products are expected to have important differences regarding size, geometry, and type of manufacturing tasks compared to the current product range.

4.2. Enablers for reconfigurability and limits

After identification of requirements based on past and estimations of future needs, enablers and restrictions embedded in the existing manufacturing or assembly system are debriefed. Outcomes of conducted interviews are summarized in Table 1. Main limitations regarding reconfigurability are linked to system's architecture and layout rigidity, due to the conveying system used to route products between workstations. Enablers are the recent increase of flexibility of the line regarding product variants within a single family, as well as real-time detection of defaults on quality control workstations.

Table 1. Enablers and constraints regarding reconfigurability

Enablers	Restrictions
Production cell: manual workstations enabling easy integration of robot modules (lightweight cobots) **Material transport system**: introduction of flexibility through transport of kits of material on Automated Guided Vehicles through the plant **Assembly line**: batches of 1 for product variants within the same family **Quality**: real-time detection of defaults on some control workstations	**Architecture**: highly automated system with complex and partitioned architecture; aging machine controllers without standard interface **Layout and material transport system**: fixed layout due to the fixed path of conveyors and very compact lines resulting from lean continuous improvement **Assembly line**: one dedicated line for each product family

4.3. Weighting of reconfigurability characteristics

From the eight interviewed experts, only six gave consistent results when comparing key reconfigurability characteristics, which are presented in this section. They work in industrialization, logistics, continuous management, production and one of them is plant manager. The results of the AHP analysis are presented Fig. 1, classified by field of expertise and represents the relative importance of each characteristic in percentage. Depending on their job and on their management level, chosen weights for reconfigurability characteristics differ.

According to the expert working in production, diagnosability, convertibility and integrability have almost the same importance. He outlined the effort to adapt to product features through system element integration, and the importance of quality for the company. From the industrialization point of view, the most importance was given to customization, then to integrability and in third place to convertibility. Indeed, the main challenge of the industrialization is to cover the adjustment of the system regarding product type. They are also aware that it is not possible in the current production system to add production system components without an extended shutdown of the assembly line. The expert from logistics enhanced integrability through the AHP analysis. Logistics faces the interface between warehouse and assembly line, and integrability of all sub-systems of the supply chain is relevant.

Then, both experts from the continuous improvement department from two distinct factories of the use case company considered scalability characteristic as a priority. Their arguments were the current need on their production lines in production volume growth, which is not possible with today's production system. Also, scalability is needed during ramp-up phase and during the end-of-life of the system.

At last, the interviewed plant manager gave priority to diagnosability and to scalability at second place. Among the three enterprise decision levels, the plant manager is at the strategical level. His vision is long-term based, but also customer-oriented, which leads to high expectations in terms of quality in order to keep the market share.

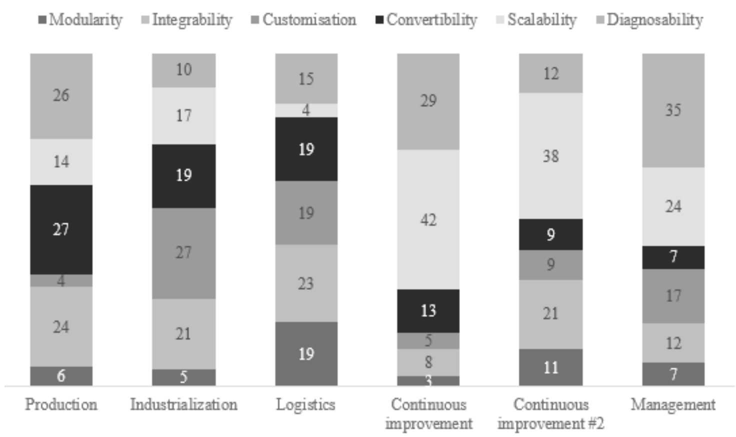

Fig. 1. Weight of reconfigurability characteristics

Modularity was perceived as less important by all participants and none of them considered modularity in their top 3 characteristics. This can be explained by the fact that, as [2] identified it previously, three of the characteristics are critical reconfiguration characteristics: customization, scalability and convertibility; while modularity, integrability and diagnosability are characteristics that allow rapid reconfiguration but are not critical.

This study reveals that depending on the point of view, the perception of relative importance of each characteristic changes. The diversity of responses raises the question of use of the obtained weightings. As the selected use case for the next steps of the study is engine assembly, the selected answer is the one coming from engine industrialization. Other responses are still interesting, but are less relevant regarding the precise use case. It would be interesting to conduct the AHP analysis with other experts from the five chosen fields to verify congruence of weightings between domains in the company.

5. Conclusion

The presented framework enabled to answer questions opened in the introduction for the studied use case. After analysis of the production line taken as example, it seems that the current assembly system is a flexible production system with high throughput, able to produce variants within the same product family if variants have a relatively close structure. Nevertheless, the system is not able yet to respond quickly to volume changes or to the introduction of a new product type. The study highlighted following research directions. The global production system lacks in modularity, and assembly line needs scalability and convertibility, as well as diagnosability.

The next steps of the work include assessment of technical solutions and layout for reconfigurable manufacturing systems based on the mathematical model defined by [9] to compute values for the six reconfigurability characteristics. The weighting of the parameters found during this study will help to propose a decision support tool to assess reconfigurability of production systems.

Besides, a simulation model using Discrete Event Simulation (DES) is developed to assess proposed reconfigurable manufacturing systems layouts regarding performance of the system: lead time, number of manufactured products, and resource utilization.

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