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Convertibility Indicator For Manual Mixed-Model Assembly Lines

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Abstract

Manufacturing different products tailored to the needs of their clients is a real challenge that industries face today. Current consumers are looking for products that carry a part of their own identities and allow them to stand apart from the crowd. To meet the requirements of the current market, industries have to adapt their resources to manage the wide variety that affects their entire production system in terms of processes, products or volumes. In this context, many indicators were proposed to evaluate the responsiveness and the flexibility of a production system such as capacity scalability and convertibility metrics. The aim of this paper is to propose a system convertibility indicator for manual mixed-model assembly lines. Convertibility is one of the flexibility aspects, it expresses the ability of a system to change the functionality or move from one product to another. The contribution of this research is to provide new metrics for quantifying system convertibility by integrating product and process information. Experimental results from the automotive industry are presented.

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1. Introduction

In recent years, in order to respond to the increasing customer needs, accelerated lead-times, tight delivery times, and shorter products' life cycles, companies have widely increased their product variety. As defined by ElMaraghy et al. [1], "variety is a number or collection of different things of a particular class of the same general kind". Variety becomes a necessity for companies to stay competitive in such unpredictable and versatile market. Agard and Tollenaere [2] distinguish between three levels of product variety: *(1) Functional variety* that comes from all the needs to be met to gain market share competition; it is linked to the diversity offered to commercial customers; it's the most apparent part to the client. Then, *(2) Technical variety* which is the translation of functional variety on the technical side. And finally, *(3) Process variety* which concerns all the processes required achieving the technical variety. Nowadays, the industries are continuously trying to figure out better ways to reduce the technical and process variety, and keep a large functional variety because of its appreciable added value for the customers.

Changeable manufacturing systems, as reported in [3], help to produce wider product variety. In this research, we focus on changeable assembly systems, which are those that can rapidly change their capacity and functionality to adapt to market demand. We can distinguish between three types of assembly lines: *(1) Single model Assembly line* which is a multi-stage line where a unique product is manufactured in a continuous way in large quantities. This kind of line was developed for mass production. Then, *(2) Multi-model assembly line* where the manufacturing of various products is performed in separate batches for every product type. And *(3) Mixed-model Assembly line,* defined as a line where different products are manufactured in the same assembly line. In this case, we are talking about a product family with several variants. The

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processes are quite similar, because the variants are slightly different. In this research paper, we present a convertibility indicator that evaluates the introduction of a product variety in mixed-model assembly lines.

To deal with this subject, we firstly, present and discuss some existing measures of manufacturing system convertibility. These measures are confronted to an automotive industry case. A model adaptation is, consequently, proposed due to the specificities of mixed-model assembly lines. Then, to cover all the aspects that impact the manufacturing system convertibility, we consider that not only information about the configuration system, material handling and machines should figure in the convertibility measure of a production system, but also information about the product itself. Thus, we propose a novel approach to measure product convertibility. In this research work, we define product convertibility as a characteristic that enables a system to manage existing product variety and to adapt its resources to potential product changes. Illustrative examples from the automotive industry are presented.

2. Problem statement

2.1. State of the art

System performance is assessed in many areas such as quality, cost, delivery and flexibility. For manufacturing plants, Koren [4] defines three goals to stay competitive: produce at low cost, enhance product quality, and respond to change rapidly and effectively. Changeability, as described by ElMaraghy [3], "is an umbrella framework that encompasses many paradigms such as adaptability, modifiability, flexibility and reconfigurability, which are themselves enablers of product variety management". Flexibility includes both scalability and convertibility [4]. In [5], Chryssolouris summarized the flexibility in three main forms: Operation flexibility, Product flexibility and Capacity flexibility. Based on Chryssolouris and Koren definitions, we propose that system convertibility can be related to product and operation flexibility and system scalability linked to capacity flexibility, as shown in fig 1:

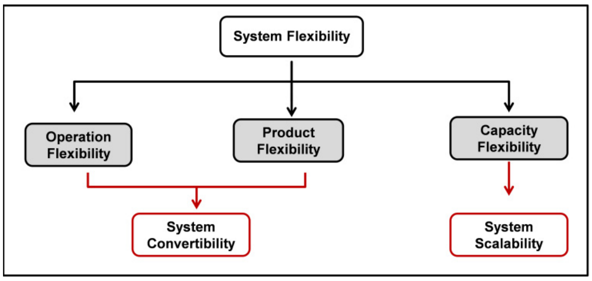

Fig. 1 Flexibility main forms

The convertibility is one of the six Reconfigurable Manufacturing System (RMS) characteristics; it expresses the ability to change the system functionality to produce different types of products. Several metrics and principles for the assessment of manufacturing system performance, including flexibility and reconfigurability, were proposed in [5, 6, 7, 8]. But more accurate convertibility metrics covering additional variety aspects are needed, especially when product and process information are available.

Multi-stage manufacturing systems are made up of many machines or assembly stations that are bound by material and information flow. Based on the manufacturing system definition, Maeir and Koren [9] presented a model for an overall intrinsic assessment of system convertibility in one equation as follow:

$$C_S = w_1\, C_C + w_2 C_M \; + \; w_3 C_H \tag{1}$$

Where C_C, C_M, C_H are convertibility metrics associated with the Configuration, Machine, and material Handling, respectively. The weightings, w_i, represent the relative importance of each term in the equation.

This metric enable the manufacturing industries to evaluate their manufacturing system convertibility based on information about the machines, their arrangements and the material handling devices. Consequently, in the early design phases, it enables the manufacturing system designers to justify higher capital investment due to higher convertibility. But for more accuracy, we propose to complete this measure by including product and process information.

2.2. Motivation and study framework

To meet the market changing requirements, manufacturing industries produce in the same assembly line a huge number of product variants. Consequently, to integrate all this variety, the assembly line facilities should integrate a great number of functionalities to process the existing products and the potential new arrivals. However, under time and budget constraints, it's very difficult to manage product variety while maintaining high system performance.

The aim of this paper is to build an indicator to quantify and evaluate mixed model assembly line convertibility. As part of Design For Manufacture and Assembly (DFMA) practices, this indicator will, firstly, be useful for the product designer who needs to integrate the existing process line information to reduce the product technical variety and facilitate the introduction of new product variants with minor modifications in the line. Meanwhile, product information will help to design the different interfaces between the product and the process in a way to easily support the different components of the variants. Sharing technical information between the product and assembly line designers minimize the consequences of the introduction of a new product by integrating adaptable interfaces, either in the product or in the assembly line, in an optimal way.

Furthermore, to reach a higher convertibility, the process planner should coordinate with the designer to make production sequences that allow an optimal utilization of the existing resources and integrate potential changes by the introduction of a new variant. Collaboration between these actors is a key to build real cost-effective and responsive production lines.

The motivation of this research lies in providing indicators that allow the company to manage successfully the hidden side of product variety (technical and process variety) and satisfy its customers by offering the required functional variety. Based on Maeir and Koren model developed in [10],