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The pursuit of responsiveness in production environments: From flexibility to reconfigurability ☆

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ABSTRACT

Many production plants are pursuing responsiveness (i.e., timely purposeful change guided by external demands) as one of their main performance priorities and are looking for ways for their responsiveness to be improved. One of the ways that they are currently trying to do this is through the flexibility provided by production practices. On the other hand, other systems are also being now developed based on reconfigurability (such as reconfigurable manufacturing systems (RMSs)) which can enhance a company's technological ability to respond to market requirements by reconfiguring its products and processes. This paper analyses how current production programmes can be a prior step to achieving reconfigurability. The analysis uses a holistic framework that considers a number of linkages or combinations of practices (technology, JIT, TQ, HR, TPM and production strategy) and how these enhance performance in terms of cost, quality and responsiveness. The framework is tested with data collected from a survey of 314 plants worldwide using a series of canonical correlation analyses. The results confirm not only the importance of practice linkages that do not only include technology as the launch pad for reconfigurability, but also that in their pursuit of responsiveness it is vital for plants to implement practices in the technology programme as well as to link them to organisational programmes. The framework presents a contribution to both theory and practice. It offers novel insights into the programme and production practices involved in transitioning from flexibility to reconfigurability in the pursuit of responsiveness and provide a basis for future research.

1. Introduction

There is a growing global trend in production to use production practices that are geared towards greater flexibility (da Silveira, 2014; Laurent Lim et al., 2014; Purvis et al., 2014; Roh et al., 2014; Agarwal et al., 2013; Fang et al., 2013; Liao et al., 2013). To a certain extent this trend is driven by the hypothesis that their use will result in improvements in competitiveness in certain performance measures, such as greater responsiveness. This is not a new trend (Slack, 1987; Upton, 1994), but the demands are growing as the markets become more competitive. The research reported in this paper examines how current production environments geared towards flexibility may be used as a basis for transitioning towards reconfigurable production systems. We start by considering some definitional issues.

Responsiveness may be seen as an outcome of, or related to both *flexibility* (Kalchschmidt et al., 2009) and *reconfigurability* (Koren, 2006). However, these three terms are sometimes used interchangeably, even though they do not necessarily represent the very same concept. This results in a certain amount of ambiguity and confusion in their use, not only on the practical level, but even in the literature (Reichhart and Holweg, 2007). The fuzziness surrounding the differences and similarities between these terms may lead to conclusions that do not enable theory building or

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support it. To avoid this, this introduction will clarify the way that these terms will be used in this paper based on a range of publications that have addressed the topic.

Flexibility is a concept that has been widely discussed in the literature according to different approaches and considering the various dimensions. De Toni and Tonchia (1998) presented a very enlightening classification of the previous literature based on six different criteria. In the work reported in our paper, *flexibility* is considered as an operational feature, a property inherent in the production system itself, which can be defined as the "ability of a system to change status within an existing configuration of pre-established parameters" (Bernardes and Hanna, 2009). Although this ability should respond to both internal and external environmental uncertainty (De Toni and Tonchia, 1998), affecting the value produced, it is seen to be wanting with regard to external changes, especially those that have not been anticipated. Flexibility for internal change can be both short term (i.e., the required operational process consisting of the flexibilities of machines, product, material handling, routing, and volume) and medium term (i.e., in the tactical process, such as operations, material and programme flexibilities). To support external changes, manufacturing systems should be contextualised for the long term in order to achieve competitive flexibility regarding strategic aspects, in terms of production, expansion, and market (Awwad et al., 2013; He et al., 2012; Hopp and Spearman, 2008; Reichhart and Holweg, 2007). However, as will be explained below, the systems currently used to achieve flexibility, one of the most advanced of which is Flexible Manufacturing Systems (FMSs), do not achieve this goal.

Reconfigurability is also a property of the production system and can be defined as the ability of manufacturing systems to respond quickly to market changes (both expected and unexpected) through efficient, effective, fast configurations optimally fit for various purposes (Eldardiry et al., 2011; Musharavati, 2010; Ismail et al., 2008; Koren, 2006). Some similarities could be found between this concept and the concept of agility by different authors. For instance, Bernardes and Hanna (2009) define agility as the ability of the system to rapidly reconfigure (with a new parameter set). Swafford et al. (2008) consider agility as a measure of reaction time, while flexibility is a measure of reaction capabilities, and consequently, flexibility is antecedent of agility. In this paper, reconfigurability includes also some reaction capabilities and therefore surpasses flexibility, as it enables the rapid reconfiguration of a system with a new set of parameters.

Finally, *responsiveness* is regarded here as a performance capability at the business level and refers to the behaviour or result of the system with respect to tasks being performed in a timely fashion (Gläßer et al., 2009). Much of the literature regarding responsiveness come from time-based competition, but there are also from other management areas, such as business process reengineering, flexible manufacturing, agile manufacturing and mass customization (Kritchanchai and MacCarthy, 1999). It can be defined as the "propensity for purposeful and timely behaviour change in the presence of modulating stimuli" (Bernardes and Hanna, 2009). Although responsiveness may require functions of several abilities within plants (Swafford et al., 2008), this paper centres on the technological aspects from Koren (2006)'s proposal of involving existing systems being able to launch new products rapidly and to react quickly, efficiently and effectively to changes (e.g., in markets/customers, regulations, failures, etc.). Market changes might occur in product specifications, mix, volume and delivery (Reichhart and Holweg, 2007). Other changes can come from regulations on safety and the environment, for example, or from machine failures, and keeping production running despite these. Accordingly, responsiveness can be achieved through both flexibility and reconfigurability.

Slack (1987) states that three types of manufacturing resources can be used to achieve flexibility: flexible technology, flexible manpower and flexible infrastructure. Major progress has been made in technology, with *flexible manufacturing systems* (FMSs) being conspicuous. FMSs include software to handle changes in work orders, production schedules, programmes, and tooling for several families of parts, enabling them to be manufactured in the same system with shorter changeover times. However, investments in current supposedly flexible systems, such as FMSs, do not yield the desired results. Empirical studies show, on the one hand, that FMSs are not living up to their full potential, and, on the other, that some manufacturers may even have purchased FMSs with excess capacity and features (Mehrabi et al., 2002). Paradoxically, the main disadvantage of FMSs is the fact that they have shortcomings when it comes to achieving long term flexibility. While a vital ability for responsiveness is "long-term" flexibility, FMSs have limited capabilities in terms of upgrades, add-ons, customisation and changes in production capacity, and thus only provide "short-term" flexibility (Fitzgerald et al., 2009). Thus, the flexibility that FMSs provide may not sustain or increase the value produced when and if it has to respond to the risks and opportunities that arise out of uncertainty.

One ofthe Hopp and Spearman (2008) factory physics laws states that "increasing variability always degrades the performance of a production system" and they observe that flexibility is a way of combating this by reducing the amount of variability buffering required. However, Ashby's (1958) Law of Requisite Variety states that, for a system to be stable, the number of control mechanism states must be greater than, or equal to, the number of states in the system being controlled. Given the previous limitations, FMSs could be said to not satisfy requirements in terms of this law, making it necessary to move on to systems that are able to handle a greater number of possible states. Thus, despite still not being readily available, *Reconfigurable Manufacturing Systems* (RMSs) could be the answer.

RMSs are technological capabilities that provide exactly the functionality and capacity needed, exactly when needed (Bader et al., 2014). This is achieved by equipment being specifically designed to be reconfigurable. As a result, manufacturers can achieve reconfigurability through technology and so increase the responsiveness of their production systems, which will thus be able to play a critical role in the success of their plants in the face of the new challenges of global competitiveness. RMSs incorporate basic hardware and software process modules that can be rearranged or replaced quickly and reliably (He et al., 2013a).

Unlike current FMSs, the RMSs of the future will enable the lead time for bringing new systems into operation or reconfiguring existing systems to be shortened by the rapid modification and integration of new technology and/or new functions. In fact, RMSs and FMSs are different because they have different goals. FMSs are geared towards product variety, while RMSs are designed for speedy responsiveness to markets. FMSs offer general flexibility, while RMSs offer a more restricted flexibility that focuses on customisation. Another difference is that FMSs are generally designed to produce small batches of products, while RMSs can be adapted to small or large production volumes. Thus, the pursuit of greater responsiveness and the technological advantages of reconfigurability over flexibility would make production managers look for something more than just flexibility and may be the reason for the change from current systems, such as FMS, to future systems, such as RMS. As FMS environments were not originally designed to incorporate basic hardware and software process modules that can be rearranged or replaced quickly and reliably, the responsiveness they can offer with the functionality and capacity exactly when needed, is rather limited. RMSs, meanwhile, are responsive production systems with a capacity that can be adjusted according to changes in market demand, and functionality adaptable to new products (Koren, 2006).