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 provides a basis for future research.

Keywords: Flexibility, responsiveness, production programme, reconfigurability, reconfigurable manufacturing system (RMS).

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.

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 & Holweg, 2007). The fuzziness surrounding the differences and similarities between these terms may lead to conclusions that do not enable theory building or 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 & Tonchia (1998) conducted a very enlightening classification of the previous literature based on six different criteria. In this 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 & Hanna, 2009). Although this ability should respond to both internal and external environmental uncertainty (De Toni & 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 (Anwar et al., 2013; He et al., 2012; Hopp & Spearman, 2008; Reichhart & 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 (Koren, 2006). Some similarities could be found between this concept and the concept of agility by different authors. For instance, Bernardes & 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 & MacCarthy, 1999). It can be defined as the "propensity for purposeful and timely behaviour change in the presence of modulating stimuli" (Bernardes & 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 & 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 of the Hopp & Sperman (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 and those of other current practices that support flexibility were not originally designed to incorporate basic hardware and software process modules that can be rearranged or replaced quickly and reliably, the responsiveness, with exactly the functionality and capacity needed, exactly when needed, they can offer 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).

In the literature, the search for reconfigurable manufacturing goes back as far as the 1990s with Liles and Huff (1990). The idea of agile manufacturing was formulated in 1991 by the Iacocca Institute to enable short changeover times between the manufacture of different products (Nagel & Dove, 1991). One of the agile production system trends in flexibility since then has been towards reconfigurability (e.g., Sheridan, 1993). In 1995, Yoram Koren formally originated the term ‘RMS’ when he opened an Engineering Research Centre (ERC) to conduct research into systems capable of allowing quick changes to be made to their structures and their components (both hardware and software) and rapid adjustments to be made to their production capacity and functionality to respond to sudden changes in a part family (Koren et al., 1999). The RMS paradigm was formally recognised when U.S. patents were granted for the following: 1) reconfigurable machine tool, filed in 1997 and issued in 1999 (Koren & Kota, 1999); and, 2) reconfigurable manufacturing system, filed in 1998 and issued in 2002 (Koren & Ulsoy, 2002).

However, to date no empirical models for reconfigurable practices (i.e., production practices that are an intrinsic part of production systems designed for reconfigurability, such as RMS) have been proposed and tested in the production literature, since RMS is still at different stages of full-scale fully-working prototypes, with very few models implemented in plants as "user experience prototypes" used to support research focusing on a range of issues (e.g., Battaïa & Dolgui, 2012; Niroomand et al., 2012). All reconfigurability research seems to be characterised by having a limited focus, particularly with regard to it being conceived mostly as a physical competitive resource (Abdi, 2009). At the same time, extant reconfigurability research does not pay enough attention to the multidimensional nature of competitiveness, and focuses on RMS' main characteristic, responsiveness, while omitting other dimensions, such as quality and cost. In addition, studies pay little or no attention to current production practice linkages that should be considered in the selection and adoption of reconfigurable practices.

On the other hand, many researchers have proposed and tested models for production practices currently implemented for greater flexibility, but they are still isolated representations rather than cumulative studies that systematically build upon each other for reconfigurable practice deployment (Rehman & Babu, 2013; Niroomand et al., 2012). This study's empirical testing of flexibility-related production practices is a first, but nonetheless important step in the process of developing a theory for near-future reconfigurable practice deployment. Even if reconfigurable practices are not yet readily available, there must be some signs that show that plants are seeking responsiveness in their performance dimensions, especially in current production environments where flexibility exists. Here, it is important to remember that flexibility is a feature of a plant-environment relationship and not a feature of the plant itself, i.e., the measurement of its implementation is contingent to a plant's environment (contingency theory contends that each company is unique and individual) (Jain et al., 2013). In the context where a plant operates, the internal environment (i.e., within the boundaries of the plant (e.g., machines, performance teams, resources, workplace, etc.)) plays an important role (Jin et al., 2014).

Hence, this research considers internal environments that are geared towards flexibility, that comprise production programmes and their practices implemented internally in plants[1] which go beyond technology, as they include not only practices that are technological in nature, but also organisational-managerial practices (Mishra, 2014; Anand, 2004; Schroeder and Flynn, 2001). It addresses the research question of *how current internal production environments geared towards flexibility* may be used as a basis for the transition *to future environments for reconfigurability.* Thus, the objectives of this paper are two-fold: a) to empirically show which production programmes, practices and linkages in currently implemented programmes in flexible environments should be considered to support the future adoption of practices aimed at reconfigurability; and b) to test whether plants worldwide are currently interrelating production practices and programmes in order to achieve responsiveness as part of their competitiveness, and if so, how they are doing this.

The literature background and framework definition are presented in the following section. In Part 3, the research methodology is presented, explaining the research variables, the data collection method and the statistical analysis tools used. Section 4 presents the results of the analysis and Section 5 discusses the findings and highlights their implications. In the last section (6), the conclusions are provided and some directions for future research are identified.

2. Literature background and framework definition

The specialised literature suggests that global economic competition and rapid social and technological changes may force industries in general to target production responsiveness (e.g., Uskonen & Tenhiälä, 2012; Ortega & Eguía, 2010). Therefore, it is important to know what plants around the world are now doing to meet the requirements of responsiveness (i.e., the main characteristic offered by RMS) with the production practices that are available to them (Rehman & Babu, 2013).

The pursuit of better performance and competitive advantage force production plants not just to acquire the latest equipment, but also to develop resources and capabilities that cannot be easily duplicated, and for which ready substitutes are not available (Flynn & Flynn, 1994). However, even if all industries were to experience ever-changing environments, it is very unlikely that all plants would be forced to reassess their production programmes (especially in the short term) to allow a new technology system, such as RMS, to

[1] A programme is made up of the practices being implemented.

be designed and operated efficiently. It would simply not be feasible for all plants to abandon many of their production programmes in order to adopt RMS. Reconfigurable technology cannot be an end in itself, since it has to be linked to other practices and areas of a plant on the path towards high performance.

Internal production environments geared towards flexibility, in which plants are able to simultaneously obtain a low per unit cost and a high degree of flexibility (Rahman & Mo, 2012), can be considered the starting point for the current platform for reconfigurability (Barad, 2013; Fitzgerald et al., 2009; Mehrabi et al., 2002). These plants use advanced integrated hardware and software systems that enable a predefined variety of products to be automatically designed and produced. As seen here and in Section 3, there are various other practices within these contexts of flexibility apart from FMS. Since practices designed to allow reconfigurability are considered the next step on from practices designed to allow flexibility, they must also be framed where the latter are currently implemented.

The foundations of internal flexible production environments include components from all three areas of the technology programme (Fang et al., 2013; Ortega, 2009; Schroeder and Flynn, 2001):

1. *Process/production technology*, i.e., the equipment and processes for making products.
2. *Product technology*, i.e., the equipment and processes for designing and building new products.
3. *Information technology*, i.e., the processes and equipment for processing information.

In addition, the success of any technological system is influenced by a plant's production programmes, including JIT, TQ, etc., and the effectiveness, (i.e., competitiveness) of all production programmes is closely interrelated with technology in both directions. That is, technology and other production programmes together affect performance. This is why a possible missing link between technology and other programmes implemented in a plant may be a cause of failure (Khanchanapong et al., 2014; Ortega et al., 2012; Schroeder & Flynn, 2001).

There are two main aspects behind this integrating view that need to be further developed: 1) competitiveness in current flexible environments, especially the search for responsiveness; and 2) technology and other production programmes as an environment for flexibility. Each of the background components and the propositions are developed in the following.

2.1. Competitiveness: responsiveness from flexible environments

Establishing links between an initiative and a performance outcome is, perhaps, the most critical and interesting aspect of a study of production practices, particularly in situations where plants need to perform well on a multidimensional level. However, most of the existing literature often ignores the role of manufacturing goals and uses a one-dimensional performance measure in models and empirical tests. On the other end, for instance, Kritchanchai & MacCarthy (1999) included both strategic and operational viewpoints on their framework of responsiveness; and later, Ketokivi & Schroeder (2004) argue that both the multidimensionality of performance and the strategic goals must be included in analysis of competitiveness.

Following the above, in order to examine the relationship between production programmes and performance, this study focuses not only on the two competitive performance priorities in production that the literature (e.g., Koren et al, 1999) claims that RMS will provide, cost and responsiveness, but also on quality, since all three are closely linked to plant production. However, the main competitive contribution that RMS will make in the future is responsiveness and this is why a specific scale (dimension) has been devised for its measurement.

The most common measures of performance are five basic competitive dimensions of manufacturing performance (cost, quality, delivery/dependability, time/speed and flexibility). This paper accepts that responsiveness supports quality, improves cost performance and can subsume speed, dependability and mix and volume adjustability, thus assuming the last three performance dimensions as the integrated components of the priority of responsiveness (this is an adaptation of Kritchanchai & MacCarthy, 1998). Several authors (Roh et al., 2013; Demeter, 2013; Bernardes & Hanna, 2009; Reichhart & Holweg, 2007) agree that responsiveness covers speed, dependability and adjustability, and addresses how they should be used and managed purposefully. The five dimensions (cost, quality and the three responsiveness dimensions) are briefly summarised in Table 1. This table also shows some internal and external indicators (listed as indices) associated with each dimension.

Table 1. Performance dimensions

Priorities and their *dimensions*	**Internal index**	**External index**
1. Cost, C	High total productivity	Low price
2. Quality, Q	Error-free process	Product specification
3.Responsiveness, R	Ability to respond	Desired result
Speed/Time	*fast throughput*	*short delivery lead time*
Dependability	*reliable production*	*dependable, fast delivery*
Adjustability	*ability to change*	*frequent new products, wide product range with adjustable volume*

In line with contingency theory, the level of responsiveness that every firm needs is different and depends on firms' individual business strategies (Roh et al., 2013; Uskonen & Tenhiälä, 2012). Hence, the basis for competitiveness must be designed individually according to the company's own particular circumstances. In accordance with this, the company selects and modifies the production practices (that lead to overall high performance) in keeping with its internal and external environments, which may vary according to country, industry, company size or other contingencies. Depending on the sector and the market, it is also true that this competitive capacity, responsiveness, might be an order-winner for some companies, whilst for others it might act as an order qualifier (Hill & Hill, 2012).

2.2. Internal environments for flexibility: production programmes

As indicated in the Introduction, this paper considers configurations of production programmes and their practices as the basis for internal environments (He et al., 2013b; Huang et al, 2013; Ketokivi & Schroeder, 2004). On the basis of the above (Section 2 and Introduction), the next two reasons will be used as the explanation for choosing the specific programmes and practices to be examined as internal flexible environments:

1. Production programmes (technology and organisational) and some of their practices recognised as important for flexibility.
2. Technology programme and some of their practices, which have been theoretically or empirically associated with one or more specific dimensions of production performance (responsiveness, cost and quality).

To select the programmes and practices, a three-stage literature review was conducted of several prominent journals to find research on flexibility- and production programme- (and their practices) performance relationships over the last four decades. The aim of the first stage was to identify flexibility-related production programmes. We found at least 29 empirical models on flexibility deployment around production programmes, providing a reasonable representation of the theoretical and empirical research for current flexible environments (see Appendix A). This production literature agrees that production strategy (PS), just-in-time (JIT), production technology (T), total quality (TQ), human resources (HR) and total productive maintenance (TPM) are production programmes that are well-established conceptually, theoretically, and empirically. All six are recognised production programmes with sets of several practices, and the successful implementation of these programmes is found to improve multidimensional production performance and help plants gain a competitive edge with respect to flexibility.

The second stage of the literature review sought to identify the specific dimensions or practices related to the technology programme (Appendix B) and showed models of proposed practices in the three areas of technology (process, product and information) presented in this section. Nine practices in this programme (in its three areas) were identified that may lead to improvements in several performance dimensions. The literature background includes three technological practices (closely related to flexibility), flexible automation[1], group technology, and proprietary equipment, which are particularly important because future reconfigurable practices may be contained in these. These previous results show that there is room for improvement when transitioning from flexibility to reconfigurability.

The third stage of the literature review (Appendix C) focused on the five remaining production programmes selected in the first stage: JIT, TQ, TPM, PS and HR. The review was conducted in order to identify the main dimensions or practices used to measure the implementation of each of these broad production programmes.

Thus, the review of all these models from Appendices revealed three levels of analysis for flexible environments: 1) the most restrictive, which would comprise the technological practices most closely related to flexibility; 2) a broadened level that combines these practices with other practices also belonging to the technology programme, but technological-organisational in nature; and 3) the broadest, which adds the other production programmes identified (JIT, TQ, TPM, PS and HR) that could impact on flexibility to the technology programme.

[1] Information technology (IT) included here.

2.3. Research framework and propositions

Combining the elements from the previous two sub-sections, this paper proposes a simple theoretical model with two different major blocks of focus adoption to assess the current flexible production environment as a platform for adopting the technological ability to make the progression to reconfigurability (Figure 1). The first block is devoted to the Technology programme, whose three areas (i.e., product, process and information), with their flexibility-linked practices, are organised into two sub-blocks with different focuses (a technological practices sub-block, and a mixed technological and organisational sub-block). The second block is devoted to other production programmes that are more organisational and that might also contribute to responsiveness (Reiner, 2009).

The *technological practices sub-block* has structural features and investments more closely related to equipment in the technology programme (e.g., proprietary equipment, group technology, cellular manufacturing, FMS and future RMS). The *technological-organisational mixed practices sub-block* includes technological practices that intrinsically require organisational methods, because investments in technology and specific hardware and software systems may not only require changes on their own level, but also organisational-managerial modifications. The *organisational programmes block* includes programmes that are primarily of a managerial/infrastructural type (e.g., TQ, HR, JIT, HR, and PS - see Section 2.2). It can never be repeated too often that technological practices are not a standalone initiative but an intrinsic part of the technology programme (including mixed practices), and currently comprise flexibility-related practices, considered as the prior step and the platform for reconfigurability. These blocks show that plants should also consider organisational programmes in the future implementation of reconfigurable practices when aiming to achieve multidimensional performance. HR provides an infrastructure on which plants establish production systems and formulate PS. JIT, TQ and TPM consist of core production systems concerning production planning, quality, and maintenance. All these blocks are combined to determine competitiveness, through cost, quality and responsiveness (i.e., the key feature offered by reconfigurability) as production performance priorities for manufacturing plants (Table 1 above).

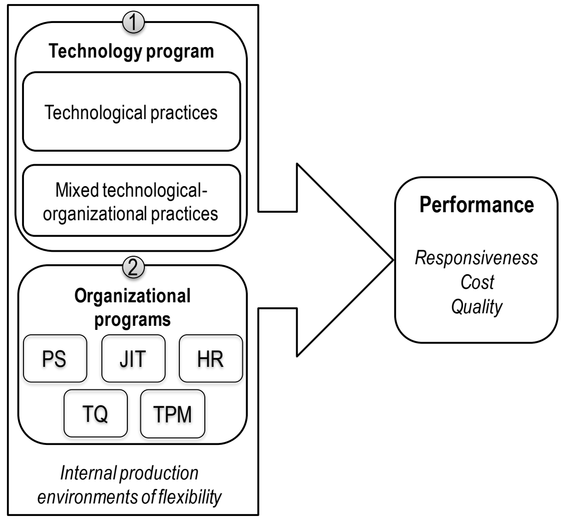

Figure 1 – Flexibility framework: current linkage platform for reconfigurability

Focusing on the technology programme, it is important to stress that the literature analysed in this Section asserts that in order to provide a better programme implementation outcome: 1) technological practices must also be internally interconnected with other practices in the technology programme, such as the technological-organisational mixed practices; 2) technology must have linkages to JIT, TQ, HR, TPM and PS; and 3) the highest holistic integration should show signs of the strongest relationships with performance (i.e. more competitive results), especially with responsiveness, in our case (see Table 1), as the key to transitioning from flexibility to reconfigurability. This is why this research analyses the interrelationships between production programmes and their practices within flexibility that may help the transition to reconfigurability via the search for responsiveness.

Therefore, the propositions of this research will be based on the idea that any new reconfigurable practice will be more successful if it is carefully linked to all the practices in the blocks mentioned in Figure 1 that plants have already implemented (i.e., having more holistic linkages achieves better results). Hence, this assertion is critical if the goal of this paper is to develop an understanding of how to progress from current flexible environments to future reconfigurable environments.

Accordingly, the first proposition aims to establish that technological practices, such as FMS and RMS, should not be implemented in isolation, but should be interconnected to other practices in plants. Meanwhile, the second proposition seeks to state that technological practices are expected to improve performance priorities, but the combination of both technological and mixed practices further improves performance, and when combined with organisational programmes the results are even better. Moreover, the search for responsiveness in current flexible environments is expected to provide some kind of evidence that there is scope for reconfigurable environments, such as RMSs, to fulfil their promise of higher degrees of responsiveness. The following propositions are therefore put forward:

P1. Practices in the technology programme are interconnected with other production programmes and linkages are stronger when a more holistic view is taken

P1a. Technological practices are interconnected with technological-organisational mixed practices.

P1b. Technological practices are interconnected with JIT, PS, HR, TPM and TQ programmes.

P1c. The interrelationships between technology, and JIT, PS, HR, TPM and TQ programmes are stronger when technological and technological-organisational mixed practices are considered jointly.

P2. Practices in the technology programme linked with organisational programmes improve multidimensional production performance (responsiveness, cost and quality) and the most systemic view achieves better results.

P2a. Technological practices improve production performance.

P2b. The combination of both technological and technological-organisational mixed practices gives better results for production performance than technological practices alone.

P2c. All practices in the technology programme combined with JIT, TPM, HR, TQ and PS programmes provide better results than the practices in the technology programme on their own.

Since the key transition element from flexibility to reconfigurability is the current search for responsiveness as a performance dimension, the following sub-proposal is made:

P2d.In the three flexible environments above, plants concentrated more on responsiveness than on any other performance dimension.

3. Research methodology

The above research is proof of a renewed interest in the study of production programmes of this type, with the emphasis on investigating interrelated programmes simultaneously. Therefore, to fill the mentioned gap in the transition from flexibility to reconfigurability, this research examines a number of production programmes and their practices, their linkages and their impact on performance within a single theoretical framework in the pursuit of responsiveness in production environments. Thus, this research identifies differences in fits (correlations) with respect to different linkage practice configurations, as flexible environments (e.g., only technology practices, only organisational programmes, etc.), and their correlations with multidimensional performance. The methodology for this is next explained in more detail.

3.1. Sample and measures

The empirical evidence used to test the propositions was taken from surveys conducted as part of the international High Performance Manufacturing project (HPM), which database was completed in 2010. Surveyed plants had a minimum of 100 workers. The international sample, from auto supplier, electronics and machinery industries, was 314 plants in 11 countries (Austria, China, Finland, Germany, Italy, Japan, South Korea, Spain, Sweden, and North America (USA and Canada)) in three continents (America, Asia and Europe). These industries were selected because they are in transition and operate in an environment of intense global competition, there are a substantial number of plants in all three continents and they are faced with different competitive environments. Table 2 presents the size (mean number of employees: by plant and industry in the last column and by country in the last row) and the number and distribution of the plants, organised by country and by industry. The selection was limited to countries in a variety of regions that were known for their strength in manufacturing. Despite the segmentation of the research sample by country and industry, it is not the aim of this research to make cross-comparisons between countries and/or industries. Furthermore, although the sampling selection sought to include representation from both high and standard performers, the rationale of the paper is not to compare the two types.

Table 2. Size and distribution of the plants, organised by country and by industry

	Country											**Size**
Industry	Austria	China	Finland	Germany	Italy	Japan	South Korea	Spain	Sweden	US/Canada	**Total**	
Electronics	10	21	14	9	10	10	10	9	7	9	109	895
Machinery	7	16	6	13	10	12	10	9	10	11	104	977
Auto supplier	4	14	10	19	7	13	11	10	7	9	104	841
Total	21	51	30	41	27	35	31	28	24	29	317	903
Size (No. employees)	311	729	353	598	393	1438	1636	450	362	480		

Twelve questionnaires were used aimed at twelve different managerial and shop-floor worker positions.

Items related to the three groups of variables of interest have been used for the study: technological practices, organisational practices and performance.

Table 3 shows the results of the adoption focus (technological, mixed (technological-organisational) and organisational), where the practices from the programmes in the proposed model (Figure 1) were derived from the literature review (Section 2.2 & Appendices B-C). These practices are the internal flexible environments as the platform for the transition to reconfigurability (composed of several configurations of production programmes and their practices) to be tested for linkages (i.e. fits). If these linkages exist, they are then tested to ascertain whether they are stronger in configurations of higher systemic integration, as stated in proposition P1.

Table 3. Reliability and validity of constructs in production programmes and practices

Programme (super scale)	**Adoption focus: production practices block**	**Production practice (scale)**	**Number of Items / factor loading range / Cronbach's α**	**Factor loading**	**Cronbach's α**
T	Technological	Group technology-cellular manufacturing (GT)	5 / 0.493-0.863 / 0.727	0.480	0.728
		Proprietary equipment (PE)	5 / 0539-0.728 / 0728	0.621	
	Mixed	Interfunctional design effort (IDE)	4 / 0.761-0.828 / 0.793	0.672	
		Anticipation of new technologies (ANT)	4 / 0.735-0.871 / 0.806	0.842	
		Effective process implementation (EPI)	5 / 0.533-0.825 / 0.757	0.824	
JIT	Organisational	Lot size	4 / 0.76-0.872 / 0.842.	0.429	0.644
		JIT/continuous flow production	1	0.794	
		Kanban/Pull system	4 / 0.824-0.856 / 0.861	0.747	
		Cellular/layout manufacturing	1	0.556	
		Set-up time reduction	6 / 0.624-0.825 / 0.814	0.674	
TPM	Organisational	Predictive/preventive maintenance	5 / 0.482-0.793 / 0.747	0.916	0.853
		Planning & scheduling strategies	4 / 0.547-0.867 / 0.768	0.865	
		New process equipment/technologies	5 / 0.533-0.825 / 0.757	0.855	
TQ	Organisational	Product design	1	0.581	0.833
		Process control	5 / 0.629-0.914 / 0.882	0.599	
		Customer focus	5 / 0.558-0.787 / 0.702	0.758	
		Feedback	6 / 0.501-0.822 / 0.779	0.833	
		Top management quality leadership	6 / 0.492-0.854 / 0.828	0.651	
		Supplier quality involvement	7 / 0.605-0.793 / 0.8.0	0.694	
		Continuous improvement	5 / 0.581-0.808 / 0.777	0.814	
HR	Organisational	Self-directed work teams/employee involvement	6 / 0.681-0.857 / 0.877	0.861	0.651
		Flexible, cross-functional workforce	5 / 0.56-0.834 / 0.82	0.861	

		Manufacturing-business strategy linkage	6 / 0.589-0.812 / 0.81	0.908	
		Manufacturing strategy strength	5 / 0.589-0.7 / 0.629	0.762	
PS	Organisational	Communication of manufacturing strategy	2 / 0553(2) / 0.778	0.663	0.814
		Formal strategic planning	4 / 0.744-0.88 / 0.847	0.869	

All questions on production practices (see Section 2.2 and Appendices B and C) appear in Table 3. They were answered in the questionnaires using 1-to-7 rating Likert scales, and checked for content validity and reliability (all scales for production practices used in the analysis exceeded Cronbach's alpha criterion level of 0.6 (Nunnally, 1967)). As far as construct validity is concerned, items/questions used to make up practices had to pass both the reliability and unidimensionality tests in order to be considered for subsequent analysis. The eigenvalues of the practices had to be greater than 1.00. In addition, the loading of each item on any practice was required to be in excess of ±0.40, showing that all the items contributed substantially to their respective practices (Hair et al., 1998). All the proposed research practices, except for concurrent engineering/phase overlapping, product design simplicity, willingness to introduce new technology and CAD/CAM/CIM/FMS/CNC, were validated. The non-validated practices were not considered. Detailed measures are available upon request.

All six production programmes (see Section 2.2) were conceptualised and defined as multidimensional constructs (see Table 3). That is, each dimension (i.e., practice) represents one facet of these broad constructs (i.e., production programmes) and all pertinent dimensions together define a programme as a whole. Once the practices had been checked for reliability and validity, the next step was to average them into the programmes that represent the six broader concepts (PS, T, TPM, JIT, HR, TQ). A set of practices can be aggregated to represent a programme if these practices load onto a single factor. Several scales were used to measure practices from each programme according to the practices presented in Table 3. The groups of practices were second-order factor analysed to verify that they were indeed measuring common constructs from the six mentioned programmes (shown in Table 3). The eigenvalue of the programmes were greater than 1.00 and their factor loadings were well above the cut-off value of ±0.40. In addition, the reliability of the programmes was found to be above 0.60. Thus, each programme, which measures its own construct, is reliable and unidimensional with all of its practices contributing significantly to forming the programme

With regard to performance (see Section 2.1, Table 1), all the questions in the questionnaires were answered using 1-to-5 rating Likert scales. Firstly, cost was measured by *unit cost of manufacturing*. Secondly, quality was assessed by *conformance to product specifications*. Thirdly, a measure of responsiveness (R) was checked for content and construct validity, and reliability to reflect a construct of the plants' achievement, constructed from the indices of speed/time (cycle time and development lead time), dependability (on-time delivery performance and on-time new product launch and flexibility (flexibility to change product mix and flexibility to change volume) dimensions (see Table 4).

Table 4. *Reliability and validity of responsiveness*

Priority	Index	Factor loadings	Cronbach's α
Responsiveness (R)	Cycle time (from raw materials to delivery)	0.612	0.764
	Development lead time (Speed of new product introduction in the plant)	0.718	
	On-time delivery performance	0.740	
	On-time new product launch	0.590	
	Flexibility to change product mix	0.683	
	Flexibility to change volume	0.719	

3.2. Method of analysis

The method of analysis must allow to test for different configurations of links between the technology programme and non-technological production programmes, seen here as internal flexible environments. Further analyses are conducted of these linkages/environments and performance (especially focusing on responsiveness).

Thus, a series of canonical correlation analyses (CCA) was found to be appropriate for testing the fit, i.e., link, between the variables in the propositions. This technique has been used for research on the economics of modern production practices (Droge et al., 2012; Chaharsooghi & Heydari, 2010) and is suitable for the type of research question addressed in this paper. This technique is also considered the most general of the multivariate techniques to test for linkages between practices and programmes and between these and performance (Hair et al., 2009). CCAs enable the relationships between the two groups of variables to be analysed, with one being considered to be dependent, or not. They also identify whether and how two sets of variables relate to each other. This is best considered a descriptive technique or a screening procedure rather than a hypothesis-testing procedure (Tabachnick & Fidel, 2007).

First, intra-relationships between practices in the technology programme (Proposition P1a), and interrelationships between these and other programmes (Propositions P1b, P1c) are analysed. In a second step, the performance measure set is considered to determine if and how implementations of different programme and practice environments relate to performance (P2a to P2d). CCA constructs a weighted linear combination of the variables in each of the two sets being correlated, with weights selected to maximise the correlation between the two weighted vectors, or canonical variates (Figure 2). One of the advantages of canonical correlation analysis is that it requires only multivariate normality of the variables in the data sets.

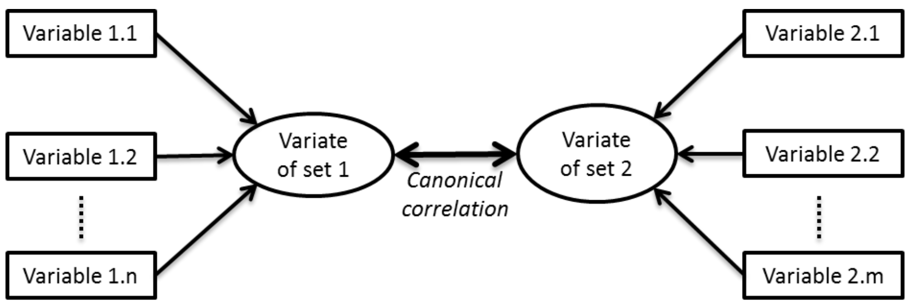

Figure 2 – Canonical Correlation Analysis

Canonical pairs have traditionally been interpreted by examining the arithmetical sign and the magnitude of the canonical weights. However, these weights are subject to considerable instability due to slight changes in sample size, particularly where variables are highly correlated. Canonical cross-loadings have been suggested as a preferable alternative to canonical weights (Hair et al., 1998). Canonical cross-loadings show the correlations of each of the dependent variables with the independent canonical variate, and vice versa. A loading of at least 0.31 is considered significantly different from zero at a maximum 0.05 significance level (Graybill, 1961). Where there are loadings of under 0.31, the lowest loading was tested using the Significance of the Pearson Correlation Coefficient for $p \leq 0.05$ as seen in Eq. (1) (Chang et al, 2013; Afonso et al., 2008).

$$t = \frac{r}{\sqrt{\frac{1-r^2}{N-2}}} \qquad (1)$$

This paper therefore considers six sets of canonical correlation models (i.e., configurations of links as flexible environments) in the analysis, distributed in two stages (Table 5). The first stage, with three sets, revolves around different combinations of fit (linkages environments) between practices, taking technological practices as the basis. The first set model uses the two technological practices and the three mixed practices (related to proposition P1a). The second set model takes the two technological practices and five organisational programmes, JIT, TPM, TQ, HR and PS (Proposition P1b). The third set model takes all five practices together from the technology programme and the five organisational programmes (Proposition P1c). The models represent a progression from the least holistic (Model 1), taking technology alone, to the most holistic view (Model 3), considering all programmes and practices.

The second stage has three set models focusing on different combinations of practice-performance relationships that take both technological and production performance as their basis. As in the first stage, they go from the least (Model 4) to the most holistic view (Model 6). The first model with one set uses technological practices and production performance (Proposition P2a). The second model with one set is made up of all the practices from the technology programme and production performance (Proposition P2b). The third model takes the technology programme with its five practices combined with five organisational programmes and production performance (Proposition P2c). The fourth proposition (P2d) of the second stage, reviews models 4-6 to check whether responsiveness is the performance dimension with the strongest relationships with the programmes and practices.

Table 5. Platforms for propositions 1 and 2: CCAs

Stage	Propositions	Model	Variable set 1	Variable set 2
1	P1a	Model 1	Technological practices	Mixed technological-organisational practices
	P1b	Model 2	Technological practices	JIT, TPM, TQ, HR, PS
	P1c	Model 3	All Technology programme-related practices	JIT, TPM, TQ, HR , PS
2	P2a	Model 4	Technological practices	Production performance (C, Q, R)
	P2b	Model 5	All Technology programme-related practices	Production performance (C, Q, R)
	P2c	Model 6	All Technology programme-related practices together with JIT, TPM, HR, TQ and PS	Production performance (C, Q, R)
	P2d	Models 4-6	Variables from models 4-6 (set 1)	Variables from models 4-6 (set 2)

The analyses with the specific practices from the technology programme (especially technological practices) and organisational programmes (P1a to P1c) enable us to determine any interconnections. Meanwhile, the analysis with specific practices from the technology programme, organisational programmes and production performance (P2a to P2d) enable us to determine whether practices from the technology programme (mainly technology-based) provide a positive contribution to a number of performance priorities, but especially responsiveness, and whether the combinations of these practices with organisational programmes provide a better explanation of relations with performance priorities (mainly responsiveness). The differences in the correlations between all three priorities will show which stands out (Hofer et al., 2012).

4. Results

As explained throughout, the argument that forms the basis for this paper is whether internal flexible environments (as the platform for transition to reconfigurability) with several different configurations of production programmes and their practices, have linkages (i.e., fits), and if so, whether these linkages are stronger in configurations of higher systemic integration. Finally, it tests whether the highest holistic integration has better/stronger relationships with performance (especially responsiveness, key to progressing from flexibility to reconfigurability).

The correlation coefficients between the scales in the technology programme (both technological and mixed: GT, PE, IDE, ANT, EPI), the super-scales in the five organisational programmes (JIT, TPM, HR, TQ, PS), and the production performance priorities (C, Q, R) have been calculated and all are significantly greater than zero, giving support to using canonical correlation analysis (CCA) in 4.1 and 4.2. The analysis will be reviewed in these subsections in the order that the propositions were developed in Table 4. Firstly, the results of the analysis of the practices in the technology programme and other production programmes (Table 7) are reviewed. This allows the importance of the interrelationships between technological practices and other practices in the technology programme (mixed) and also organisational programmes to be evaluated. The results of the analysis of fit (linkages) are then considered regarding the same sets of practices and their impact on performance (Table 8).

4.1. Fits between different blocks of production practices: flexible environments

Table 6 shows the analysis of models one to three. The results for Model 1 are from a CCA between the two technological practices and the three mixed practices representing main operations management in the technology area. The canonical correlation results in Model 1 indicating a significant multivariate relationship across all variable sets, thus *lending support to the P1a proposition of a relationship between technological and mixed practices in the technology programme*. Specifically, proprietary equipment (PE) takes the most important position to account for the first canonical variable of the technological practices. However, mixed practices, anticipation of new technologies (ANT) and effective process implementation (EPI) show the highest correlations with the first canonical variable (the technological practices).

Table 6. Stage 1 (P1.a-P1c) Overall fit measures & cross canonical correlations of first canonical pair in models 1-3.

		Model 1	**Model 2**	**Model 3**
Canonical Correlation		0.487	0.492	0.909
Likelihood ratio		0.962	0.912	0.952
Significance		0.003	0.000	0.005
Redundancy index: Variable set 1		0.155	0.175	0.404
Redundancy index: Variable set 2		0.160	0.122	0.453
Correlations between variable set 1 and the canonical variate of set 2 (canonical cross-loadings)				
	Group technology-cellular manufacturing (GT)	0.291*	0.208*	0.212*
	Proprietary equipment (PE)	0.439	0.479	0.560
Variable set 1	Interfunctional design effort (IDE)	-	-	0.738
	Anticipation of new technologies (ANT)	-	-	0.866
	Effective process implementation (EPI)	-	-	0.455
Correlations between variable set 2 and the canonical variate of set 1 (canonical cross-loadings)				
Interfunctional design effort (IDE)		0.273*	-	-
	Anticipation of new technologies (ANT)	0.462	-	-
	Effective process implementation (EPI)	0.414	-	-
	JIT		0.244*	0.400
Variable set 2	TPM		0.485	0.895
	TQ		0.274	0.609
	HR		0.304	0.543
	PS		0.287*	0.715

* Cross-loadings < 0.31 with Significance of Correlation Coefficient different from zero: $P \leq 0$ .01

Model 2 column in Table 6 summarises the results of the CCA between the two technological practices and the five production programmes highlighted: HR, TQ, JIT, TPM and PS. A pair of the first canonical correlation variables gives clear evidence that technological practices in the technology programme are related to all five organisational programmes, with proprietary equipment (PE) as the most influential in the technology programme and TPM in the organisational programmes. *Therefore, overall, the results for Model 2 show significant support for P1b.*

The results for Model 3 in Table 6 show a CCA between five technology-related production practices and the five organisational programmes representing the main production programmes. The canonical correlation (close to 0.91) is quite high. Although there are no guidelines about the minimum acceptable value for the redundancy index, generally the higher the value of the index, the better. Thus, there is evidence of an impact between technology practices and the organisational programmes-set, since the redundancy index shows that almost half of the variance in the T-related practice set is explained by the first canonical variate of the five programme set. The opposite is also true: approximately half of the variance in the organisational programme set is explained by the first canonical variate of T related-practices. *These results indicate that there is a very strong relationship between T practices and organisational programmes*. The Table proves that anticipation of new technologies (ANT), interfunctional design effort (IDE), and proprietary equipment (PE), in that order, are the most influential technology-related measurement practices in a link with organisational programmes. In addition, the first canonical variable of technology-related measurement practices is highly correlated with such programmes as TPM, PS and TQ, in that order. *In general, the analysis of the results for Model 3 gives support to P1c.*

4.2. Interrelationships between blocks of production practices and performance: from flexible environments to beyond responsiveness

The analyses of models four to six are shown in Table 7. A CCA between the two technological practices and the production performance priorities shown in Model 4 *proves P2a*. More specifically, the proprietary equipment (PE) technological practice has a greater influence on competitiveness than the other technological practice: group technology-cellular manufacturing (GT). In addition, the first canonical variable of technological practice measurement has a higher correlation with responsiveness, the key characteristic promised by reconfigurable practices.

Model 5 shows the result of a CCA between all five technology-related practices and the three performance priorities. A pair of the first canonical correlation variables provides clear evidence that all five technology practices are related to all performance priorities, *giving support for P2b*. There was an improvement in both canonical correlation and responsiveness compared to technological practices alone, showing the importance of considering all technology practices for enhancing the most important reconfigurable characteristic (see Model 4). Interfunctional design effort (IDE) has the highest loading of all the practices in the technology programme, and responsiveness the highest of the performance priorities.

Furthermore, as shown in Model 6, all the organisational programmes, JIT, TPM, TQ, HR and PS, as well as all the five technology-related measurement practices, are correlated with all the performance priorities, *confirming support for P2c*. The results reveal that interfunctional design effort (IDE) and effective process implementation (EPI) technology practices, accompanied by sophisticated PS and TPM, are likely to be a more important reason why some production companies have gained competitive advantages, especially in responsiveness. It is important to stress that the combination all of technology practices along with all organisational programmes further improved not only the canonical correlation, but also both quality and responsiveness loadings more than technological practices alone (see Model 4) or all technology practices alone (see Model 5). This may show the importance of linking all technology practices individually with the rest of programmes for a better reconfigurability platform. On the other hand, of all the production performance priorities, responsiveness shows the highest correlation with the first canonical variable of the programmes, with Model 6 having a clear improvement from Model 4 (only technological practices), or better than in Model 5 (all technology practices), *significantly supporting P2d*. This shows the importance of linking all programmes for future reconfigurable practices to work better to improve the main feature that they offer: responsiveness.

Table 7. Stage 2 (P2a-P2c) Overall fit measures & cross canonical correlations of first canonical pair in models 4-6.

		Model 4	**Model 5**	**Model 6**
Canonical Correlation		0.384	0.519	0.570
Likelihood ratio		0.852	0.718	0.632
Significance		0.000	0.000	0.000
Redundancy index: Variable set 1		0.088	0.118	0.124
Redundancy index: Variable set 2 (performance priorities)		0.075	0.144	0.182
Correlations between variable set 1 and the canonical variate of set 2 (canonical cross-loadings)				
	Group technology-cellular manufacturing (GT)	0.198*	0.197*	0.193*
	Proprietary equipment (PE)	0.368	0.197*	0.198*
	Interfunctional design effort (IDE)	-	0.493	0.489
	Anticipation of new technologies (ANT)	-	0.360	0.354
Variable set 1	Effective process implementation (EPI)	-	0.363	0.360
	JIT	-	-	0.315
	TPM	-	-	0.369
	TQ	-	-	0.314
	HR	-	-	0.315
	PS	-	-	0.440
Correlations between variable set 1 and the canonical variate of set 1 (canonical cross-loadings)				
	Cost	0.235*	0.316	0.281*
Variable set 2	Quality	0.213*	0.346	0.402
	Responsiveness	0.352	0.449	0.508

* Cross-loadings < 0.31 with Significance of Correlation Coefficient different from zero: P ≤ 0 .01

5. Discussion and implications

As previously stated, the results are empirical findings from an international survey. The sample therefore encompasses broad cultural variability, and there is no doubt that these issues affect the implementation of production practices. However, this research does not try to analyse cultural questions, but focuses more on linkage environments worldwide. The very reality of business economics and the literature in general also suggest that production practices are universally applicable, regardless of cultural differences (Schroeder & Flynn, 2001). On the other hand, this variance from the sample is a strong point, since it allows other countries in the world to observe data from a set of industrialised countries that are known for having world class production. Hence, *the findings of this paper may help in the evolution from current flexibility to future reconfigurability, and also to establish the environments needed for its implementation*.

The analysis regarding selective fits between technological practices, other practices from the technology programme (mixed technological-organisational), and JIT, TPM, TQ, HR, PS programmes through the association of canonical correlation between these variables, allows environments of linkages to be deduced, as described in Table 6. The results of Model 1 imply that *technological practices, which are assumed to be more closely related to flexibility, must consider other practices from the technology programme as part of the stage for a possible implementation of reconfigurable practices*. The results of the analysis clearly show that a relationship exists between technological and mixed technology programme practices. This implies that technological practices should be accompanied by technology management. This is important for theory and practice as it indicates that, if the aim is to incorporate it onto the shop floor, technology management is required for reconfigurability to be achieved in plants. Plants should consider that RMS on its own is not a guarantee of success, but that it has to be accompanied by appropriate technology management.

Model 2 presents results showing that *technology practices need to consider organisational (non-technology) programmes, such as PS, TPM, TQ, and HR in their operationalisation*. *This means that a combination of organisational and managerial practices in the technological stage needs to be considered for possible reconfigurability adoption*. The results of the analysis show a relationship between the technological practices and the five organisational programmes. This implies that technological practices need to be accompanied by various non-technological production programmes. From the theory point-of-view, this shows that for reconfigurability and proper integration to be achieved, they have to be accompanied by organisational programmes. From the practice perspective, this implies that when implementing RMSs, senior management should also consider what the plant is currently doing, apart from just technology itself and its management.

Model 3 results suggest that *when all practices from the technology programme are adjusted, they present a better relationship with all organisational programmes (JIT, PS, HR, TPM and TQ).* The results of the analysis show a clear relationship between all practices in the technology programme and the five organisational programmes. This implies that it is important to consider the implementation of all the technology programme practices, and not only the most technological, for a better link with the various non-technological programmes. This confirms the importance of the total integration of any possible RMS with all the production practices.

Meanwhile, interesting findings are also obtained when the fit between these practices and production processes are considered with respect to performance, as described in Table 7. It is clear from the results in Model 4 that *technology practices are related to performance, but performance is better explained when combined with other practices in the technology programme* (Model 5), *and best explained when combined with JIT, TPM, HR, TQ, PS programmes* (Model 6). *This implies that, in order to obtain better performance, the implementation of new reconfigurable practices in this current flexible platform should consider all other practices and programmes that are currently implemented (i.e., plants need to link future RMS to what they are doing now).* Finally, *the most sought-after performance priority is responsiveness, which means that plants may benefit from the reconfigurability adoption*. The results of the analysis show that the link between the technology practices and organisational programmes seek to improve costs, quality and responsiveness. This implies that future RMS technological practices can contribute to obtaining greater responsiveness, but that they should be integrated not only with other technology programme practices, but also with the organisational practices used by the plant. For theory this indicates that obtaining responsiveness requires a holistic vision of all the practices involved, not just the technology practices. As far as practice is concerned, contrary to what some authors seem to suggest (Koren, 2006), it shows that plants that obtain responsiveness require more than what the reconfigurability capacity of RMS can provide.

Thus, the holistic framework proposed here, suitable for both qualitative and quantitative studies, provides novel insights into responsiveness in the programme and production practices involved in transitioning from flexibility to reconfigurability. This is important since the *implication for managers of plants that do not evolve to reconfigurable practices such as RMS when they are technologically accessible, is that this is likely to put them at a performance disadvantage compared to the international competitors that do*.

6. Conclusions and future research

This research analyses the interrelationships between production practices in flexibility that may help to transition to reconfigurability via the search for responsiveness, i.e., timely purposeful change guided by external demands. As was stated in the introduction, flexibility is seen as an inherent property of manufacturing systems that allows them to change within their own limitations (especially expected external changes). And reconfigurability is increasing the technological responsiveness of production systems to not only foreseen, but also unforeseen events, such as sudden market changes or unexpected machine failures.

Since present flexible systems comprised hardware and software that were not technically designed for this last purpose, the pursuit of greater responsiveness by means of obtaining technological reconfigurable product capability in current flexible environments such as FMS might be both a long drawn-out affair and rather impractical. Thus, reconfigurability electiveness may be critical in the current environment of an economic and financial crisis that is driving up the deployment of technological initiatives to withstand constant market changes. Unfortunately, the mere presence of technology is not sufficient. It has to be embedded in its organisational environment in order to be effective. While there has been substantial research into the effectiveness and efficiency of reconfigurable designs of technological prototypes, reconfigurable practice implementation in production has not been reviewed empirically. This paper takes the modest step of presenting one approach based on current flexible environments as the prior stage to technological reconfigurability adoption. There is no study on reconfigurability (such as RMS) that provides an empirical examination of the joint implementation of several production programmes, such as JIT, TPM, TQ, etc., and their joint impact on the pursuit of responsiveness.

This is done from perspectives published in major production-related journals. A broad framework is proposed that espouses notions of linkages and contingencies between production practices and performance dimensions. The results of this empirical study from an international survey on modern production practices conducted in eleven countries in three continents provide some important insights into these relationships. In general, there seems to be support for the validity of the interactions between all organisational programmes and practices in the technology programme tested. Therefore, it is apparent from the results that some current flexible environments seem to better facilitate the future transition from flexibility to reconfigurability in order for RMS to be implemented.

Although sets of practices without technological reconfigurability seen here are already targeting responsiveness and other performance priorities, they can however be improved and extended with the consideration of reconfigurability adoption and implementation. This shows that linking all programmes for future reconfigurable practices is important for working better to improve the main feature that they offer: responsiveness.

The results of the analysis therefore show the importance of plants not only considering the link between technology, its management and organisational programmes systemically, but also their impact on improving costs, quality and, especially, responsiveness.

The research presented here may also contribute to knowledge on implementing and operating reconfigurable practices. To begin with, while confusion between the meanings of these terms may have been noted before, this paper is one of the few to consider the three terms together yet separately, with responsiveness as the performance priority for transitioning from flexible practices to reconfigurable practices, thus proposing their differentiation as a step forward. Furthermore, the detailed review of the dimensions associated with this performance priority allows this paper to develop and test a generic definition of plant priority and production practices in current flexible environments, which will also support further empirical studies on future reconfigurable environments, such as RMS.

Therefore, this paper shows that plants may evolve more easily towards adopting RMS if the framework proposed here is considered, and believes that the fields of reconfigurability and production economics will better progress with the development of paradigms for future RMS deployment, such as linkages and contingencies.

This research may help theory building regarding the evolution from current production practices and programmes in flexible environments to the future implementation of reconfigurable practices, from an international inter-industry perspective. The proposed framework can also be used to further examine flexibility, for example FMS, in other environments. This may lead to a better theory being built on the future implementation of RMS, once its technology becomes available. Although the proposed model is evaluated on performance priorities, production programmes and their flexibility, and responsiveness-related practices, the "linkages and contingency" notion is also supported.

The available database for this research did not include empirical concrete information about FMS and RMS, not allowing a comparison between them. Yet, this limitation offers opportunities and help to identify insights for further research. To begin with, the framework will have extensive empirical examination with the testing of data from FMS and reconfigurable-based practices when they become available in the next round of data collection.

This paper has not included contextual variables related to the external environment, i.e., beyond plant boundaries (e.g., customer preference and service, market feedback, etc.), which is proposed for future research. Although these might be important, there is nonetheless evidence that the application of the production practices considered here is universal, i.e., that they can be applied and, indeed, are applied in many industries and countries in widely differing contexts. The question is whether any contextual variables exist, such as size, complexity, types of production processes, etc., that affect the pursuit of responsiveness through reconfigurability that might be interesting for future studies.

Hence, caution should be shown going forward, for there may not be a single path to competitiveness, since, in practice, these three terms (flexibility, reconfigurability and responsiveness) may depend on the needs of the environment (e.g., probably, and especially, the more technology-oriented plants). Thus, the future direction could be a research plan based on the proposed model for reconfigurable practices in the hope of facilitating future work on reconfigurability of imminent and growing importance. However, to propose reconfigurability as "one size fits all" may not meet the requirements for achieving competitiveness when plants take wrong paths in their pursuit of responsiveness and other performance priorities. Further investigating the various paths that exist, and determining which might be the most suitable in each case, is a major line of future research.

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Appendix A. Production programmes in flexible environments

Table A.1 Programmes with links to flexibility

Authors	Year	Production programmes
Monden	1981a	JIT
Monden	1981b	JIT
Monden	1981c	JIT
Schonberger	1982	JIT
Monden	1983	JIT
Schonberger	1986	JIT
Monden	1989	JIT
Dean &Snell	1991	JIT, TQ, HR, PS
Sakakibara et al.	1993	JIT
Parthasarthy & Sethi	1993	HR, PS
Suarez et al.	1995	HR, T
Dean &Snell	1996	JIT, TQ, PS
Filippini et al.	1996	JIT, TQ, HR, PS, T
Chen et al.	1996	HR
Gowan & Mathieu	1996	T
Boyer et al.	1997	TQ, HR
Filippini et al.	1998	JIT, TQ. HR, PS, T
Filippini et al.	2001	JIT, TQ, HR, T
Forza	2001	JIT, T, TQ, HR
Matsui & Sato	2001	TQ, T
Youssef & Al-Ahmady	2002	TQ, HR
Youssef & Al-Ahmady	2002a	TQ
Cua et al.	2006	JIT, TPM, TQ, HR
Konecny & Thun	2011	TQ, HR, TPM
Furlan et al.	2011	JIT
Phan et al.	2011	TQ
Agarwal et al.	2012	JIT, TQ, TPM
Gunasekaran & Ngai	2012	JIT, TQ, TPM
Jin et al.	2013	TQ, T

Appendix B. Technology practices in flexible environments

Table B.1 Technology areas and performance

Authors	Year	Programme area	Production practices
Filippini et al.	1996	Product technology.	Concurrent engineering/phase overlapping
Dean & Snell	1996	Product, process & information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC)
Filippini et al.	1998	Product, process & information technology	Flexible automation (CAD/CAM/CIM/FMS/CNC), Group technology-cellular manufacturing
Maier	1997	Product, process & information technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment, IT
Boyer et al.	1997	Product, process & information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC)
Maier	1998	Process technology	Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment

Authors	Year	Programme area	Production practices
Maier	1998a	Process technology	Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment
Maier & Schroeder	2001	Product & process technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment
Matsui	2002	Product & process technology	Product design simplicity, Interfunctional design effort, Effective Process Implementation
Milling et al.	2003	Product, process & information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing
Ahmad et al.	2010	Process & information technology	Group technology-cellular manufacturing
Danese & Filippini,	2010	Process & information technology	Group technology-cellular manufacturing
Ortega Jimenez et al.	2011	Product & process technology	Effective Process Implementation, Interfunctional Design Effort, Supplier involvement
Machuca et al.	2011	Product & process technology	Effective Process Implementation, Interfunctional Design Effort, Supplier involvement
Ortega et al.	2012	Product & process technology	Effective Process Implementation, Interfunctional Design Effort, Supplier involvement
Jin et al.	2013	Process technology	Proprietary equipment

Appendix C. Organisational programmes and practices: common & broader view of technology linkages

Table C.1 Programmes and performance

Authors	Year	Programme	Production practices
Flynn et al.	1994	JIT, TQ, HR	JIT: Lot size, JIT/continuous flow production, Setup time reduction. TQ: Product design, Feedback, Top Management Quality Leadership. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.
Flynn	1994	PS	Communication of manufacturing strategy
Filippini et al.	1996	JIT, TQ, HR	JIT: Kanban/Pull system, Cellular/layout manufacturing, Setup time reduction. TQ: Product design, Process Control, Feedback, Supplier Quality Involvement, Continuous improvement. HR: Self-directed work teams/Employee involvement.
Dean & Snell	1996	PS	PS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing strategy strength
Morita & Flynn	1997	JIT, TPM	JIT: Lot size, JIT/continuous flow production, Kanban/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/preventive maintenance, Planning & scheduling strategies, New process equipment or technologies.
Sakakibara et al.	1997	JIT	JIT/continuous flow production, Kanban/Pull system, Cellular/layout manufacturing, Setup time reduction.
Boyer et al.	1997	TQ, HR	TQ: Feedback, Top Management HR: Self-directed work teams/Employee involvement
Maier	1997	HR	HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.
Nakamura et al.	1998	JIT	JIT: JIT/continuous flow production, Kanban/Pull system, Setup time reduction.
Milling et al.	1998	TPM	Predictive/preventive maintenance, Planning & scheduling strategies, New process equipment or technologies.
Flynn et al.	1999	JIT, TPM, TQ, HR	JIT: JIT/continuous flow production, Kanban/Pull system, Cellular/layout manufacturing. TPM: Predictive/preventive maintenance, New process equipment or technologies. TQ: Process Control, Customer focus, Feedback, Continuous improvement. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.

Milling et al.	2000	JIT, TPM, TQ, HR	JIT: Lot size, JIT/continuous flow production, Kanban/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/preventive maintenance, New process equipment or technologies. TQ: Process Control, Feedback, Continuous improvement. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.
Cua et al.	2001	JIT, TPM, TQ, HR, PS	JIT: JIT/continuous flow production TPM: Predictive/preventive maintenance, Planning & scheduling strategies, New process equipment or technologies. TQ: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. PS: Formal strategic planning
McKone et al.	2001	TPM	New process equipment or technologies
Matsui	2002	JIT, TQ, HR, PS	JIT as a programme TQ: Process Control, Customer focus, Feedback, Top Management Quality Leadership, Supplier Quality Involvement, Continuous improvement. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. PS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing-business strategy linkage, Production Manufacturing strategy strength
Milling et al.	2003	JIT, HR	JIT: Lot size, Cellular/layout manufacturing, Setup time reduction. HR: Flexible or cross-functional workforce.
Sohel et al.	2003	JIT, TQ	JIT: JIT/continuous flow production, Kanban/Pull system, Setup time reduction. TQ: Process Control, Customer focus, Feedback, Supplier Quality Involvement.
Tu et al.	2004	JIT, TPM	JIT: Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/preventive maintenance.
Cua et al.	2006	JIT, TPM, TQ, HR, PS	JIT: JIT/continuous flow production, Kanban/Pull system, Setup time reduction. TPM: Planning & scheduling strategies, New process equipment or technologies. TQ: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership, Supplier Quality Involvement. HR: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. PS: Formal strategic planning
Furlan et al.	2011	JIT	Lot size, JIT/continuous flow production, Kanban/Pull system, Cellular/layout manufacturing, Setup time reduction.
Ortega Jimenez et al.	2011	PS	Formal Strategic Planning, Anticipation of New Technologies, Manufacturing-Business Strategy Linkage
Machuca et al.	2011	PS	Formal Strategic Planning, Anticipation of New Technologies, Manufacturing-Business Strategy Linkage
Ortega et al.	2012	PS	Formal Strategic Planning, Anticipation of New Technologies, Manufacturing-Business Strategy Linkage

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