A STRATEGIC PLATFORM FOR RECONFIGURABILITY: INTERCONNECTIONS BETWEEN RECONFIGURABLE TECHNOLOGY, JIT, TQM, HR, TPM, AND RESPONSIVENESS

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Universidad de Sevilla, Dissertations, No. ISBN:
ISSN:
Distributed by:
Gestión Estratégica y Negocios Internacionales
Avenida Ramón y Cajal 1, SEVILLA, SPAIN
Printed by:

To my parents

Jose Cesar (R.I.P.)

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ABSTRACT

The present dissertation addresses the topic of reconfigurability from the paradigm of High-Performance Manufacturing (HPM). It especially focuses on the interconnections between production programs (i.e.., technology management, manufacturing strategy, reconfigurable technology, JIT, TQM, HR and TPM), and their effects on multidimensional operational performance (included, but not limited to responsiveness) of manufacturing plants. We call production programs to sets of common production practices that have become the standard way of doing things and are composed of methods, technologies, capabilities, initiatives, and techniques preferred by manufacturers and managers because their outcomes are more efficient and effective than any other alternative. The focus of this research is three-fold: (1) the impact of technology management and manufacturing strategy on performance, especially responsiveness; (2) flexibility as a basis for reconfigurability, which is provided by interconnections among manufacturing strategy with a structured decision-making approach for technology management and other production programs such as JIT, TQM, HR and TPM, and how these enhance performance in terms of cost, quality and responsiveness; and (3) achieving plant responsiveness from reconfigurable technology, manufacturing strategy and technology management linkage and the intervening role of SCM between such linkage and responsiveness

Hence, it is intended to facilitate that, both the Spanish industry as well as the international industry, can make the transition to reconfigurability, considering technological systems such as Reconfigurable Manufacturing System (RMS), which can enhance a company's technological ability to respond to market requirements by quickly adjusting production capacity and functionality reconfiguring its products and processes. To do so, the starting point is the consideration of today flexibility environments as a platform for the implementation of technological "reconfigurability".

Persistent crises and the dynamism of the global business environment encourage companies to make constant changes to adapt to changing requirements of markets. Given that the RMSs, which provide the functionality and capacity needed at any time, are being developed so that plants can adapt quickly to changes in market requirements, interest in the RMS, especially its potential effect on competitiveness, is increasing. However, RMS research has a narrow focus, particularly since it is being considered as a physical competitive resource. Moreover, there seems not to be stablished the basis in production and operations for the proposition that the RMSs could have a competitive value as part of a holistic structure within factories. Studies pay little or no attention into the interconnections of production programs that would be involved in the possible adoption of RMSs. In addition, existing research does not pay enough attention to the multidimensional nature of competitiveness. However, ahead of the market crisis, manufacturers may be looking for competitiveness through greater responsiveness to indeterminate and sudden changes. Thus, there must be room for RMSs, especially in contexts where flexibility (e.g., it may be derived from manufacturing strategy and technology, among other production programs) may be currently playing a key role. However, if the RMS is the next step toward competitiveness in flexibility, these RMSs must be connected to the production programs which are currently being implemented in plants.

Accordingly, the foundation that will guide this thesis is the following proposition: Is it possible, and not improbable, that there are plants exceeding their competitors simultaneously both on responsiveness as well as on various measures of performance such as cost, quality, flexibility, etc. (these plants will be identified as high performers), adjusting to changing requirements of the market through production

programs in environments of flexibility, especially in aspects related to technology and manufacturing strategy?

To verify this proposition, the overall objective is to investigate how manufacturing plants make use of different manufacturing practices and/or their programs to develop certain sets of flexibility capabilities (as a platform for reconfigurability), or even sets of reconfigurability, with the "ultimate" goal of adjusting to market requirements. This aims to increase the understanding of the role of production and operations, as well as its immediate impact on manufacturing competitiveness. Following the overall research objective, three areas are identified to be of particular interest to investigate: (1) relationships among responsiveness and other different dimensions of operational performance; (2) the way responsiveness and other different performance dimensions are affected by certain manufacturing practices and/ or their programs; and (3) whether there are contingencies that may help explain the relationships between dimensions of flexible or reconfigurable capabilities or the effects of manufacturing practices or their programs toward operational performance. This leads out to a number of sub objectives: (i) to perform an analytical review of the research on the relationship between high performance programs (e.g. JIT, TQM, etc.) and their practices, with particular attention to performance in responsiveness, as an integrative framework; (ii) to establish if there are aspects and practices of technology and manufacturing strategy that influence different dimensions of performance, especially in responsiveness; and (iii) to check if the levels of implementation of production programs related to flexibility (e.g. JIT, TQM, etc.) are connected with competitiveness (that is, to assess whether they are necessary for high performance).

The empirical elements from the present research were constructed as part of the data from the Spanish High-Performance Manufacturing (HPM) project, which in turn is part of an international project, involving three industries and different countries from around the world (with research groups of different specialties from 21 countries in three different geographic areas: America, Asia, and Europe).

This thesis contributes to several insights to the areas of reconfigurability (e.g., reconfigurable technology, market enablers, among others), flexibility, technology, manufacturing strategy, as well as to practitioners and academics in production and operations. The research develops measurements for and evaluates the effects of several manufacturing practices and their programs on operational performance. The results are aimed at providing guidance for decision making in manufacturing plants. The different frameworks present a contribution to both theory and practice. They offer novel insights into the programs and production practices involved in transitioning from flexibility to reconfigurability in the pursuit of responsiveness and provide a basis for future research. Some of the most prominent implications for researchers to consider, when studying production and operations, are threefold: (1) the manifestation of responsiveness as one of the most important competitive dimension; (2) plants should consider the joint implementation of production programs (and their practices), since their interdependencies may affect competitiveness, outweighing the possible differences between industries in which plants operate; and (3) the research confirms 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 programs as well as to link them to organizational programs.

DISSERTATION OUTLINE

This research entitled *"A Strategic Platform for Reconfigurability: Interconnections between Reconfigurable Technology, JIT, TQM, HR, TPM, and Responsiveness"* is a doctoral dissertation in

Production and Operations Management at the Universidad de Sevilla. The dissertation is constituted by two parts, where the first is the structure of the compendium of publications and the second provides a collection of three publications. The first part has six sections, where the first is an introductory section, to justify the topic, sustained with the context, background, with the purpose of positioning the problems treated in the papers, by relating them to earlier work, as a basis for the objectives of this dissertation. Hence, Section 1 presents the background, included but not limited to eight papers published by the author of this dissertation, while the PhD student was still part of the Doctoral Program of the Engineering School. It comprises the previous research done as the foundation for this thesis, which started before transferring to the current Doctoral Program of "Gestión Estratégica y Negocios Internacionales (GENI)."

The Section 2 displays the objectives to be achieved. Section 3 presents the basis for the global results: theoretical foundation and methodology of the thesis. Section 4 overviews the global results. Section 5 shows the discussion of results as a summary of papers. The conclusions are presented in Section 6, summing up the combined contribution of the main high impact papers and envisions future research directions and possible extensions.

Lastly, the second part provides a collection of three papers after transferring to the GENI Doctoral Program. This part includes the papers listed below, showing the foundation and the current state of publication.

Research line for this Thesis: Compendium of three papers

Paper 1, JCR/SCOPUS Q1

Pedro Garrido-Vega, Cesar H. Ortega Jimenez (**Corresponding Author**), José Luis Díez Pérez de los Ríos, Michiya Morita. 2015. Implementation of technology and production strategy practices: Relationship levels in different industries. *International Journal of Production Economics* 161, 201-216. doi:10.1016/j.ijpe.2014.07.011.

Paper 2, JCR/SCOPUS Q1

Cesar H. Ortega Jimenez (**Corresponding Author)**, Jose A.D. Machuca, Pedro Garrido-Vega, Roberto Filippini. 2015. The pursuit of responsiveness in production environments: from flexibility to reconfigurability. *International Journal of Production Economics* 163, 157–172. http://dx.doi.org/10.1016/j.ijpe.2014.09.020.

Paper 3, JCR/SCOPUS Q1

Cesar H. Ortega-Jimenez (**Corresponding Author)**, Pedro Garrido-Vega, Cristian Andrés Cruz Torres. 2020. Achieving plant responsiveness from reconfigurable technology: Intervening role of SCM. *International Journal of Production Economics* 210, 195-203. https://doi.org/10.1016/j.ijpe.2019.06.001.

Contents

1. INTRODUCTION

With current global and persistent crisis, the general and primary aim of all plants is long time resilience and the ability to produce competitive and responsively according to changing market needs. In plants, the expected results are usually products supplied to customers resulting in earnings divided by its titleholders. One area of Production and Operations Management studies how plants deploy their probable limited resources within the process of transforming inputs into a value-added product/service. In this, technology, manufacturing/production strategy , flexibility, reconfigurability, and other non-technological production programs offer a structured approach to decision making in facilitating a competitive and responsive production (Slack and Brandon-Jones, 2019). Production/Operations Management (POM) is defined as “the process, which combines and transforms various resources used in the production/operations subsystem of the organization into value added product/services in a controlled manner as per the policies of the organization” (Suresh and Kumar, 2008), which clearly corresponds to the managing role of production. POM is subordinated by manufacturing strategy since strategy should lead management. While manufacturing strategy is concerned with providing long term guidelines, POM is more concerned with the production/manufacturing programs, such as reconfigurability, flexibility, technology, and others, taken to plan, schedule and control the value adding activities that contribute to higher competitiveness manifested through multidimensional performance.

1.1. Context

Since the first paper on reconfigurable manufacturing in 1990, this field has established itself as a well-defined research area (Liles and Huff, 1990). Adaptability through reconfigurable manufacturing has since received much attention, both within the academic communities but also from practitioners involved in technology. Some of the purposes of research on reconfigurable manufacturing started as with the identification of key components to enable short changeover times between the manufacture of different products. Since then, trends in flexibility have been towards reconfigurability. In 1999, Yoram Koren formally originated the term " *Reconfigurable Manufacturing System (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 recognized when U.S. patents were granted for the following: (1) reconfigurable machine tool, filed in 1997 and issued in 1999 (Koren and Kota, 1999); and (2) reconfigurable manufacturing system, filed in 1998 and issued in 2002 (Koren and Ulsoy, 2002). RMSs are technological capabilities that provide exactly the functionality and capacity needed, exactly when needed (Bader *et al.*, 2014).This is achieved by the 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.

More recently, there is a growing global trend in production to use practices such as manufacturing strategy, technology, JIT, HR, TPM, which are geared towards greater flexibility (Agarwal *et al.*, 2013; Arana-Solares *et al.*, 2019; Chang *et al.*, 2013; Machuca *et al.*, 2011; Ortega-Jimenez *et al.*, 2011, 2012; Purvis *et al.*, 2014; Roh *et al.*, 2014). 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.

Over the years many production programs related to improving responsiveness have been advocated and put forward as the solution and the key to improve not only responsiveness but also other dimensions of performance and a sustainable competitive advantage. However, like the idiosyncrasy of people, plants are not a homogeneous group that responds equally to certain actions. Hence, there are no action plans, improvement programs or manufacturing concepts that are universally applicable (Ortega Jiménez *et al.*, 2017). Hence, the research reported in this thesis examines how current production environments may be used as basis for transitioning towards reconfigurable production systems from two perspectives (Ortega-Jiménez *et al.*, 2014): (1) production environments geared towards flexibility; and (2) production environments geared toward reconfigurability.

1.1.1. Toward flexibility

The relationships among production practices in flexible contexts have been the focus for much attention in POM research. Although the area has received much attention, there still exist differences in opinion within the academic community as to the differences between concepts. Hence some definitional issues are considered next. *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 support it. To avoid this, this introduction will clarify the way that these terms will be used in this thesis 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. In the work reported in our thesis, *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"* (Santos Bernardes and Hanna, 2009). Although this ability should respond to both internal and external environmental uncertainty, affecting the value produced, it is seen to be wanting regarding 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 program flexibilities). To support external changes, manufacturing systems should be contextualized for the long term to achieve competitive flexibility regarding strategic aspects, in terms of production, expansion, and market (Gunasekaran and Reichhart, 2007). However, as will be explained below, the systems currently used to achieve flexibility fall short of achieving this goal.

1.1.2. Toward reconfigurability

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, (Santos

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 thesis, reconfigurability also includes some reaction capabilities and therefore surpasses the “inflexibility” of current manufacturing contexts, as it enables the rapid reconfiguration of a system with a new set of parameters. Reconfigurability may be inserted in a broader context of a manufacturing program with both responsive capabilities as well as market-responsive initiatives. Since (Wiendahl *et al.*, 1999) first introduced reconfigurability as an important capability for manufacturing systems, many papers have been published on this topic.

Responsiveness is regarded here as a performance capability at the business level and refers to the behavior 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 behavior change in the presence of modulating stimuli*" (Santos Bernardes and Hanna, 2009). Although responsiveness may require functions of several abilities within plants (Swafford *et al.*, 2008), this thesis centers 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 (Gunasekaran and Reichhart, 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 (Ortega-Jiménez *et al.*, 2014).

1.2. Background

The background includes the eight following papers (chronological order) into the two lines below (lines 1 & 2), which converged into the research line for this Thesis with its three papers.

Line 1: Interrelations between manufacturing strategy, technology, and performance

Paper 1, JCR/SCOPUS Q1

Iván Andrés Arana-Solares, César H. Ortega-Jiménez, Rafaela Alfalla-Luque, José Luis Pérez-Díez de los Ríos, 2019. Contextual factors intervening the relationship between manufacturing strategy and technology management on performance. *International Journal of Production Economics*, 207, 81-95. ISSN 0925-5273.

Paper 2, JCR/SCOPUS Q1

Cesar H. Ortega, Pedro Garrido-Vega, Jose Antonio Dominguez Machuca, 2012. Analysis of interaction fit between manufacturing strategy and technology management and its impact on performance. *International Journal of Operations & Production Management* 32 (8), 958-981

Paper 3, JCR/SCOPUS Q1

César H. Ortega Jiménez, Pedro Garrido-Vega, José Luis Pérez Díez de los Ríos, Santiago García González, 2011. Manufacturing strategy–technology relationship among auto suppliers, *International Journal of Production Economics* 133 (2), 508-517.

Paper 4, JCR/SCOPUS Q1

José A.D. Machuca, Cesar H. Ortega Jiménez (**Corresponding Author**), Pedro Garrido-Vega, José Luis Pérez Diez de los Ríos, 2011. Do technology and manufacturing strategy links enhance operational performance? Empirical research in the auto supplier sector, *International Journal of Production Economics* 133(2), 541-550.

Paper 5

Cesar H. Ortega Jimenez, 2009. Operating strategy, technology, and performance of operations in the Honduran industry: proposal of a universal model. *Science and Technology Journal*, 5 (2), 47-65 (ISSN 1995-9613). http://dx.doi.org/10.5377/rct.v0i5.519. (Spanish)

Paper 6

Cesar H. Ortega Jimenez, 2008. Operations Strategy-Technology Link in the Honduran Industry: Selection fit. *Science and Technology Journal*, 2, 93-111. (ISSN 1995-9613) http://dx.doi.org/10.5377/rct.v0i2.1821 (Spanish)

Line 2: Reconfigurability and responsiveness: Technology, manufacturing strategy, and other production programs

Paper 7

Cesar H. Ortega Jimenez, Jose A.D. Machuca, Pedro Garrido-Vega, 2014. From lean to reconfigurability: systematic review of High-Performance Manufacturing. *The International Journal of Management Science and Information Technology (IJMSIT)* 12, 99-131. Editorial: The North American Institute of Science and Information Technology (NAISIT). SSN: ISSN 1923-0265 (Print) - ISSN 1923-0273 (Online) - ISSN 1923-0281 (CD-ROM) https://www.econstor.eu/handle/10419/178776?locale=de

Paper 8

Cesar H. Ortega Jimenez, 2010. Reconfigurable manufacturing system and industrial competitiveness. *Economics and Administration (E&A)* 1 (2), 97-113. ISSN: 2219-6722; e-ISSN: 2222-2707 (Spanish). http://www.iies-https://doi.org/10.5377/eya.v1i2.4352.

1.2.1. Flexibility

Contexts of flexibility can be studied from many different perspectives. The theories presented in this thesis are based on POM literature with some instances of reconfigurability.

The extent of this thesis is concerned with operational performance of plants and the relationships between on the one hand, different dimensions of operational performance and on the other, how certain practices or programs (i.e., bundles of practices) impact operational performance. Four basic dimensions of operational performance are treated initially in this thesis: quality performance, delivery performance, cost performance, and flexibility performance (Ortega Jiménez, 2009). The thesis also investigates structural and strategic contingencies, which may influence the impact on relationships between programs and operational performance dimensions.

One of the (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 (1958)´s 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, it could be said that current flexible contexts do not satisfy requirements in terms of this law, making it necessary to move on to systems that are able to manage a greater number of states. Thus, despite still not being readily and widely available, *Reconfigurable Manufacturing Systems* (RMSs) could be the answer.

Unlike current flexible contexts, 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 recent technology and/or new functions. RMSs 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 and Dove, 1991). One of the agile production system trends in flexibility since then has been towards reconfigurability (Ortega-Jimenez *et al.*, 2015; Sheridan, 1993).

However, to date just few 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 fully working full-scale prototypes, with few models implemented in plants used to support research focusing on a range of issues (Niroomand *et al.*, 2012). All reconfigurability research seems to be characterized by having a limited focus, particularly about 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 (Ateekh-Ur-Rehman and Subash Babu, 2013). This thesis is the first to assess empirically flexibility-related production practices, but nonetheless crucial 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) (Goyal *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).

1.2.2. Beyond reconfigurability

Responsiveness is currently considered a critical performance metric of competitive capabilities (Moradlou *et al.*, 2017) and customer responsiveness is one of the end-goals of an end-to-end Supply Chain (SC). So, as important parts of the SC, plants must respond to product and market changes. Plant Responsiveness (PR) therefore plays a crucial role in achieving SC customer responsiveness (Santos Bernardes and Hanna, 2009) as the ability to quickly adjust to any such changes in production plants (Um *et al.*, 2017). PR can be measured as the combinations of time, dependability and flexibility with which plants respond to customer demands (Ortega-Jimenez *et al.*, 2015). In this context, the newly developed reconfigurable production technologies, RT (a set of computer numerical control (CNC) machines that can be rearranged to execute different machining functions required in dynamic manufacturing) could be instrumental in achieving Plant Responsiveness. Therefore, organizations implement RT to improve responsiveness in their plants (Abdi and Labib, 2017). Indeed, extant research states that RT implementation is essential for gaining a competitive advantage, as it not only enhances PR (Koren *et al.*, 2017), but also Supply Chain Responsiveness (Chandra and Grabis, 2016)

However, empirical study of RT as a source of plant responsiveness has been limited, *presenting a first literature gap*. Effective RT implementation needs to be supported with adequate in-plant technology management (TM) and an adequate Manufacturing Strategy (MS) (Ortega-Jimenez *et al.*, 2015). This RT-TM-MS fit/integration is referred to here as a strategic reconfigurable system (SRS), since it is reconfigurability-based and yields strategy-focused PR as a mechanism to guide plants' RT management, a distinctive competency that generates SC competitive advantage. In this context, plant SCs can be considered the vehicle that extends Plant Responsiveness to customers; so adequate SCM should favor this process. The study of SCM dimensions in plants is therefore considered important as it equips plants with the innovative strategies that they require to build broad responsiveness (Stevens and Johnson, 2016). The strategic view of SCM dimensions in plants could be crucial for enhancing PR, extending it along the SC, and so gaining a competitive advantage (Barney, 2012). However, few studies exist on this topic, leaving a *second literature gap*: i.e., whether SCM dimensions implemented in reconfigurable plants have a positive impact on PR.

This thesis therefore analyzes whether specific SCM dimensions intervene/mediate the SRS→PR relationship. As a *third literature gap,* there are mixed results regarding the impact of the SCM and strategy program on customer responsiveness, and therefore on performance and PR (Roh *et al.*, 2014). As this thesis is focusing on Plant Responsiveness and not on responsive SC, one sub-gap would be the lack of empirical literature discussing the question of the production programs and practices that are important for both SCM and PR, and how they give support. It is also important to identify which PR-enhancing production programs are likely to be mediated by SCM. Likewise, no prior empirical study exists of these relationships. In a research effort to respond to the above questions and address the mentioned gaps, this thesis will analyze SCM's intervening role in the SRS-PR relationship. Plant Responsiveness may be a key that can be measured as an outcome of these relationships due to two main reasons: (1) Plant Responsiveness has become essential for industry competitiveness (Uskonen and Tenhiälä, 2012); and (2) the functionality and production capacity that plants require for these relationships may make them responsive to increasingly interconnected markets (Koren, 2013; Koren *et al.*, 2000); i.e., one main purpose of this study is to investigate the interrelationships among three variables: SRS, SCM and PR.

1.3. Empirical data

Finally, the empiricism of this thesis is based upon the data from the High-Performance Manufacturing (HPM) project, which is based on an international survey of many production plants worldwide. The project is focused to plants within three industries, auto suppliers, electronics, and machinery.

Hence, the HPM database is very comprehensive and covers most of the research areas important in flexibility, reconfigurability, technology, manufacturing strategy, and other production programs, thus offering a multitude of possibilities. Hence, during this study the database content has never posed any restrictions whatsoever, as to the research ideas put forward in this thesis. As matter of fact, just a small portion of the available data has been used to explore the questions raised in the three empirical papers in question for this thesis of compendium. Instead, the research opportunities that have arisen through the author's participation in the HPM project have been acknowledged and appreciated, by including his proposals of flexibility, reconfigurability and responsive measures, which are a part of the last round of the project that were not on previous rounds.

2. OBJECTIVES

This dissertation considers two internal environments, one is geared towards flexibility and the other toward reconfigurability. Both types of environments comprise a set of production programs[1]. and their practices implemented internally in plants The thesis focuses first on whether there are differences when implementing practices from manufacturing strategy (MS) and technology management (TM) in different contexts, as both programs are basis for both flexibility and reconfigurability. However, the research goes beyond technology, as it includes not only practices that are technological in nature, but also organizational-managerial practices (Anand and Ward, 2009; Mishra *et al.*, 2014; Schroeder and Flynn, 2001). Hence, it addresses three main research questions with multiple levels:

1. MS, TM, and performance (Paper 1)
   - 1.1. Do plants need to implement the same production practices from MS and TM regardless of their industry?
   - 1.2. Are high performers in all industries implementing the production practices from MS and TM in the same way?
   - 1.3. Are contextual factors the key to industry differences in the implementation of TM and MS practices?
   - 1.4. Are there any links between practices from manufacturing strategy and practices from technology?
2. Flexible contexts, reconfigurability and responsiveness (Paper 2).
   - 2.1. How production programs, practices, and linkages in currently implemented programs in flexible environments should be considered to support the future adoption of practices aimed at reconfigurability?
   - 2.2. Are plants worldwide currently interrelating production practices and programs to achieve responsiveness as part of their performance? and if so, how they are doing this?
3. Beyond reconfigurability: effects of SCM on Reconfigurable technologies, with the latter as part of a more holistic view, Strategic Reconfigurable System (SRS) that includes Technology Management and Manufacturing Strategy (Paper 3).

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[1] A program is made up of a bundle of production practices being implemented for the same purpose.

3.1. Does Reconfigurable Technologies contribute to achieving Plant Responsiveness (PR) and whether this benefits from the fit with Technology Management and Manufacturing Strategy, thus forming SRS?
3.2. Is there an effect of SCM mediation in the SRS → PR relationship?

Three framework references are then proposed to help to untangle each of the three groups of research questions:

1. One with a single analytical framework for Paper 1, to assess empirical interrelationships between production/manufacturing strategy and technology with two major building blocks of practices. These two blocks are combined along a contextual factor block to determine the effectiveness of production plants.
2. A second framework considers a simple theoretical model for Paper 2, 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. The first block is devoted to the Technology program, whose three areas (i.e., product, process, and information), with their flexibility-linked practices, are organized into two sub-blocks with different focuses (a technological practices sub-block, and a mixed technological and organizational sub-block). The second block is devoted to other production programs that are more organizational 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 program (e.g., proprietary equipment, group technology, cellular manufacturing, and RMS). The technological–organizational mixed practices sub-block includes technological practices that intrinsically require organizational methods, because investments in technology and specific hardware and software systems may not only require changes on their own level, but also organizational-managerial modifications. The organizational programs block includes programs that are primarily of a managerial/infrastructural type (e.g., TQM, HR, JIT, HR, and MS). In order to provide a better program implementation outcome: (1) technological practices must also be internally interconnected; (2) technology must have linkages to JIT, TQM, HR, TPM and MS; and (3) the highest holistic integration of both should show signs of the strongest relation- ships with performance (i.e., more competitive results), especially with responsiveness.
3. The third framework for Paper 3 will analyze Supply chain management (SCM)'s intervening role in the strategic reconfigurable system (SRS)-plant responsiveness (PR) relationship. PR may be a key that can be measured as an outcome of these relationships due to two main reasons: (1) Plant Responsiveness has become essential for industry competitiveness (Uskonen and Tenhiälä, 2012); and (2) the functionality and production capacity that plants require for these relationships may make them responsive to increasingly interconnected markets (Koren, 2013, 2010; Koren et al., 2000). Therefore, i.e., the main purpose of this framework study is to investigate the interrelationships among three variables: SRS, SCM and PR.

Following the above, *the **overall objective of this thesis** is to investigate how plants make use of different programs as bundles of manufacturing practices starting out but not limited to technology and strategy, with the goal of supporting responsiveness and other performance dimensions*. In doing so, this thesis describes the current state in plants, tests theories and enhances the collective body of knowledge by developing conceptual models. The research objective encompasses several research areas of importance in technology management, manufacturing strategy, flexible contexts, reconfigurability, responsiveness, among others. From such areas, the subobjectives of this thesis as a compendium of three papers are threefold: (a) In Paper 1 is to examine whether there are differences in how TM & MS are implemented in different sectors, whether such implementation is linked to performance, including responsiveness, and whether contextual factors explain the differences; (b) in Paper 2 is to empirically show which other production programs and practices, besides MS and TM, as well as linkages in currently implemented programs in flexible environments should be considered to support the adoption of practices aimed at responsiveness; and (c) in Paper 3 is to analyze whether Reconfigurable Technologies benefits from the fit with Technology Management and Manufacturing Strategy, thus forming a Strategic Reconfigurable System (SRS), to achieve Plant Responsiveness (PR), and the possible effect of SCM mediation in the SRS→PR relationship.

Following the overall research objective and its sub-objectives, three areas are identified to be of interest in this thesis. The three parts to investigate are as follows: (1) the relationship among different dimensions of operational performance, including responsiveness; (2) the way manufacturing practices or programs impact responsiveness and other performance dimensions; (3) whether there are contingencies that may help explain the relationships between practices/programs, or the effects of manufacturing practices or programs on responsiveness and other dimensions of operational performance.

3. THEORY AND METHODOLOGY

3.1. Theoretical foundation of the thesis

This section will provide an introduction into the theoretical foundation upon which the thesis is built upon. Theory on technology management, manufacturing strategy, as well as responsiveness and other dimensions from operational performance, considered within flexible or reconfigurable environments, are next discussed.

3.1.1. Technology management (TM)

Since technology is always a sparkling term, it must be clarified here first and foremost as the means to accomplish objectives for the production function through either one or both ways: (1) knowledge initiatives by means of practices, processes, techniques, methods, etc.; and/or (2) the harder based initiatives with machines run by humans, who may not necessarily know the machines internal operations. Hence, the general trend towards an increase in the use of technology in manufacturing plants exists on the premise that it will impact on effectiveness and efficiency (Torkkeli and Tuominen, 2002). However, these investments are often criticized for not providing the desired results, i.e., technology initiatives often lead to neither effective deployment of new practices nor the desired competitiveness being reached as quickly as desired. For this to be understood, it is necessary to consider that the performance effects of technology are influenced by several factors, some of which can be controlled, and others which cannot, but nonetheless they are all important for the final result. Thus, plants need to have an even more progressive and dynamic vision of the management of technologies in production by going beyond merely following the universal recommendation of simply increasing technology use, by also considering in the "equation," the various aspects of its production practices.

The specialized literature on reconfigurability suggests that global economic competition and rapid social and technological changes may force industries in general to target production responsiveness (Ortega Jiménez *et al.*, 2017; Uskonen and Tenhiälä, 2012). Therefore, it is important to know what plants around the world are now doing to meet the technological requirements of responsiveness (i.e., the main characteristic offered by RMS) with the production practices that are available to them (Ateekh-Ur-Rehman and Subash 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 and Flynn, 2004; 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 programs (especially in the short term) to allow an innovative technology system, such as RMS, to be designed and operated efficiently. It would simply not be feasible for all plants to abandon many of their production programs to adopt RMS. Reconfigurable technology cannot "be an end in itself," since it must 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 can simultaneously obtain a low per unit cost and a high degree of flexibility (Rahman and Mo, 2012), can be considered the starting point for the current platform for reconfigurability (Barad, 2013; 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. There are various other practices within these contexts of flexibility. 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 management program (Ortega Jiménez, 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 (IT), i.e., the processes and equipment for processing information.

In addition, the success of any technological system is influenced by a plant's production programs (including JIT, TQM, among others), and effectiveness, (i.e., competitiveness) of all production programs is closely interrelated with technology in both directions. That is, technology management and other production programs together affect performance. Therefore, a possible missing link between technology and other programs implemented in a plant may be a cause of failure (Khanchanapong *et al.*, 2014; Ortega-Jimenez *et al.*, 2012; Schroeder and Flynn, 2001).

Going back to the TM program, when practices from technology aspects, such as product and process are widely applied in a factory, plants are more likely to steer towards a path to competitiveness, through this more complete view of technology. Hence, an open definition of technology comprises not only of hardware systems, but also human and organizational aspects of the way that the plant operates (Heim and Peng, 2010). Consequently, this part of the study focuses on the following four production practices considering two of the three main aspects of technology mentioned above: process and product[2] (Fang *et al.*, 2013). These TM practices should have a significant impact on the effectiveness of production and product technology and, hence, should lead to competitive advantages: group technology-cellular manufacturing, proprietary equipment, anticipation of new technologies, modularization of products,

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[2] For its immense importance in flexible contexts such as automation.

manufacturing involvement in product design, effective process implementation, inter-functional design efforts, new product introduction cooperation, supplier involvement.

3.1.2. Manufacturing strategy (MS)

The concept of manufacturing strategy (MS), also universally known as production strategy or operations strategy (i.e., this term may refer to both manufacturing and service), was first acknowledge by Skinner (1969), referring to it as to manage certain properties of the manufacturing function to achieve competitive advantages. Hayes and Wheelwright (1984) go beyond by describing it as a consistent pattern of decision making in manufacturing functions linked to business strategies. Even further, Swamidass and Newell (1987) consider MS as a tool for effective use of production strengths as a competitive weapon for achievement of business and corporate goals.

Manufacturing strategy (MS) determines how production supports the general objectives of the plant for competitiveness, through the appropriate design and use of production resources and capacities (Demeter, 2003). For this, plants continuously make decisions regarding the deployment of resources, to succeed with the goal of long-term survival and the ability to produce useful short-term output. Since conscious and/or unconscious decisions determine how plants are operated, MS may play an integral part in shaping over time the competitive position of plants, by actively taking charge over the decisions.

To achieve this support and thus taking charge, it is essential for MS to be aligned with both marketing strategy and business strategy in general (Bates *et al.*, 2001). Furthermore, there is still insufficient broad empirical research in the documented production literature that clearly addresses a well- implemented MS based on its practices (Hill, 2000; da Silva Gonçalves Zangiski *et al.*, 2013). Consequently, this sub-section focuses on the fact that for a properly implemented and well-aligned MS, plants should consider five of its practices: MS Formulation, anticipation of new technology; manufacturing-business strategy linkage; formal strategic planning involving plant management; and communication of manufacturing strategy (Schroeder and Flynn, 2001). Logically, these five aspects (practices) do not represent the whole content of MS, but they are sufficiently significant to have been studied in previous research.

3.1.3. Responsiveness and other dimensions from operational performance

Establishing links between an initiative and a performance outcome is 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 and MacCarthy (1999) included both strategic and operational viewpoints on their framework of responsiveness; and later, Ketokivi and Schroeder (2004) argue that both the multi-dimensionality of performance and the strategic goals must be included in analysis of competitiveness.

Operational performance dimensions may be seen as cumulative (Ferdows and Meyer, 1990). Plants that manage their strategy by pursuing competitive priorities in a specific sequence will be more successful than those that do not. In other words, quality, specifically, provides the foundation for dependability, which provides the foundation for speed. Only after speed capabilities have been developed should cost be addressed. The reason for this is the infrastructure that is developed as each of these dimensions is pursued, with quality management practices at its foundation. Thus, quality provides the base for long-term improvements in other dimensions of competitive performance.

Dimensions of performance such as manufacturing cost, speed, and flexibility (i.e., adjustability) are relatively invisible to customers (if they are inferior, however, it will be tough for a plant to compete), but quality, responsiveness, and delivery dimensions are directly evaluated by them. Therefore, organizations are motivated to improve the visible measures to survive competitive threats, without disregarding the invisible ones. See Table 1 for detail on the six performance dimensions.

Therefore, in order to examine the relationship between production programs and performance, this study focuses not only on the two competitive performance priorities in production that the literature (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 therefore such a specific scale (dimension) has been devised for its measurement.

Table 1. Performance dimension: improving competitiveness
(Ortega-Jimenez *et al.*, 2015)

	Affects Speed	**Affects Cost**	**Affects Dependability**	**Affects Flexibility performance/ adjustability**
Quality *Internal*: error free products/ *External*: conformance quality	Improves Response	Reduces cost	Improves it	
Speed Internal: fast throughput/ External: faster customer response	Speed of response	Reduces inventories and risks	Improves it	
Dependability *Internal*: reliable processes/ *External*: on time delivery	Improves fast response	Saves time, reduces costs, gives stability and thus efficiency		
Flexibility performance/ adjustability *Internal*: ability to change/ *External*: wider variety (wide product/service range); more customization; more innovation (frequent new products); cope with volume fluctuations (volume & delivery adjustments)	Speeds up response	Saves time	Maintain dependability	
Cost *External*: Low price, high margin, or both/ *Internal*: High total productivity		Lower prices and or higher profits		
Responsiveness *Internal*: launch new products rapidly and to react quickly, efficiently, and effectively to changes (e.g., in markets/customers, regulations, failures, etc.)/ *External*: Market changes might occur in product specifications, mix, volume and delivery	To react to changes rapidly	Cost effectively		Scalable to produce more products; easily convertible from one product to another

In line with contingency theory, the level of responsiveness that every firm needs is different and depends on firms' individual business strategies (Uskonen and Tenhiälä, 2012; Williams *et al.*, 2013). Hence, the basis for competitiveness must be designed individually according to the company's own 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 both the industry 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 and Hill, 2012)-

3.1.4. Three views to achieve responsiveness

3.1.4.1. Fit: linkages among technology, strategy, contextual effects, and performance

Many industries face open, global markets with requirements for rapid response and low costs. Given the key role that technology plays in business competitiveness, proper technology management (TM) in combination with a good manufacturing strategy (MS), is important to address current challenges. This research analyzes the nature of TM & MS implementation in different industrial contexts to examine whether there are differences in how TM & MS are implemented in different sectors, whether implementation is linked to performance, and whether contextual factors explain the differences. Cost, quality, and responsiveness are used to observe overall multidimensional competitiveness for a more objective analysis to distinguish between two plant types based on performance classification in all three performance measures considered here: *high performer (HP)* for *higher-than-average in all measures*, and *standard performer (SP)* for *lower-than-average* (Garrido-Vega *et al.*, 2015) .

3.1.4.2. Internal environments for flexibility: toward reconfigurability

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 research analyses how current production programs can be a prior step to achieving reconfigurability. The analysis uses a holistic framework that considers a few linkages or combinations of practices from not only technology and manufacturing strategy, but also JIT, TQM, HR, and TPM and how these enhance performance in terms of cost, quality, and responsiveness (Ortega-Jimenez *et al.*, 2015).

3.1.4.3. Supporting production programs for reconfigurability: MS, TM, RT, and intervening role of SCM

Supporting practices are conceptualized as infrastructure practices that create an environment that is conducive for reconfigurability to be effective in a plant. Thus, this research examines relationships between the following production programs that lead to the greater plant responsiveness-PR necessary for market needs: strategic reconfigurable system-SRS (reconfigurable technology-RT supported by manufacturing strategy-MS and technology management-TM), with the emphasis on SCM's intervening role (Ortega-Jimenez *et al.*, 2020).

3.2. Research design

This thesis presents research which investigates relationships between characteristics and constructs of production and operations management, by both theorizing and conceptual modelling, as well as using two large-scale surveys based empirical methods to assess and construct knowledge. Frequently, one of the first steps when conducting any type of research (descriptive, exploratory, or confirmatory) is the development of conceptual models (Meredith, 1993). In such development, researchers go beyond theories already established, to use them to be: (1) combined, (2) intertwined, and/or (3) extended, into models that help better explain problems in question. Therefore, in such modelling, researchers build on current theories to assess derived hypotheses, which may lead to the formation of knowledge.

All three papers are mixed, from established theory to develop conceptual models, as well as based on data from a multi-industry, multi-country survey, the High-Performance Manufacturing (HPM) project. The project and the survey study are next presented. The data used in the empirical papers are treated using several statistical methods, *e.g.,* correlation analysis, subgroup analysis, path analysis and structural equation modelling. These methods are briefly described in section 3.2.4.

3.2.1. High-Performance Manufacturing (HPM) project

There are still many important unanswered questions or with little empirical research regarding how to achieve a sustainable competitive advantage through continuous improvement of manufacturing capacity and what is the relationship between performance and production programs to apply to increase it (Dubey, Gunasekaran & Chakrabarty, 2015). It was precisely the above and the observation that management approaches transcend national borders that led to the creation of the international research project on High-Performance Manufacturing (HPM) in 1991 (Schroeder and Flynn, 2001). The research is based on the development of an international survey, currently coordinated by Dr. Barbara Flynn, to obtain an intercontinental database (America, Asia, and Europe) of the automotive, electronics and machinery sectors, which allows empirically evaluating different critical factors for the HPM. The HPM research was started in Spain in 2006 for the third round and continued with the 4th round. However, the research presented in this thesis use data from either round (i.e., data that were available on the third round for papers 1 or 2, and on fourth round for paper 3).

3.2.2. Survey instrument, data collection, and sample

This thesis uses, either the third or the fourth-round datasets of the international High-Performance Manufacturing survey. In both rounds, twelve questionnaires were targeted at twelve specific management positions of the production plants, from General Manager to supervisors or workshop managers (third round included direct laborers), through those responsible for accounting, human resources, process engineering, product development, chain of supply, or sustainability / environment, among others, to minimize the risk of common method bias-CMB. Besides, the common latent factor test found no indications for CMB since delta differences were < 0.2 when estimations were compared (MacKenzie and Podsakoff, 2012; Podsakoff *et al.*, 2003).

The design of these questionnaires has been conducted by experts from the different research groups participating in the international HPM project, based on the existing literature, and they have been validated, refined, and updated through the different rounds of surveys conducted since the beginnings of the international project (90s). The variables and constructs that are studied are measured through questions or items, distributed in different questionnaires addressed to the mentioned positions within each plant. These questions or items include both objective data of the plant (on performance, characteristics of the plant, and various exogenous variables), and subjective information (normally measured on Likert scales). Many items of the latter type are included in two or more different questionnaires, to be able to triangulate the information and thus minimize the possible biases of the informant. The questionnaires are originally designed in English, the official language of the HPM project, and translated into the languages of the participating countries. In Spain, our team conducted this task, initiated by the author of the thesis. To minimize translation errors and interpretation problems, not only back-translation was used, but also a pilot test was conducted with executives from the different sectors analyzed.

As major differences exist between practices, performance and contextual factors in plants owned by the same company, the unit of analysis is the plant. Also, as some of the analyzed practices may not apply to small plants, it was determined that sample plants should have a minimum of 100 workers (Machuca *et al.*, 2011; MacHuca *et al.*, 2015). In each country plants were stratified into three industries (auto suppliers, electronics, and machinery) that face global but different market competition (Garrido-Vega et al., 2015). Countries were selected for their mix of HP and standard plants, manufacturing strength, and diverse national cultural and economic characteristics to ensure variability in the database. This survey is updated and modified in a series of successive rounds; the 4th, currently the last one, having been completed in 2017 with 330 plants, with more than 25 research groups from 10 developed countries (Germany, Austria/Switzerland, Spain, Finland, Italy, Japan, Sweden, UK, and USA) and 6 emerging (Brazil, China, Israel, South Korea, Taiwan, and Vietnam). For the third round, 2010, there were 314 plants in 11 countries (Austria, China, Finland, Germany, Italy, Japan, Spain, Sweden, and North America (USA and Canada)).

A stratified design was used to randomly select an equal number of plants in each country and each industry. They were therefore distributed evenly between three industrial sectors. Additionally, about half of the plants were randomly selected from lists of "world class reputation" plants that had been extolled as leaders in the literature or by industry experts. This was done to ensure that the sample contained a good representation of some of the best (high performing) plants in the world. The other half of the plants were selected at random from the lists of remaining plants. This provided a comparison group consisting of the more standard plants.

In other words, when conducting the survey, the plants were pre-classified as high or standard performers according to opinions in the sector, such as the company's position in national rankings. However, this is just initial information and is not objective, as it does not come from real performance measurement data (this would be the initially declared status). This aim of this information is, therefore, to function as an initial guide to obtain a certain number of the two types of plant. Subsequently, and precisely to meet the various research objectives, papers that use the database should provide objective confirmation as to which plants are really, high performers, regarding the performance measures considered in the research. This can only be done using the real performance measures obtained in the survey and this is what any research does in this respect (work with the real empirical data and not with information taken from lists and external opinions).

Despite the stratification of the sample, 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. In general, the sample exhibits high variety and seems appropriate for examining the research questions in the papers in this dissertation.

3.2.3. Role of the author in High Performance Manufacturing (HPM)

Spain entered the HPM project in late 2006. By then, the survey instruments were already developed, and pilot evaluated by the project leaders in USA. The Spanish team, directed by Prof. J.A.D. Machuca, conducted the actual data collection using the readily available questionnaires during 2006/2007. Early 2006, the author of this thesis was invited to coordinate technically the universities part of the Spanish HPM project. Since then, the role of the author has been to coordinate information with other countries participating in the study and to respond to questions related to the Spanish data. The study has also provided the author with the opportunity to spend a semester with Prof. Forza at University of Padova and another semester with Prof. Gupta at Florida International University. Finally, the author provided the constructs of reconfigurability and responsiveness for the international HPM project, which were included in the fourth round of the intercontinental data collection and are fundaments for this dissertation.

3.2.4. Statistical methods for research models

3.2.4.1. Canonical correlation analyses (CCA)

Canonical correlation analyses (CCA) were found to be appropriate for *Papers 1 and 2* to assess 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 (Chaharsooghi and Heydari, 2010; Droge *et al.*, 2012) and is suitable for the type of research question addressed in this research. This technique is also considered the most general of the multivariate techniques to evaluate for linkages between practices and programs, and between these and performance (Hair *et al.*, 2010). CCAs enable the relationships between the two groups of variables to be analyzed, with one being 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 and Fidell, 2019).

First, intra-relationships between practices in the technology program and interrelationships between these and other programs and are analyzed. In a second step, the performance measure set is considered to determine if and how implementations of different program and practice environments relate to performance. CCA constructs a weighted linear combination of the variables in each of the two sets being correlated, with weights selected to maximize the correlation between the two weighted vectors, or canonical variates. One of the advantages of canonical correlation analysis is that it requires only multivariate normality of the variables in the data sets.

This research considers six sets of canonical correlation models (i.e., configurations of links as flexible environments) in the analysis, distributed in two stages. 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. The second set model takes the two technological practices and five organizational programs, JIT, TPM, TQM, HR, and MS. The third set model takes all five practices together from the technology program and the five organizational programs. The models represent a progression from the least holistic (Model 1), taking technology alone, to the most holistic view (Model 3), considering all programs 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. The second model with one set is made up of all the practices from the technology program and production performance. The third model takes the technology program with its five practices combined with five organizational programs and production performance. The second stage reviews models 4–6 to check whether responsiveness is the performance dimension with the strongest relationships with the programs and practices.

The analyses with the specific practices from the technology program (especially technological practices) and organizational programs enable us to determine any interconnections. Meanwhile, the analysis with specific practices from the technology program, organizational programs and production performance enable us to determine whether practices from the technology program (mainly technology- based) provide a positive contribution to a number of performance priorities, but especially responsiveness, and whether the combinations of these practices with organizational programs 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).

3.2.4.2. Multivariate multiple regression analysis (MMR): MS to TM linkages across industries

A multivariate focus congruence model is used with multivariate multiple regression analysis (MMR) for *Paper 1*. Fit has been widely measured through regression coefficients in the congruence/selection perspective (Umanath and Kim, 1992). Regression analysis not only shows the general direction of the association, but also provides the degree to which the independent variables affect the dependent variable. The multivariate part of the regression is due to the four outcome variables from each of the production programs (MS and TM). The multiple part of the regression is because there are four predictor variables for the other corresponding program. It is important to note that this method is not being suggested for simultaneous equations, since it may cause the regression coefficients to be biased. Therefore, each of the two tests (i.e., MS practices to TM practices and TM practices to MS practices) tests industry differences.

Simple correlation coefficients are reviewed between the production practices for TM and MS. Next, a model that simultaneously analyses two or more dependent variables that are to be predicted from two or more predictor variables is used. For the analysis, the scales for each practice are considered as dependent or independent variables depending on the test that is being performed. In the first MMR analysis, the technology scales depend on production strategy scales. In the second MMR analysis, the strategy scales function as dependent variables and the technology scales as independent variables. The independent variables that are significant in the multivariate tests (Pillai's Trace, Wilks' Lambda, Hoteling’s Trace and Roy's largest root) will be shown with the level of significance. The dependent variables that are significant will be shown with the coefficient of determination (adjusted R^2).

3.2.4.3. Multiple correspondence analysis (MCA): Relationship between TM and MS practice implementation and performance

Multiple correspondence analysis (MCA) is used to assess for the performance impact of both sets of practices: MS and TM in *Paper 1*. Plants are classified by competitive position as high and standard performers. Although the sample was originally designed to include both high and standard performing plants, this research decided not to rely on their initially declared statuses, as it was sometimes based on subjective information. Instead, a more objective analysis was performed to distinguish between two plant types based on performance classification in three performance measures considered here (cost, quality, and responsiveness): high performer (HP) for higher-than-average in all measures, and standard performer (SP) for lower-than-average. To confirm the importance of linkages between practices in both groups, multiple correspondence analysis (MCA) was proposed. MCA is a technique for nominal categorical data used to detect and represent underlying structures of practice linkage in the resulting groups. Depending on their scores, plants were classified as high implementation and low implementation for each of the MS and TM practices.

Measurement of the plant's operating performance level is next included to gain further insight into TM and MS practice implementation in the 3 sectors under analysis. With the performance measures included, the plants are classified as HP: if cost, quality, and responsiveness are greater than their respective means, and SP: otherwise. This classification is conducted considering the joint mean for the industries and considering the mean of each of the industries for each industry.

TM and MS practices are also classified into two levels of implementation. A practice is considered either “above average” or “below average,” depending on whether its value is higher or lower than the mean for each industry individually. An MCA is then performed to see whether the implementation of TM and MS practices is linked to the HP/SP classification considered. The correspondence analysis graphs for each of the industries will be shown with the resulting Burt table showing the structure.

3.2.4.4. One-way ANOVA: Contextual factors

A one-way ANOVA is used in *Paper 1*, to compare the means of the contextual variables to confirm the results of the contextual variables as differentiators of industry differences.

For this, a test for the homogeneity of variance (Levene's statistic) is performed previously. Next, if there are significant F-values in the ANOVA, multiple comparisons are used to confirm that all the means are not equal, with pairwise comparisons by Tukey's HSD. Finally, confirmation is achieved by testing for homogeneous subsets, which reflected the previous information. This is done by means of grouping together industry results; both those that did not differ from each other in a common group, as well as others that did not differ from each other, but are different from other groups.

Finally, there may be some contextual factors that contribute to the explanation of some industry differences between MS and TM practices. Contextual factors that are believed to affect the common implementation of TM and MS practices differently between industries are considered here. These are: geographic market focus (exports), degree of vertical integration, size, and scale of operations (number of employees), process structure, product line customization, parts per product line, workplace design, and equipment and processes. A series of one-way ANOVA tests with Tukey's HSD to compare means between contextual variables between industries may show which one, if any, of eight contextual variables function as the industry differentiator, by showing different results between industries. The Levene tests may indicate which contextual variables have a homogeneity of variances that cannot be accepted. Accordingly, the ANOVA F should not be used but robust Welch and Brown–Forsythe tests instead. Similarly, the post-hoc comparisons for these cases should be performed with Games–Howell test. These tests may show which contextual variables are differentiated in the industries.

3.2.4.5. Covariance-based structural equation modelling (CB-SEM)

Structural equations modelling (SEM), used in *Paper 3*, is a technique to specify, estimate and evaluate models of linear relationships among a set of observed variables in terms of a smaller number of unobserved variables (Shah and Goldstein, 2006), having the ability to examine multiple relationships simultaneously and allowing for measurement errors (Bollen, 1989). Besides, covariance-based SEM (CB-SEM) is a flexible and compelling data analysis method, with reflective measurement, where hypothetical constructs are estimated as common factors that are assumed to cause their indicators (i.e., observed, or manifest variables). In the data of the thesis, the Hausman test (Hausman, 1978), which satisfies the requirements to be trustworthy (Ketokivi and Mcintosh, 2017), indicated that almost 85% of the variables showed a p value>0.01, showing then a small degree of endogeneity. Relationships between observable variables were also evaluated in the exploratory analysis (Haans *et al.*, 2016) and no quadratic relationship was found. Therefore, they can be assumed to be linear, which justifies adopting CB-SEM.

Two steps are required to evaluate the research model in the PR context:

(1) verification that RT, MS, and TM are correctly aligned with the SRS framework, and with SCM–I, SCM–Q and SCM–H as the SCM framework. Second-order and third-order CFA is considered the best analysis technique for testing in this first step. Starting with RT, MS and TM, results should show the integrated SRS framework, and the SCM fit for the three practices. If values from path coefficients are significant, there may be consistency among the practices or capabilities involved, thereby making both SRS and SCM conceptually equal to an effect construct (Polites *et al.*, 2012; Venkatraman, 1989). Further, to assess the relationships between SRS, SCM, and PR, the significance of the results may give an insight into the model and if it supports it. It is expected that both programs (SRS and SCM) have direct effects on PR, as does SRS on SCM.

(2) to assess for the possible mediation effect of SCM in the SRS→PR relationship and to analyze whether the environmental complexity (EC) contextual factor is the key to interaction in the above relationship. SEM analysis with bootstrapping is used for mediation and interaction in the remaining steps. In addition, FIML (Full information maximum likelihood) from the R Lavaan package is used as the estimation method.

The methodology used for the mediation hypotheses is assessment of indirect effects with the BK method (Baron and Kenny, 1986) from bootstrapping SEM. However, this study will go further than simply theorizing for mediation processes with BK and will include a post hoc analysis. So, following Rungtusanatham et al. (2014), a more explicit procedure to evaluate for mediation processes will be used: bootstrapping. For this, a practice rule recommended by Nitzl, Roldan, and Cepeda (Carrión *et al.*, 2017; Nitzl *et al.*, 2016) will be followed, using the VAF (variance accounted for) ratio to verify whether there is little (< 0.2), partial ($0.2 \leq x < 0.8$) or full mediation (> 0.8).

The interactive effect of context and SRS will have implications for SCM. In other words, the implementation level of the SRS effect on SCM is contingent with the form and/or strength of plant context; at the same time, the form and/or strength of plant context on SCM is contingent on the SRS implementation level (Bergeron *et al.*, 2001). When interaction fit is adopted, subsample correlations are one of the appropriate methods to use (Venkatraman, 1989).

4. OVERVIEW OF GLOBAL RESULTS

In Table 2, an overview of the papers in the thesis is presented. The papers are categorized according to their relationships to thesis objective, methodology and method.

Table 2. Papers, research objective, methodology and method

Papers *Categorization*	1	2	3
Research objective			
TM & MS implementation is linked to performance, including responsiveness, and even if contextual factors explain differences	☑	☑	☑
Production programs and practices, besides MS and TM, as well as linkages in currently implemented programs in flexible environments to support the adoption of practices aimed at responsiveness		☑	☑
Reconfigurable Technologies benefits from the fit with Technology Management and Manufacturing Strategy, thus forming a Strategic Reconfigurable System (SRS), to achieve Plant Responsiveness (PR), and the possible effect of SCM mediation in the SRS → PR relationship			☑
Research methodology			
Descriptive			
Exploratory	☑	☑	
Confirmatory			☑
Research method			
Conceptual modelling	☑	☑	☑
Empirical	☑	☑	☑

The objective of this thesis is threefold, as stated in Section 2. The first part of the objective tests if MT & MS implementation is linked to performance, including responsiveness, and if contextual factors explain differences. Paper 1 takes on manufacturing strategy, technology, contextual factors, and performance that includes responsiveness and considers them both conceptually and empirically. Further, paper 2 is devoted to conceptually and empirically studies relationships between manufacturing strategy, technology, JIT, TQM, HR, and TPM as a flexible configuration toward reconfigurability in the pursuit of responsiveness and other performance dimensions. Finally, Paper 3 aim on exploring how a reconfigurable technology needs to be configured with MS and T as a system along SCM for faster plant responsiveness.

The second part of the thesis objective concerns the way production programs and practices, besides MS and TM, as well as linkages in currently implemented programs in flexible environments, support the adoption of practices aimed at responsiveness. A structured methodology for the pursuit of responsiveness through manufacturing strategy, technology, JIT, TQM, HR, and TPM as a step of flexibility toward reconfigurability is presented in Paper 2. In Paper 3 reconfigurable technology is linked to manufacturing strategy and technology management as a system to improve plant responsiveness, while verifying the mediation of SCM.

The third part of the thesis objective is concerned with the investigation of how Reconfigurable Technologies benefits from the fit with Technology Management and Manufacturing Strategy, thus forming a Strategic Reconfigurable System (SRS), to achieve Plant Responsiveness (PR), and the possible effect of SCM mediation in the SRS→PR relationship. Paper 3 investigates whether plant responsiveness is achieved from the fit of reconfigurable technology, MS, and TM, as well as the intervening role of SCM.

In summary, the three papers touch parts of the thesis objective in several ways as seen next. Together the objective is covered in the collection of papers that constitute the second part of this thesis. Although an overview of the results of each paper is next presented, the discussion of such results is followed in Section 5.

Paper 1 overview

In this paper, the findings are analyzed in the three industrial sectors according to the hypotheses, the data of the international survey described above, and prior studies on the interrelationships (linkages) between MS and TM. Reviews of analyses and discussions of results are in the same order that the hypotheses were developed.

A) MS to TM linkages across industries

The results show some similarities among industries such as:

1. Dependence
   a. Effective process implementation (T1) is positively affected by communication of manufacturing strategy (S3) in all three industrial sectors.
   b. Manufacturing-business strategy linkage (S4) affects T1significantly in both electronics and machinery.
   c. Anticipation of new technologies (S2) has a significant effect on inter-functional design efforts (T2) in all three industries.
   d. Communication of manufacturing strategy (S3) has significant effects on T2 in both electronics and auto supplier.
   e. S3 affects T2 significantly in electronics and auto sectors.
   f. Anticipation of new technologies (S2) is the only MS practice that impacts on new product introduction cooperation (T3) in all industries.
2. No dependence
   a. Formal strategic planning (S1) has no significant impact on any of the TM practices in all industries. This is surprising, since it shows that TM practices do not consider strategic formalization for their implementation to any great extent. This may be caused by ever-changing global markets, making TM practices more responsive and less rigid to long-term planning.
   b. Supplier involvement (T4) is not affected by any MS practices in any industry. This is probably because technology suppliers are external and not under plant control.

B) Dependence of TM practices to MS practices

We see the following similarities in dependence:

1. Effective process implementation (T1) impacts all MS production practices significantly in all industries, but S3 in electronics.
2. T4 impacts significantly S1 both in electronics and in auto supplier.
3. S2 is affected significantly by T3 in all three industries.
4. S3 has the same TM practices impacting it significantly in the following industries
    a. T2 in electronics and auto supplier
    b. T1 in machinery and auto supplier
5. T4 affects significantly S4 both in electronics and auto supplier.

There are some minor differences in some dependence cases. For instance, only in machinery, T2 affects S1 and S2, and T3 impacts S4.

Regarding cases where dependence was not found:

- Similarities in all three industries: T3 did not affect S1; T4 did not affect S2 or S3; T2 did not affect S4.

The only difference between industries was that T4 did not impact any of the MS practices in machinery significantly. This shows that the MS practices under consideration are implemented in this industry without considering technology supplier involvement. This may be due to industry plants either buying standardized technology or making their own technology, which makes them independent from technology suppliers.

C) Reciprocal interdependence of MS and TM practices

On a general level it can be mentioned that MS practices have relationships with TM practices in all three industrial sectors, by a common implantation of their practices. A bi-directional effect could therefore exist between practices from both programs, except for T4 for auto supplier only.

D) Contextual insights from TM-MS common implementation and industry environment

As proposed, there may be some contextual factors that contribute to the explanation of some industry differences between practices from MS and TM. Contextual factors, such as geographic market focus (exports), degree of vertical integration, size, and scale of operations (number of employees), process structure, product line customization, parts per product line, workplace design, and equipment and processes are believed to affect the common implementation of TM and MS practices differently between industries.

A series of one-way ANOVA tests with Tukey's HSD to compare means between contextual variables between industries shows three of eight contextual variables (product line customization, process design and parts per product line) as industry differentiators, since they show that all have different results between industries. Therefore, we found that, except for these three variables, there are no significant differences in the contextual variables among industries

Paper 2 overview

The argument that forms the basis for Paper 2 is whether internal flexible environments (as the platform for transition to reconfigurability) with several different configurations of production programs and their practices, have linkages (i.e., fits), and if so, whether these linkages are stronger in configurations of higher systemic integration. Finally, it assesses whether the highest holistic integration has better/stronger relationships with performance (especially responsiveness, key to progressing from flexibility to reconfigurability).

A) Fits between different blocks of production practices

The canonical correlation results in Model 1 indicate a significant multivariate relationship across all variable sets. Specifically, proprietary equipment (PE) takes the most prominent position to account for the first canonical variable of technological scales. However, mixed scales, anticipation of new technologies (ANT) and effective process implementation (EPI) show the highest correlations with the first technological scales canonical variable.

Model 2 summarizes results of the canonical correlation analysis between the two technological scales and measurement scales in the five production programs highlighted: HR, TQM, JIT, TPM and MS. A pair of the first canonical correlation variables gives unmistakable evidence that technological scales in technology have a relationship on the super-scales, with PE as the most influential from technology and TPM from the super-scales.

Model 3 results show a canonical correlation analysis between five production practices related to technology and five super-scales representing main production programs. The canonical correlation (close to 0.91) is quite high. Although there are no guidelines about the minimum acceptable value for the redundancy index, the higher the value of the index, the better. Thus, there is evidence of the impact between technology scales and super-scales sets, since the redundancy index shows that close to half of the variance in the TM-related practices set is explained by the first canonical variate of the five super-scales set. The opposite is also true: that around half of the variance in the super-scales set is explained by the first canonical variate of TM related practices. These results indicate there is an extraordinarily strong relationship between TM scales and TM practices. Findings prove that ANT, Interfunctional design effort (IDE), and PE, in that order, are the most influential technology-related measurement scale in a link with super-scales. In addition, the first canonical variable of the technology-related measurement scales is highly correlated with such super-scales as TPM, MS and TQM, in that order.

B) Interrelationships between blocks of production practices and performance

A canonical correlation analysis between the two technological scales and the production performance priorities is Model 4. 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 the technological scale's measurement has higher correlation with responsiveness, the key characteristic promised by reconfigurable practices.

Model 5 shows the result of a canonical correlation analysis between all five technology-related scales and the three performance priorities. A pair of the first canonical correlation variables provides unmistakable evidence that all five technology scales have a relationship with all performance priorities. There was an improvement in both canonical correlation and responsiveness rather than with just the technological scales, showing the importance of considering all technology scales to increase the most important reconfigurable characteristic (see Model 4). IDE has the highest loading from technology and responsiveness from performance.

Furthermore, as shown in Model 6, all the JIT, TPM, TQM, HR, and MS super-scales, as well as all the five technology-related measurement scales, are correlated with all the performance priorities. The results reveal that the ANT technology scale, accompanied by sophisticated MS, is likely to be a more important reason of why some manufacturing companies have gained competitive advantages, especially in responsiveness. It is important to stress that the combination all of technology scales along with all super-scales further improved not only the canonical correlation, but also both quality and responsiveness loadings more than technological scales (see Model 4) or all technology scales on their own (see Model 5). This may show the importance of linking all technology scales individually with the rest of programs for a better reconfigurability stage. On the other hand, of all the production performance priorities responsiveness shows the highest correlation with the first canonical variable of the super-scales, with a clear improvement from Model 4 (just technological scales), or better than in Model 5 (all technology scales). This shows the importance of linking all programs for future reconfigurable practices for working better to improve the main feature that they offer: responsiveness.

Paper 3 overview

Specially, starting with RT, MS and TM, results in Paper 3 show the integrated SRS framework, and the SCM fit for the three practices. Since values from path coefficients are significant, there is consistency among the practices or capabilities involved, thereby making both SRS and SCM conceptually equal to an effect construct (Polites *et al.*, 2012; Venkatraman, 1989).

Besides, the significance of the results gives an insight into the model and supports it. Both programs (SRS, and SCM) have direct effects on PR, as does SRS on SCM.

Furthermore, the result for environmental complexity (EC) on SRS (0.220) regarding its respective interaction with SCM is significant at $p<0.05$. The SRS relationship with SCM becomes weaker.

Finally, Paper 3 gives the mediation analysis results using the BK method. Hence, the partial mediation hypothesis is supported, as the value of the direct/mediator effect is between zero and the direct effect's value. Further, results from bootstrapping empirically confirm partial mediation.

5. DISCUSSION OF RESULTS: SUMMARY OF PAPERS

The three papers in this dissertation are summarized below to give the reader a brief understanding of their respective aims and results. Although there are some contributions and managerial implications here, they are better explained in Section 6.1 For more details and limitations, you may read each of the three papers, which are appended in full in the second part of the thesis. For each of the three papers that are coauthored, there is a brief statement to clarify the contributions and responsibilities of the author of this thesis.

5.1. Paper 1: Implementation of technology and production strategy practices: Relationship levels in different industries

Paper 1 analyzes the nature of TM & MS implementation in different industrial contexts to examine whether there are differences in how TM & MS are implemented in different sectors, whether implementation is linked to performance, and whether contextual factors explain the differences. The findings show some differences between the TM and MS practice modes in the three industries. TM and MS implementation is observed to be related to performance, but not in the same way. Three of the eight contextual factors are found to differ in the three sectors, which may explain the differences found in TM and MS implementation. The results imply that plants should consider the joint implementation of TM and MS as their interdependencies may affect performance, outweighing the possible differences between industries in which plants operate. However, when implementing a specific technology practice, not all plants necessarily consider the same MS practices across industries. Likewise, when adopting a certain MS, it is not necessarily influenced by the same technology practices across industries.

This paper was co-authored with Profs. Pedro Garrido Vega, and José Luis Díez Pérez de los Ríos, Michiya Morita. The basic scientific idea, data analysis and results were developed by the author of this thesis, who also wrote it. The author of this thesis and Prof. Garrido-Vega jointly edited and commented the paper on the contributions of the author of this thesis. Prof. Diez helped with the statistics of the paper, and Prof. Morita commented on some contextual issues of the paper. Although, strategically, it was decided to put the authors of this thesis as the second author, he is the corresponding author of the paper.

5.2. Paper 2: The pursuit of responsiveness in production environments: From flexibility to reconfigurability

Paper 2 analyses how current production programs can be a prior step to achieving reconfigurability. The analysis uses a holistic framework that considers several linkages or combinations of practices (technology, JIT, TQM, HR, TPM and production strategy) and how these enhance performance in terms of cost, quality, and responsiveness. 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 program as well as to link them to organizational programs.

The paper was co-authored with Profs. Jose A.D. Machuca, Pedro Garrido Vega, and Roberto Filippini. The basic idea, data analysis and results were developed by the author of this thesis, who also wrote it. The author of this thesis and Profs. Machuca and Garrido-Vega jointly edited and commented the paper on the contributions of the author of this thesis. Prof. Filippini commented on some contextual issues of the paper.

5.3. Paper 3: Achieving plant responsiveness from reconfigurable technology: Intervening role of SCM

Paper 3 examines relationships between the following production programs that lead to the greater plant responsiveness-PR necessary for market needs: strategic reconfigurable system-SRS (reconfigurable technology-RT supported by manufacturing strategy-MS and technology management-TM), with the emphasis on SCM's intervening role. First, RT, MS and TM together form SRS, with a significant impact on PR. Second, when theorizing for mediation processes, SCM intervenes the relationship between the SRS program and PR. Third, the intervening role of SCM is also confirmed by testing for mediation processes. Fourth, environmental complexity interacts with the SRS program in its relationship with SCM. Research implications are twofold: (1) more responsive plants need a more holistic view in which SCM must be deployed in conjunction with SRS; and (2) SCM supports the execution of SRS by playing a key role in improving PR, even when contextual factors are present. Applied implications are that plants can achieve greater responsiveness if they match their production resources around RT through SRS programs. Further, due to SCM's intervening role, SC practitioners should link SCM dimensions to SRS to improve PR.

The paper was co-authored with Profs. Pedro Garrido Vega, and Cristian Andrés Cruz Torres. The basic idea, data analysis and results were developed by the author of this thesis, who also wrote it. The author of this thesis and Prof. Garrido-Vega jointly edited and commented the paper on the contributions of the author of this thesis. Prof. Cruz helped with the statistics of the paper.

6. CONCLUSIONS

6.1. Research contribution

As an overall thesis contribution, an enhanced understanding of operations management is sought for and provided. The thesis contribution is touching several areas of technology management (TM), manufacturing strategy (MS), and responsiveness, especially showing that a TM in combination with a good MS, is important to address current industries challenges such as open, global markets with requirements for rapid response and low costs, thus confirming the major role that technology plays in business competitiveness, including responsiveness. As said above, although Paper 1 shows that there may be some contextual factors that contribute to the explanation of some industry differences between MS and TM practices, plants should consider the joint implementation of TM and MS as their interdependencies may affect not only responsiveness but also other performance dimensions, outweighing the possible differences between industries in which plants operate. Further, when implementing a specific technology practice, not all plants necessarily consider the same MS practices across industries; as well as when adopting a certain MS, it is not necessarily influenced by the same technology practices across industries.

The thesis contributes to the existing body of knowledge by taking a novel perspective on the fit among and between different operational programs. As stated above, Paper 2 presents a holistic framework that considers a few linkages or combinations of practices (technology, JIT, TQM, HR, TPM and strategy) and how these enhance performance in terms of cost, quality, and responsiveness. The framework presents a contribution to both theory and practice. It offers novel insights into the program and production practices involved in transitioning from flexibility to reconfigurability in the pursuit of responsiveness and provide a basis for future research. The results of the analysis show that the link between the technology practices and organizational programs 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 program practices, but also with the organizational 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 program 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.

On the other hand, Paper 3 defines a new concept, as strategic reconfigurable system (SRS), as reconfigurable technology-RT supported by manufacturing strategy-MS and technology management-TM. Thus, a fuller SRS is defined and its impact on PR is empirically evaluated. In addition, SCM fit logic is developed theoretically with empirical evidence of its intervention in the relationship between SRS and PR. This research has discussed several literature gaps regarding theoretical and empirical confirmation of reconfigurability using plant data. Plant managers should adopt RT to obtain greater responsiveness; however, for it to be effective, an adequate SRS (acting simultaneously on TM and MS) should be created, as its implementation is a key factor in gaining a competitive advantage through PR enhancement. Besides, plant managers should improve their SCM dimensions to achieve responsiveness more quickly, both through their direct effects on PR, and their mediating effects (intervening role) on the direct relationships between SRS and PR. Further, when going beyond theorizing for mediation, by testing for mediation processes, SRS-PR is shown to be partially mediated by SCM. Several further contributions can be highlighted. First, the SRS holistic framework (where RT is not isolated but used in a fit with MS and TM) is assessed for the first time and proven to be effective. Second, we theorize for mediation processes by examining how such a framework is supported by SCM. Specifically, by theoretically considering two of the main underlying concepts of the High-Performance Manufacturing research (program integration and contingency) and the mediation fit, the study outlines an understanding of how the relationship between SRS, on the one hand, and plant operational responsiveness on the other, are mediated by the fit between the SCM integration, SCM quality, and SCM senior management support dimensions. This was done by assessing mediation processes theory. Third, this study started with two unconnected literature strands (i.e., reconfigurability's and SCM's individual influence on responsiveness) and has combined them in the proposed analytical framework. Fourth, since results are limited to the programs and PR in question, researchers should be cautious with respect to the generalization of SCM intervening effects for two reasons: (1) when testing for mediation processes, the relationships between other programs (such as TQM, HR, TPM, lean, etc.) and PR may not be mediated by SCM; and (2) program composition measures of different practices may present differences. Finally, the paper reveals how important SCM relationships are, even when contextual factors are present.

6.2. Ideas for future research

Since the three papers were sequential, Paper 2 did some of the proposed future research in Paper 1, and Paper 3 did so of the Paper 2. In the future research into the management and development of manufacturing operations it would be most interesting to answer further research from Paper 3. First, although mediation theory was significant for SCM intervening role, and even when complementing with further testing for mediation processes, the SRS-PR relationship mediated by SCM was confirmed, and future research can expand responsiveness and other programs apart from SRS by further testing the intervening role of SCM suggested in this study, as well as expanding toward a framework for SRS mediations in other relationships. Second, this study has been conducted at the plant level, which is not the entire SC. Future research could involve other supply chain informants. Third, future research could consider other contingent factors (e.g., market information) as other combinations of SCM and SRS practices may be more successful in enhancing responsiveness. Similarly, service industries might obtain different findings regarding the SC practices that support SRS. In addition, this study reports a cross-sectional questionnaire survey, focusing solely on testing correlations between variables. Thus, it might not show dynamic trends or changes and an awareness of fallacies may be required (e.g., correlation does not imply causation, spurious correlations, omitted-variable bias (OVB), coincidental correlation and false causality). So, further research could include longitudinal data to assess causal effects. Furthermore, although the use of subjective data from surveys is commonly used in empirical research, well-established and highly credible archive and secondary data sources offer many benefits (Ellram and Tate, 2016) and provide the opportunity to perform complementary tests on the present research model. As the research results suggest that the integrated implementation of manufacturing practices can mask the effects of contextual factors on SCM, future studies should further investigate any interactions.

ACKNOWLEDGMENTS

This research has been partly funded by the Spanish Ministry of Science and Innovation, Project DPI-2009-11148, Junta de Andalucía project 2015/148 (ref. SBAPA 2015/006), Junta de Andalucía Project P08-SEJ-03841, PID2019-105001GB-I00 (MCIN/AEI/10.13039/501100011033/ - Ministerio de Ciencia e Innovación- Spain); PY20_01209 (PAIDI 2020- Consejería de Transformación Económica, Industria, Conocimiento y Universidades -Junta de Andalucia). The authors wish to acknowledge the support afforded by the Spanish and Andalusian Governments.

REFERENCES

Abdi, M.R. (2009), “Fuzzy multi-criteria decision model for evaluating reconfigurable machines”, *International Journal of Production Economics*, available at: http://www.sciencedirect.com/science/article/pii/S0925527308002867.

Abdi, M.R. and Labib, A. (2017), “RMS capacity utilisation: product family and supply chain”, *International Journal of Production Research*, Vol. 55 No. 7, pp. 1930–1956.

Agarwal, R., Green, R., Brown, P.J., Tan, H. and Randhawa, K. (2013), “Determinants of quality management practices: An empirical study of New Zealand manufacturing firms”, *International Journal of Production Economics*, Vol. 142 No. 1, pp. 130–145.

Anand, G. and Ward, P.T. (2009), “Fit, Flexibility and Performance in Manufacturing: Coping with Dynamic Environments”, *Production and Operations Management*, Blackwell Publishing Ltd, Vol. 13 No. 4, pp. 369–385.

Arana-Solares, I.A., Ortega-Jiménez, C.H., Alfalla-Luque, R. and Pérez-Díez de los Ríos, J.L. (2019), “Contextual factors intervening in the manufacturing strategy and technology management-performance relationship”, *International Journal of Production Economics*, Vol. 207, available at:https://doi.org/10.1016/j.ijpe.2018.11.003.

Ashby, W.R. (1958), "Requisite Variety and its Implications for the Control of Complex Systems (Ashby, 1958)", *Cybernetica* , Vol. 1 No. 2, pp. 83–99.

Ateekh-Ur-Rehman and Subash Babu, A. (2013), "Reconfigurations of manufacturing systems—an empirical study on concepts, research, and applications", *The International Journal of Advanced Manufacturing Technology*, Vol. 66 No. 1–4, pp. 107–124.

Bader, A., Rauscher, M., Heisel, U. and Göhner, P. (2014), "Knowledge Based Configuration of Re-configurable Transfer Centres", *Enabling Manufacturing Competitiveness and Economic Sustainability*, Springer International Publishing, Cham, pp. 371–376.

Barad, M. (2013), "Flexibility development – a personal retrospective", *International Journal of Production Research* , Taylor & Francis, Vol. 51 No. 23–24, pp. 6803–6816.

Barney, J.B. (2012), "Purchasing, Supply Chain Management and Sustained Competitive Advantage: The Relevance of Resource-based Theory", *Journal of Supply Chain Management*, Vol. 48 No. 2, pp. 3–6.

Baron, R.M. and Kenny, D.A. (1986), "The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations.", *Journal of Personality and Social Psychology*, Vol. 51 No. 6, pp. 1173–1182.

Bates, K., Blackmon, K., Flynn, E. and Voss, C. (2001), "Manufacturing Strategy: Building... - Google Scholar", in Schroeder, R. and Flynn, B. (Eds.), *High Performance Manufacturing-Global Perspectives*, John Wiley & Sons, Inc., New York, pp. 42–72.

Bergeron, F., Raymond, L. and Rivard, S. (2001), "Fit in strategic information technology management research: an empirical comparison of perspectives", *Omega*, Pergamon, Vol. 29 No. 2, pp. 125–142.

Bollen, K.A. (1989), *Structural Equations with Latent Variables*, *Structural Equations with Latent Variables*, John Wiley & Sons, Inc., New York, available at:https://doi.org/10.1002/9781118619179.

Carrión, G.C., Nitzl, C. and Roldán, J.L. (2017), "Mediation Analyses in Partial Least Squares Structural Equation Modeling: Guidelines and Empirical Examples", *Partial Least Squares Path Modeling*, Springer International Publishing, Cham, pp. 173–195.

Chaharsooghi, S.K. and Heydari, J. (2010), "LT variance or LT mean reduction in supply chain management: Which one has a higher impact on SC performance?", *International Journal of Production Economics*, Elsevier, Vol. 124 No. 2, pp. 475–481.

Chandra, C. and Grabis, J. (2016), "Reconfigurable supply chains: an integrated framework", *Supply Chain Configuration*, New York, NY, pp. 69–86.

Chang, P.-C., Liao, C.-J., Gen, M., Tiwari, M.K., Tomlinson, P.R. and Fai, F.M. (2013), "The nature of SME co-operation and innovation: A multi-scalar and multi-dimensional analysis", *International Journal of Production Economics*, Vol. 141 No. 1, pp. 316–326.

Demeter, K. (2003), "Manufacturing strategy and competitiveness", *International Journal of Production Economics*, Vol. 81–82, pp. 205–213.

Droge, C., Vickery, S.K. and Jacobs, M.A. (2012), "Does supply chain integration mediate the relationships between product/process strategy and service performance? An empirical study", *International Journal of Production Economics*, Vol. 137 No. 2, pp. 250–262.

Fang, E.A., Wu, Q., Miao, C., Xia, J. and Chen, D. (2013), "The impact of new product & operations technological practices on organization structure", *International Journal of Production Economics*, Elsevier, Vol. 145 No. 2, pp. 733–742.

Ferdows, K. and Meyer, A. de. (1990), "Lasting improvements in manufacturing performance: in search of a new theory", *Journal of Operations Management*, available at: http://www.sciencedirect.com/science/article/pii/027269639090094T.

Flynn, B. and Flynn, E. (2004), "An exploratory study of the nature of cumulative capabilities", *Journal of Operations Management*, No longer published by Elsevier, Vol. 22 No. 5, pp. 439–457.

Flynn, B.B. (1994), "The Relationship between Quality Management Practices, Infrastructure and Fast Product Innovation", *Benchmarking for Quality Management & Technology*, MCB UP Ltd, Vol. 1 No. 1, pp. 48–64.

Garrido-Vega, P., Ortega Jimenez, C.H., de los Ríos, J.L.D.P. and Morita, M. (2015), "Implementation of technology and production strategy practices: Relationship levels in different industries", *International Journal of Production Economics*, Vol. 161, pp. 201–216.

Gläßer, D., Nieto, Y. and Reiner, G. (2009), "Performance Evaluation of Process Strategies Focussing on Lead Time Reduction Illustrated with an Existing Polymer Supply Chain", *Rapid Modelling for Increasing Competitiveness*, Springer, London, pp. 79–90.

Goyal, K.K., Jain, P.K. and Jain, M. (2013), "A novel methodology to measure the responsiveness of RMTs in reconfigurable manufacturing system", *Journal of Manufacturing Systems*, available at: http://www.sciencedirect.com/science/article/pii/S0278612513000575.

Gunasekaran, A. and Reichhart, A. (2007), "Creating the customer-responsive supply chain: a reconciliation of concepts", *Production Management*, available at: http://www.emeraldinsight.com/doi/abs/10.1108/01443570710830575.

Haans, R.F.J., Pieters, C. and He, Z.-L. (2016), "Thinking about U: Theorizing and testing U- and inverted U-shaped relationships in strategy research", *Strategic Management Journal*, Vol. 37 No. 7, pp. 1177–1195.

Hair, J., Black, W., Babi, B. and Anderson, R. (2010), *Multivariate Data Analysis: Global Edition*, 7th ed., Pearson Education, Upper Saddle River., available at: https://www.pearson.com/uk/educators/higher-education-educators/program/Hair-Multivariate-Data-Analysis-Global-Edition-7th-Edition/PGM916641.html (accessed 12 May 2022).

Hausman, J.A. (1978), "Specification Tests in Econometrics", *Econometrica*, Vol. 46 No. 6, p. 1251.

Hayes, R.H. and Wheelwright, S.C. (1984), *Restoring Our Competitive Edge : Competing through Manufacturing*, Wiley.

Heim, G.R. and Peng, D.X. (2010), “The impact of information technology use on plant structure, practices, and performance: An exploratory study”, *Journal of Operations Management*, No longer published by Elsevier, Vol. 28 No. 2, pp. 144–162.

Hill, A. and Hill, T. (2012), *Operations Management*, edited by Hill, A., 3th ed., Palgrave Macmillan , Basingstoke, UK, available at: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.727.5849 (accessed 12 May 2022).

Hill, T. (2000), *Manufacturing Strategy: Text and Cases*, 3th ed., Irwin/McGraw-Hill, Burr Ridge, available at:https://doi.org/10.1007/978-1-349-13724-4.

Hofer, C., Eroglu, C. and Rossiter Hofer, A. (2012), “The effect of lean production on financial performance: The mediating role of inventory leanness”, *International Journal of Production Economics*, Elsevier, Vol. 138 No. 2, pp. 242–253.

Hopp, W. and Spearman, M. (2008), *Factory Physics*, 3th ed., available at: https://books.google.com/books?hl=en&lr=&id=TfcWAAAAQBAJ&oi=fnd&pg=PP2&ots=w-WGL7j2gK&sig=3_Wap6Dt-c2BuEh-fuIc58eAQSQ (accessed 11 May 2022).

Jin, Y., Vonderembse, M. and Ragu-Nathan, T.S. (2014), “Exploring relationships among IT-enabled sharing capability, supply chain flexibility, and competitive performance”, *Of Production Economics*, available at: http://www.sciencedirect.com/science/article/pii/S0925527314000966.

Kalchschmidt, M., Nieto, Y. and Reiner, G. (2009), “Managing Demand Through the Enablers of Flexibility: The Impact of Forecasting and Process Flow Management”, *Rapid Modelling for Increasing Competitiveness*, Springer, London, pp. 265–276.

Ketokivi, M. and Mcintosh, C.N. (2017), “Addressing the endogeneity dilemma in operations management research: Theoretical, empirical, and pragmatic considerations”, *Journal of Operations Management*, Vol. 52, pp. 1–14.

Ketokivi, M. and Schroeder, R. (2004), “Manufacturing practices, strategic fit and performance: a routine-based view”, *International Journal of Operations &*, available at: http://www.emeraldinsight.com/doi/abs/10.1108/01443570410514876.

Khanchanapong, T., Prajogo, D., Sohal, A.S., Cooper, B.K., Yeung, A.C.L. and Cheng, T.C.E. (2014), “The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance”, *International Journal of Production Economics*, Elsevier, Vol. 153, pp. 191–203.

Koren, Y. (2006), “General RMS characteristics. Comparison with dedicated and flexible systems”, in Dashchenko, A.I. (Ed.), *Reconfigurable Manufacturing Systems and Transformable Factories*, pp. 27–45.

Koren, Y. (2013), “The rapid responsiveness of RMS”, *International Journal of Production Research*, Vol. 51 No. 23–24, pp. 6817–6827.

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G. and van Brussel, H. (1999), “Reconfigurable manufacturing systems”, *CIRP Annals - Manufacturing Technology*, Vol. 48 No. 2, pp. 527–540.

Koren, Y. and Kota, S. (1999), “US5943750A - Reconfigurable machine tool”, Google Patents, available at: https://www.google.com/patents/US5943750.

Koren, Y., Mehrabi, M.G., Ulsoy, A.G. and Koren, Y. (2000), “Reconfigurable manufacturing systems: key to future manufacturing”, *Journal of Intelligent Manufacturing*, Vol. 11 No. 4, pp. 403–419.

Koren, Y. and Ulsoy, A. (2002), “US6349237B1 - Reconfigurable manufacturing system having a production capacity method for designing same and method for changing its production capacity - Google Patents”, available at: https://patents.google.com/patent/US6349237B1/en (accessed 10 May 2022).

Koren, Y., Wang, W. and Gu, X. (2017), “Value creation through design for scalability of reconfigurable manufacturing systems”, *International Journal of Production Research*, Vol. 55 No. 5, pp. 1227–1242.

Kritchanchai, D. and MacCarthy, B.L. (1999), “Responsiveness of the order fulfilment process”, *International Journal of Operations and Production Management*, MCB UP Ltd, Vol. 19 No. 8, pp. 812–833.

Liles, D.H. and Huff, B.L. (1990), “A computer based production scheduling architecture suitable for driving a reconfigurable manufacturing system”, *Computers & Industrial Engineering*, Pergamon, Vol. 19 No. 1–4, pp. 1–5.

Machuca, J.A.D., Ortega Jiménez, C.H., Garrido-Vega, P. and de Los Ríos, J.L.P.D. (2011), “Do technology and manufacturing strategy links enhance operational performance? Empirical research in the auto supplier sector”, *International Journal of Production Economics*, Vol. 133 No. 2, available at:https://doi.org/10.1016/j.ijpe.2010.12.010.

MacHuca, J.A.D., Ortega Jiménez, C.H., Garrido-Vega, P. and de Los Ríos, J.L.P.D. (2015), “Erratum: Do technology and manufacturing strategy links enhance operational performance? Empirical research in the auto supplier sector (Int. J. Prod. Econ. (2011) 133:2 (541-550) 10.1016/j.ijpe.2010.12.010)”, *International Journal of Production Economics*, Vol. 170, available at:https://doi.org/10.1016/j.ijpe.2015.03.003.

MacKenzie, S.B. and Podsakoff, P.M. (2012), “Common Method Bias in Marketing: Causes, Mechanisms, and Procedural Remedies”, *Journal of Retailing*, Vol. 88 No. 4, pp. 542–555.

Mehrabi, M.G., Ulsoy, A.G., Koren, Y. and Heytler, P. (2002), “Trends and perspectives in flexible and reconfigurable manufacturing systems”, *Journal of Intelligent Manufacturing*, Kluwer Academic Publishers, Vol. 13 No. 2, pp. 135–146.

Meredith, J. (1993), “Theory Building through Conceptual Methods”, *International Journal of Operations & Production Management*, MCB UP Ltd, Vol. 13 No. 5, pp. 3–11.

Mishra, R., Pundir, A.K. and Ganapathy, L. (2014), “Manufacturing Flexibility Research: A Review of Literature and Agenda for Future Research”, *Global Journal of Flexible Systems Management*, available at:https://doi.org/10.1007/s40171-013-0057-2.

Moradlou, H., Backhouse, C. and Ranganathan, R. (2017), “Responsiveness, the primary reason behind re-shoring manufacturing activities to the UK”, *International Journal of Physical Distribution & Logistics Management*, Vol. 47 No. 2/3, pp. 222–236.

Nagel, R. and Dove, R. (1991), *21st Century Manufacturing Enterprise Strategy: An Industry-Led View*, Vol. 1, Iacocca Institute, Bethlehem, PA., available at: https://books.google.com/books?hl=en&lr=&id=dSjsn_ECSSsC&oi=fnd&pg=PP1&ots=uykOORc55W&sig=k7PnoVac0wf8xYzf42VXaTqpl9Q (accessed 11 May 2022).

Niroomand, I., Kuzgunkaya, O. and Bulgak, A.A. (2012), "Impact of reconfiguration characteristics for capacity investment strategies in manufacturing systems", *Journal of Production Economics*, available at: http://www.sciencedirect.com/science/article/pii/S0925527312001880.

Nitzl, C., Roldan, J.L. and Cepeda, G. (2016), "Mediation analysis in partial least squares path modeling", *Industrial Management & Data Systems*, Emerald Group Publishing Limited, Vol. 116 No. 9, pp. 1849–1864.

Ortega Jiménez, C.H. (2009), "Estrategia de operaciones, tecnología y rendimiento de operaciones en la industria hondureña: propuesta de un modelo universal", *Revista Ciencia y Tecnología*, Latin America Journals Online, pp. 47–65.

Ortega Jiménez, C.H., Eguía Salinas, I., Ortega-Jiménez, C.H. and Salinas, I.E. (2017), "Sistema de manufactura reconfigurable y competitividad industrial", *Economía y Administración (E&A)*, Latin America Journals Online, Vol. 1 No. 2, p. 97.

Ortega-Jiménez, C.H., Domínguez Machuca, J.A. and Garrido-Vega, P. (2014), "From lean to reconfigurability: systematic review of high performance manufacturing.", *International Journal of Management Science & Technology Information*, Vol. 12 No. 12, pp. 99–131.

Ortega-Jimenez, C.H., Garrido-Vega, P. and Cruz Torres, C.A. (2020), "Achieving plant responsiveness from reconfigurable technology: Intervening role of SCM", *International Journal of Production Economics*, Vol. 219, available at:https://doi.org/10.1016/j.ijpe.2019.06.001.

Ortega-Jimenez, C.H., Garrido-Vega, P., Machuca, J.A.D.A.D., Ortega, C.H., Garrido-Vega, P. and Machuca, J.A.D.A.D. (2012), "Analysis of interaction fit between manufacturing strategy and technology management and its impact on performance", *International Journal of Operations & Production Management*, Vol. 32 No. 8, pp. 958–981.

Ortega-Jimenez, C.H., Garrido-Vega, P., Pérez Díez De Los Ríos, J.L. and García González, S. (2011), "Manufacturing strategy–technology relationship among auto suppliers", *International Journal of Production Economics*, Vol. 133 No. 2, pp. 508–517.

Ortega-Jimenez, C.H.O., Machuca, J.A.D.D., Garrido-Vega, P., Filippini, R., Ortega Jimenez, C.H., Machuca, J.A.D.D., Garrido-Vega, P., *et al.* (2015), "The pursuit of responsiveness in production environments: From flexibility to reconfigurability", *International Journal of Production Economics*, Vol. 163, pp. 157–172.

Podsakoff, P.M., MacKenzie, S.B., Lee, J.-Y. and Podsakoff, N.P. (2003), "Common method biases in behavioral research: A critical review of the literature and recommended remedies.", *Journal of Applied Psychology*, Vol. 88 No. 5, pp. 879–903.

Polites, G.L., Roberts, N. and Thatcher, J. (2012), "Conceptualizing models using multidimensional constructs: a review and guidelines for their use", *European Journal of Information Systems*, Vol. 21 No. 1, pp. 22–48.

Purvis, L., Gosling, J. and Naim, M.M. (2014), “The development of a lean, agile and leagile supply network taxonomy based on differing types of flexibility”, *International Journal of Production*, available at: http://www.sciencedirect.com/science/article/pii/S0925527314000425.

Rahman, M.A.A. and Mo, J.P.T. (2012), “Development of theoretical reconfiguration structure for manufacturing automation systems”, *International Journal of Agile Systems and Management*, Inderscience Publishers, Vol. 5 No. 2, pp. 132–150.

Roh, J., Min, H., Hong, P. and Min, H. (2014), “Implementation of a responsive supply chain strategy in global complexity: The case of manufacturing firms”, *International Journal of Production Economics*, Vol. 147, pp. 198–210.

Rungtusanatham, M., Miller, J.W. and Boyer, K.K. (2014), “Theorizing, testing, and concluding for mediation in SCM research: Tutorial and procedural recommendations”, *Journal of Operations Management*, Vol. 32 No. 3, pp. 99–113.

Santos Bernardes, E. and Hanna, M.D. (2009), “A theoretical review of flexibility, agility and responsiveness in the operations management literature”, *International Journal of Operations & Production Management*, Vol. 29 No. 1, pp. 30–53.

Schroeder, R.G. and Flynn, B.B. (2001), *High Performance Manufacturing : Global Perspectives*, John Wiley.

Shah, R. and Goldstein, S.M. (2006), “Use of structural equation modeling in operations management research: Looking back and forward”, *Journal of Operations Management*, No longer published by Elsevier, Vol. 24 No. 2, pp. 148–169.

Sheridan, J.H. (1993), “Agile manufacturing: stepping beyond lean production - Document - Gale Academic OneFile”, *Industry Week*, Vol. 242 No. 8, pp. 30–46.

da Silva Gonçalves Zangiski, M.A., Pinheiro De Lima, E. and Gouvea Da Costa, S.E. (2013), “Organizational competence building and development: Contributions to operations management”, *International Journal of Production Economics*, Elsevier, Vol. 144 No. 1, pp. 76–89.

Skinner, W. (1969), “Manufacturing-missing link in corporate strategy”, *Harvard Business Review*, No. May-June, pp. 136–145.

Slack, N. (1987), “The Flexibility of Manufacturing Systems”, *International Journal of Operations & Production Management*, Emerald, Vol. 7 No. 4, pp. 35–45.

Slack, N. and Brandon-Jones, A. (2019), *OPERATIONS MANAGEMENT*, Ninth., Pearson, Harlow, England; New York, available at: www.pearson.com/uk.

Stevens, G.C. and Johnson, M. (2016), “Integrating the Supply Chain 25 years on”, *Distribution & Logistics Management*, Vol. 46 No. 1, pp. 19–42.

Suresh, N. and Kumar, S.A. (2008), “Production and Operations Management : With Skill Development, Caselets and Cases”, *New Age Inernational Publishers*, pp. 1–284.

Swafford, P.M., Ghosh, S. and Murthy, N. (2008), “Achieving supply chain agility through IT integration and flexibility”, *International Journal of Production*, available at: http://www.sciencedirect.com/science/article/pii/S0925527308003046.

Swamidass, P.M. and Newell, W.T. (1987), “Manufacturing Strategy, Environmental Uncertainty and Performance: A Path Analytic Model”, *Management Science*, INFORMS , Vol. 33 No. 4, pp. 509–524.

Tabachnick, B. and Fidell, L. (2019), *Using Multivariate Statistics*, 7th ed., Person, Boston, available at: https://scholar.google.com/scholar?q=+author:B.G.%20Tabachnick (accessed 12 May 2022).

Torkkeli, M. and Tuominen, M. (2002), “The contribution of technology selection to core competencies”, *International Journal of Production Economics*, Elsevier, Vol. 77 No. 3, pp. 271–284.

Um, J., Lyons, A., Lam, H.K.S., Cheng, T.C.E. and Dominguez-Pery, C. (2017), “Product variety management and supply chain performance: A capability perspective on their relationships and competitiveness implications”, *International Journal of Production Economics*, Vol. 187, pp. 15–26.

Umanath, N.S. and Kim, K.K. (1992), “Task-Structure Relationship of Information Systems Development Subunit: A Congruence Perspective*”, *Decision Sciences*, John Wiley & Sons, Ltd, Vol. 23 No. 4, pp. 819–838.

Upton, D.M. (1994), “The Management of Manufacturing Flexibility”, *California Management Review*, SAGE PublicationsSage CA: Los Angeles, CA, Vol. 36 No. 2, pp. 72–89.

Uskonen, J. and Tenhiälä, A. (2012), “The price of responsiveness: Cost analysis of change orders in make-to-order manufacturing”, *International Journal of Production Economics*, available at: http://www.sciencedirect.com/science/article/pii/S0925527311003707.

Venkatraman, N. (1989), “The Concept of Fit in Strategy Research: Toward Verbal and Statistical Correspondence”, *Academy of Management Review*, Vol. 14 No. 3, pp. 423–444.

Wiendahl, H.-P., Hernández, R. and Scheffczyk, H. (1999), “Die Wandlungsfähige Fabrik - Ansätze und Lösungen”, in Tagungsband zur Fachkonferenz (Ed.), *Verschwendung Vermeiden in Der Produktion*, IFA - Publikation, Frankfurt am Main, available at: https://www.ifa.uni-hannover.de/ifa_publikation.html?&no_cache=1&tx_tkpublikationen_pi1%5BshowUid%5D=1442.

Williams, B.D.B.D., Roh, J., Tokar, T. and Swink, M. (2013), “Leveraging supply chain visibility for responsiveness: The moderating role of internal integration”, *Journal of Operations Management*, Elsevier B.V., Vol. 31 No. 7–8, pp. 543–554.