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DISSERTATION

"OPERATIONAL RESPONSIVENESS IN A MANUFACTURING CONTEXT: ANALYSIS OF ITS IMPACT ON ORGANISATIONAL PERFORMANCE FROM A STRATEGIC PERSPECTIVE"

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"Hay una fuerza motriz más poderosa que el vapor, la electricidad y la energía atómica: la voluntad" (Albert Einstein). Por ella afirmamos la personalidad, templamos el carácter, desafiamos la adversidad, reconstruimos el cerebro y nos superamos diariamente" (Santiago Ramón y Cajal).

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D O C T O R A L D I S S E R T A T I O N

"OPERATIONAL RESPONSIVENESS IN A MANUFACTURING CONTEXT: ANALYSIS OF ITS IMPACT ON ORGANISATIONAL PERFORMANCE FROM A STRATEGIC PERSPECTIVE"

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INTRODUCCIÓN

El actual entorno competitivo, con mercados globales y constante innovación tecnológica, ha provocado una intensificación de la competencia, así como una mayor incertidumbre de la demanda. Los clientes se han vuelto más exigentes y solicitan una mayor variedad de productos en un menor tiempo a fin de que se satisfagan sus requerimientos. Esta situación provoca una reducción constante de los ciclos de vida de los productos que incrementa la incertidumbre a la que deben enfrentarse las organizaciones (D'Souza & Williams, 2000; Ainhoa et al., 2012; Jain et al., 2013), instigando cambios constantes en el entorno de manufactura de las mismas a fin de mantener la utilización de la capacidad instalada (Francas et al., 2011).

Esta circunstancia hace que se exija a las empresas una elevada capacidad de respuesta a los rápidos procesos de cambio derivados de esta situación. La capacidad de responder, o en su caso liderar, estos procesos de cambio es uno de los factores que afectan a la capacidad de supervivencia de las empresas así como a sus rendimientos (Sánchez, 1995; De Toni & Tonchia, 2005) y está íntimamente relacionada (Martínez Sánchez et al., 2007) con la capacidad de responder mejor y en mejores condiciones de tiempo, coste o esfuerzo (Upton, 1994; Dyer & Shafer, 1999) a las demandas del mercado con productos y/o servicios innovadores, de calidad y ofrecidos a un precio adecuado, dentro del marco de la estrategia competitiva de la empresa (Porter, 1986).

La definición de esta estrategia competitiva implica que las empresas desarrollen y mantengan una ventaja competitiva para la creación de riqueza (Hitt et al., 2001), de tal forma que sean capaces de alinear los recursos clave que poseen con los cambios acaecidos en el entorno. En este sentido, de entre las diferentes áreas funcionales que conforman una organización, la capacidad de respuesta del área de operaciones ocupa una posición central en cómo las operaciones pueden ser desarrolladas estratégicamente para desempeñar un papel eficaz en el logro de ventajas competitivas (Slack, 2005).

En la literatura hay una amplia lista de herramientas que permiten posicionar estratégicamente a las organizaciones en el mercado utilizando como base el área de operaciones. Así, en el ámbito mundial se han reconocido muchos elementos de competencia que se centran fundamentalmente en cuatro situaciones básicas (Russell & Taylor, 2006): competencia basada en el coste, la calidad, el servicio y la flexibilidad. Sin embargo, a lo largo de la última década, el foco de la competencia del área de operaciones se está desplazando desde estrategias basadas en el coste, la calidad y el servicio de entrega a estrategias basadas en la flexibilidad (Jain et al., 2013).

En 1984 Upton definió la flexibilidad de manufactura como "*un concepto complejo y multidimensional que representa la habilidad o capacidad de un sistema de producción para adaptarse con éxito a las condiciones cambiantes del entorno, a las necesidades del proceso y de los clientes sin incurrir en grandes trastornos de tiempo, esfuerzo, calidad, costo y desempeño".* De esta forma la flexibilidad de manufactura empezó a considerarse un elemento importante para la definición de la estrategia de operaciones, así como una herramienta esencial que permitía aumentar la capacidad de respuesta del sistema de fabricación mitigando los efectos del aumento de la competencia, la alta volatilidad de los mercados, la reducción de los ciclos de vida y las necesidades cada vez más sofisticadas de los clientes.

Sin embargo, a pesar de que en los últimos años la flexibilidad de manufactura ha pasado a ser considerada, tanto en el ámbito académico como en el profesional, una panacea para todos los problemas de la organización (Redman et al., 2009) y un requisito básico para garantizar la supervivencia de las empresas en el actual entorno competitivo (Shi & Daniels, 2003; Patel, 2011; Patel et al., 2012; Arafa & El Maraghy, 2012; Barad, 2013; Chryssolouris et al., 2013; Jain et al., 2013) la complejidad conceptual y operativa que ha rodeado tradicionalmente a este concepto ha provocado que tanto directivos como investigadores carezcan de una visión completa acerca del efecto sobre el rendimiento empresarial generado por la implantación de prácticas flexibles en el área operativa (Hallgren & Olhager, 2009). De hecho, los trabajos que han analizado la relación entre la capacidad de respuesta, medida como flexibilidad de manufactura, y la performance empresarial han obtenido resultados contrapuestos que evidencian la necesidad de ahondar aún más en este campo (Jain et al., 2013; Pagell & Krause, 1999).

Una primera aproximación a esta literatura indica que pueden ser varias las causas que han provocado que se carezca de una visión completa del efecto generado por la implantación de prácticas flexibles de manufactura en la performance:

En primer lugar, la problemática asociada a la conceptualización del constructo de flexibilidad de manufactura, derivada de su carácter multidimensional. En este sentido, la flexibilidad de manufactura puede manifestarse a través de varios elementos y en la literatura no parece existir una taxonomía ampliamente aceptada sobre el concepto que identifique el número y denominación de los tipos de flexibilidad que conformarían este constructo, así como su nivel de desarrollo. Baste comentar que se ha llegado a identificar la existencia de al menos 50 tipos diferentes de flexibilidad los cuales han sido utilizados además de manera intercambiable (Pérez Pérez et al., 2016).

En segundo lugar, y como consecuencia de la anterior ambigüedad conceptual, la literatura empírica evidencia asimismo una ambigüedad operativa. En este sentido existe una proliferación de escalas parciales e incompletas de medición que son consecuencia de una falta de consenso a la hora de identificar el número de elementos necesarios para medir el alcance de cada tipo individual de flexibilidad.

En tercer lugar, el análisis de la relación entre la flexibilidad y el rendimiento organizacional se ha desarrollado fundamentalmente sobre la base de una gran explosión empírica en lugar de la previa fundamentación teórica (Malhotra & Sharma, 2008). Este hecho ha provocado una proliferación de modelos parciales (que incluyen un número limitado de tipos de flexibilidad) a la vez que heterogéneos, lo que ha dificultado el establecimiento de relaciones claras entre los diferentes tipos de flexibilidad que componen el constructo, así como la comparativa de los resultados entre los diferentes estudios.

Es por esta razón por la que la presente tesis doctoral profundiza en el análisis de la capacidad de respuesta del área de operaciones, medida a través de la flexibilidad de manufactura, y su relación con la performance de la organización.

De una forma más específica se pretende contribuir al desarrollo de una comprensión más completa de la multidimensionalidad del constructo, que permita definirlo y operativizarlo de una forma sistematizada en futuros estudios. Asimismo se pretende proporcionar evidencia empírica sobre el efecto generado por la implantación de prácticas flexibles en el ámbito operativo de la organización, estableciendo relaciones fundamentadas en un marco teórico sólido y una óptica estratégica a fin de estudiar si la flexibilidad en el área de operaciones provoca un mejor desempeño empresarial.

Objetivos de la investigación

Esta tesis doctoral presenta, por tanto, cuatro objetivos principales.

El primer objetivo es proporcionar una revisión objetiva y sistematizada que permita conocer en profundidad la línea de investigación que desarrolla el tema sobre la relación existente entre la capacidad de respuesta del área de operaciones de una organización y su impacto en la performance. Para ello en este estudio se plantea el uso de técnicas bibliométricas (de primera y segunda generación) que permitan describir la estructura del campo en la actualidad y conocer así cuáles son las líneas más actuales de investigación susceptibles de ser investigadas para contribuir a su desarrollo.

El segundo objetivo es proponer una sistematización conceptual del constructo flexibilidad de manufactura que sirva como referencia a futuros investigadores y permita clarificar la controversia conceptual que tradicionalmente ha rodeado a su definición. De esta forma se pretende avanzar en su conceptualización, facilitando un marco teórico para su posterior estudio, así como la justificación de los tipos de flexibilidad que integran este constructo multidimensional en base a marcos teóricos correctamente definidos.

Derivado de lo anterior un tercer objetivo de esta tesis doctoral es avanzar en el desarrollo de escalas generalizables, homogéneas y simplificadas que pudieran ser aplicadas de forma consistente en futuros estudios, complementando de esta forma la sistematización conceptual del constructo y especificando el número de elementos necesarios para definir el alcance de cada tipo de flexibilidad.

Finalmente el cuarto objetivo es presentar una contrastación empírica a partir de un marco teórico claramente definido y aceptado, más concretamente el vinculado al enfoque estratégico del estudio de la flexibilidad, a fin de analizar las relaciones existentes entre los diferentes niveles de flexibilidad, así como identificar el impacto generado en el rendimiento organizacional. Para tal fin se propone la creación de constructos formativos multidimensionales. Este estudio utiliza la metodología PLS-SEM de ecuaciones estructurales basada en la varianza proporcionando conclusiones interesantes sobre la estimación de la flexibilidad de manufactura interna y externa y los efectos correspondientes en el rendimiento de la organización a través de los resultados obtenidos con una muestra de 266 empresas españolas del sector manufacturero.

Estructura de la tesis doctoral

Esta tesis se estructura de la siguiente manera.

En el Capítulo 1 se presenta una revisión sistemática de la literatura académica del campo que relaciona la capacidad de respuesta del área de operaciones de las organizaciones y su impacto en la performance empresarial utilizando técnicas bibliométricas.

En el Capítulo 2 se presenta un proceso de sistematización conceptual en torno a la variedad de nombres y definiciones de flexibilidad que se habían propuesto en la literatura académica para el constructo flexibilidad de manufactura. Este proceso constituye un primer intento para desarrollar una taxonomía estandarizada de términos y definiciones de los tipos de flexibilidad que componen el constructo flexibilidad de manufactura.

El Capítulo 3 presenta un proceso de sistematización operativa que permite avanzar en el diseño de escalas de medición de la flexibilidad de manufactura de forma consistente. Esta discusión teórica, junto con su posterior validación empírica, constituye un primer esfuerzo de operativización homogénea en base a un patrón sistematizado que proporciona las bases necesarias para la futura homogeneización del campo.

El Capítulo 4 presenta el desarrollo de una propuesta de modelo explicativo de las relaciones entre los diferentes tipos de flexibilidad identificados y sus efectos sobre la performance empresarial. De una forma más específica el modelo propuesto se fundamenta en las premisas teóricas procedentes de la perspectiva estratégica, construyéndose así sobre la base de un marco teórico sólido.

El Capítulo 5 presenta la recolección de los datos, la metodología, y el análisis de los resultados; el cual sustenta la mayoría de las hipótesis formuladas en este estudio.

Para finalizar, se desarrollan las conclusiones y una discusión sobre las contribuciones teóricas y las prácticas de gestión, las limitaciones, y las sugerencias para futuras investigaciones.

Esta tesis clarifica el concepto de flexibilidad de manufactura y su operativización, a la vez que representa un esfuerzo válido por profundizar en la teoría estratégica de flexibilidad de manufactura validando empíricamente este marco teórico. Asimismo, esta tesis podría figurar entre un número reducido de investigaciones en flexibilidad de manufactura en transmitir avances teóricos al proponer, operativizar y validar constructos formativos de segundo orden, los cuales han sido escasamente utilizados en la literatura hasta el momento.

INTRODUCTION

Nowadays, the current competitive environment with global markets and constant technological innovation has led to an intensification of competition, as well as increased demand uncertainty. Customers have become more demanding and they request a greater variety of products in a shorter time. This situation forces a reduction of product life cycles making that organisations have to face to the increasing uncertainty (D'Souza & Williams, 2000; Ainhoa et al., 2012; Jain et al., 2013) that instigates constant changes in manufacturing environment in order to maintain sufficient capacity utilization (Francas et al., 2011).

This scenario makes that companies are required high responsiveness capacity to rapid change processes arising from this situation. The ability to respond to these processes of change is one of the factors that affects the survivability of companies and their yields (Sánchez, 1995; De Toni & Tonchia, 2005) and it is related (Martínez Sánchez et al., 2007) with the capacity to react better and with little penalties in time, effort or cost (Upton, 1994; Dyer & Shafer, 1999) to market demands with innovative and quality products and/or services offered at an affordable price, within the framework of the competitive strategy of the firm (Porter, 1986).

Strategy implies that firms develop and maintain a competitive advantage for wealth creation (Hitt et al., 2001) aligning their key resources with environmental disturbances. In this sense, within the different areas that conform an organisation, the responsiveness capacity of operational area occupies a central position in how operations can be strategically developed to play an effective role in achieving competitive advantages (Slack, 2005).

In the literature there is an extensive list of tools that enable organisations to be strategically positioned in the market using the operation area as a base. Thus, at the global level it has been recognized many elements of competition that are mainly focused on four basic situations (Russell & Taylor, 2006): cost-based, quality, service and flexibility competition. However, over the last decade, the focus of competition has moved away from strategies based on cost, quality and service to strategies based on flexibility (Jain et al., 2013).

Upton in 1984 defines manufacturing flexibility as *"a complex and multidimensional construct that represents the ability of the production system to react successfully to changes on environmental conditions with little penalty in time, effort, cost or performance*". Thus, manufacturing flexibility began to be considered a relevant element for defining operations strategy and an essential tool that allowed to increase the responsiveness of the manufacturing system mitigating the effects of the challenges listed above (i.e. increased competition, high volatility of the markets, shorter product life cycles, among others).

However, even though recently manufacturing flexibility has been recognized as an important element, both in academia and by practitioners, for solving all the problems of the organisation (Redman et al., 2009) and a basic requirement to ensure the survival of businesses in today's competitive environment (Patel 2011; Patel et al., 2012; Arafa & El Maraghy, 2012; Barad, 2013; Chryssolouris et al., 2013; Shi & Daniels, 2003; Jain et al., 2013) the conceptual and operational complexity that has traditionally surrounded this concept has increased the ambiguity to establish the impact on performance generated by the implementation of operational flexible practices (Hallgren & Olhager, 2009). In fact, studies that have analysed the relationship between operational responsiveness, measured as manufacturing flexibility, and business performance, have shown conflicting results highlighting the need to further research into this field (Jain et al., 2013; Pagell & Krause, 1999).

A first approach to the literature indicates that several causes could have provoked this situation:

Firstly, there is the need to clarify the existing controversy around its conceptualisation (Jain et al., 2013; Narain et al., 2000) as a consequence of its multidimensional character. In this sense, manufacturing flexibility can be manifested through different aspects and in the literature there is not a widely accepted taxonomy of the concept that identifies clearly the number, the level of development and the name of flexibility types that conform this construct. For example, some studies have noted the existence of at least 50 different flexibility types which have been used interchangeably (Pérez Pérez et al., 2016; De Toni & Tonchia, 2005).

Secondly, and due to the above conceptual ambiguity, the empirical literature has also been controversial. In this sense, there is an extensive proliferation of partial measurement scales that are the consequence of a lack of agreement for defining the number of elements needed to measure the scope of each individual flexibility type.

Thirdly, the analysis of flexibility-performance relationship has been built fundamentally on the base of a great empirical explosion but one that lacks a previous and solid theoretical foundation (Malhotra & Sharma, 2008). This situation resulted in a proliferation of partial and heterogeneity models (that usually include a reduced number of flexibility types). Thus, it is difficult to establish the trade-offs among the various flexibility types, or to compare the results obtained in different studies.

For this reason, this dissertation explores the analysis of the operational responsiveness capacity, measured as manufacturing flexibility, and its relationship to the business performance.

More specifically, this dissertation tries to contribute to the development of a more complete understanding of this multidimensional construct, which allows to define and operationalise it in a systematic way in future studies. It also seeks to provide empirical evidence of the effect on business performance generated by the implementation of flexible practices at the operational level of the organisation, founded on establishing its relations based on a solid framework and a strategic perspective.

Research objectives

This dissertation presents four main objectives. The first objective is to provide a comprehensive, systematic and objective review of the academic research on the operational responsiveness capacity and its impact on performance. This study applies bibliometric indicators (first and second generation relation indicators) that allows to describe the current structure of the field and to identify potential avenues for future research in order to contribute to the development of the field.

The second objective is to provide a conceptual systematisation of manufacturing flexibility construct that could be used easily and consistently in future studies. In this sense, this study tries to advance on the conceptualisation of the construct identifying the flexibility types that make up this multidimensional construct based on properly defined theoretical frameworks.

Due to the above, the third objective is to advance on the development of generalisable, structured, homogeneous and simplified measurement scales of the construct that could be easily and consistently applied in future studies.

And finally, the fourth objective is to conduct an empirical study by assessing a clearly framework, more specifically the strategic perspective of manufacturing flexibility. The study propose the use of formative multidimensional constructs. This study used structural equation modeling (SEM) based on variance, which provided interesting results in the assessment internal flexibility, external flexibility, and the effects between these two upon business performance. The results, obtained from a sample of 266 manufacturing Spanish firms, provided support to most of the formulated hypotheses in this study. In addition, the discussion and conclusions from this empirical study highlight the need to address future lines of research.

Structure of the Doctoral Dissertation

This dissertation is structured as follows:

In chapter 1, a systematic review of academic literature of the field that relates operational responsiveness capacity of an organisation and its impact on performance through bibliometric indicators is presented.

In chapter 2, a conceptual systematisation process of the names and definitions of manufacturing flexibility types that make up this construct is presented. This process constitutes a first attempt for developing a standardised taxonomy of manufacturing flexibility construct.

In chapter 3, an operational systematisation process that lets to advance on the design of consistent measurement scales is presented. The discussion presented together with the empirical validation constitutes a first effort to the homogenous operationalisation of the construct.

Chapter 4, presents the theoretical discussion for the development of the model proposal. More specifically, it is based on the theoretical premises from the strategic perspective, so it could be considered that it is built on the basis of a solid theoretical framework.

Chapter 5 presents the methodology, the data collection, and analysis of the results, which provide support to most of the hypotheses formulated in this study.

Finally, the conclusions, contributions to theory and managerial practice are presented, as well as the limitations and directions for future research.

CHAPTER 1

BIBLIOMETRIC REVIEW OF MANUFACTURING FLEXIBILITY FIELD

1.1 Introduction

In spite of the general agreement among professionals and scholars about the relevance of manufacturing flexibility and its benefits, the articles whose main goal is to identify both the structure of this topic and potential avenues for future research published in journals indexed in the ISI Web of Knowledge database are scarce (Jain et al., 2013; Beach et al., 2000; Vokurka & O'Leary Kelly, 2000) and with regard to their methodology, it cannot be said that there has been a systematic review of the topic of manufacturing flexibility to date.

Therefore, the main goal of the first chapter of this dissertation is to provide a comprehensive, systematic and objective review of the academic research on manufacturing flexibility through applying bibliometric indicators. Additionally, this review will allow us to have a more realistic view of the development and size of this research line, to synthesise and organise existing knowledge through the identification of research clusters and to identify potential avenues for future research. The rest of the chapter is organised as follows: in the next section, we describe the methodology of the systematic review and bibliometric analysis. The results of the process are explained in the third section, and finally, we present the main conclusions that can be drawn from our research.

1.2 Methodology

This section first describes the methodology for the systematic review of the scientific literature. Second, we briefly present the types of indicators used in the second stage of the bibliometric analysis.

1.2.1 Methodology used in the systematic review process

For the development of this research, we carried out a previous systematic search, accessing the ISI Web of Knowledge database during the month of July 2013 with the criteria detailed below and in Table 1. ISI database has been selected for most of the researchers that develop this analysis (Ramos-Rodríguez & Ruiz-Navarro, 2008). The time selected was the maximum allowed by the database. However, we did not include the year 2013 in our time limit because the complete results for this year will not be available until mid-2014. The use of the entire Web of Knowledge database avoids a potential bias and/or omission in the final set of the selected articles given that we have considered a set of relevant journals.

The multidimensional nature of the term “flexibility” – some studies have noted the existence of at least 50 different dimensions (De Toni & Tonchia, 2005) – has led to a lack of consensus on the definition of the term (Shi & Daniels, 2003, Xu et al., 2011; Wadhwa & Rao, 2000) as well as its dimensions and measures (Gerwin, 1993, Suarez et al., 1996, Swafford et al., 2006; Buzacott & Mandelbaum, 2008; Urtasun-Alonso et al., 2012). For this reason, to ensure the comprehensive nature of our search, we selected the most generic term possible: “flexibi*.” The search also included keywords referring to the nature of manufacturing flexibility. In this sense, we included the terms “operat*” and “manufact*” because the literature has generally used them interchangeably (De Toni & Tonchia, 2005).

These keywords were used as selection criteria for the title (Dong et al., 2012; Yang et al., 2012; Kulacoglu & Oztuna, 2011), given that title words present the core information that the authors would like to express (Yang et al., 2012) and provide a reasonably detailed picture of an article's theme (Fu et al., 2013).

Table 1. Systematic Description of the Terms Used in the Search Process

Key words	("flexibi*")AND (“operat* or “manufact*”")
Type of document	"article" AND "review" (but not "book review")
Language	"English"
Research Area	Operations Research Management Science OR Business Economics
Publications Year	Exclude 2013

Source: Authors

With regard to the publication language in JCR magazines, our research revealed that 95.06 percent of the journals were published in English, which was therefore chosen as the search language. With regard to the type of documents searched, it was decided to select the articles and reviews published in journals as the basis for analysis because both types of documents are the sources of the most up-to-date knowledge.

With these search criteria, we obtained an initial sample of 251 documents, which were reduced to 245 documents after a filtering process to eliminate a misclassification of items in the database (see Appendix I). This sample size is similar to (Chao et al., 2007; Vossen et al., 2000; Wallin, 2012; Rojas, et al., 2011) or bigger than (Sifrim et al., 2012; Wan et al., 2009; Terajima & Áneman, 2003; Pinheiro et al., 2012) sample sizes in other bibliometric studies, confirming that the sample size used in this study is suitable for the development of this type of methodology.

When the final sample was obtained, the second phase of the study began, involving the creation of an ACCESS database that was adjusted to perform the analysis without distorting the results. In a more precise way, adjustments during data downloads were made, verifying that references to the same author were carried out in the same manner or homogenising the *keywords* from the text in plural and singular terms.

1.2.2 Methodology used in the bibliometric analysis.

Bibliometrics can be defined as a division of scientometrics that applies mathematical and statistical methods to study and analyse scientific activity in a field of research (Callon et al., 1995). In this dissertation, we used diverse types of bibliometric indicators, which can be classified into two categories:

1. *Activity indicators*. These indicators have a higher quantitative component because they provide data about the volume and impact of research. In this particular case, we analysed the productivity of authors and journals, the evolution of the field of study, and compliance with Lotka's Law[1] (Lotka, 1926).

2. *First and second generation relation indicators.* Particularly, we used Author Co-citation Analysis (ACA) and co-word analysis. ACA allows us to trace the connections

[1] Lotka's Law is formulated as $Y= K/X^n$ where *K* and *n* are constants, usually *n = 2, Y* is the number of authors publishing *n* papers and *X* is the number of authors publishing one paper in an area of research over a period (Chung and Cox, 1990). Thus, values close to 2 indicate a higher field concentration.

between researchers and fields, emphasising the idea that joint references contained by scientific articles let us identify the seminal documents as well as those that contribute to the development of the field. Its validity as a means of exploring the intellectual structure of a scientific discipline has been amply demonstrated in numerous studies (Ramos-Rodríguez & Ruiz-Navarro, 2004). The co-words technique is based on the analysis of the co-occurrences of keywords, which allows the depiction of the state of the art research, identifying and classifying clusters or research topics in a strategic matrix associated according to their levels of development.

With regard to the tools used for the calculation of these indicators, for activity indicators and ACA we used the software programs SITKIS along with UCINET and Netdraw, while for the analysis of co-words the specific software REDES 2005 was used.

1.3 Results

In this section, we first present the main results of the application of the activity indicators. Second, we discuss the results obtained from the first and second generation relation indicators.

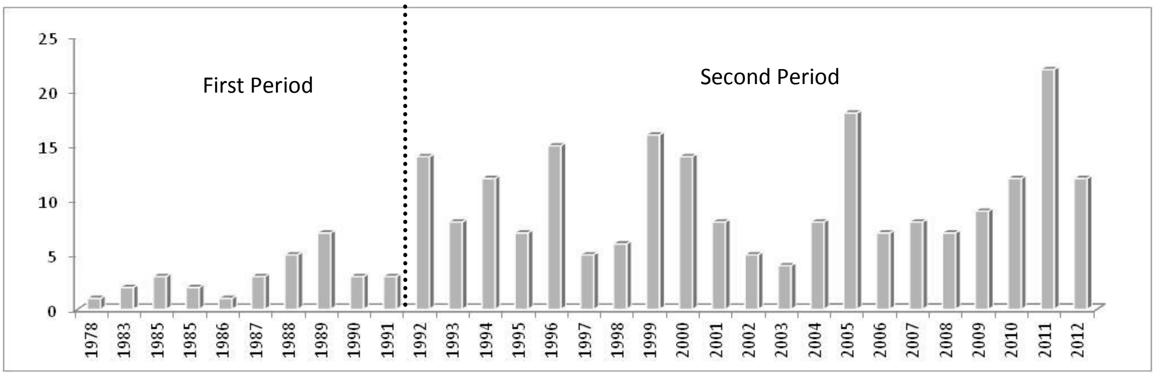
1.3.1 Results of the activity indicators

The main results obtained in relation to the application of activity indicators are summarised in Figure 1 and Table 2.

Regarding the first indicator, the evolution of the field of study, the analysis shows that the field of manufacturing flexibility is a relatively long-standing field, as the first documents on the topic date from the late 1970s. Its evolution has confirmed the existence of two research cycles differentiated by their production level (see Figure 1). The first period covers 1978-1991, and in it scientific production was quite limited (indicated by several years with very low production). The issues covered in this period mainly concentrated on the study of Flexible Manufacturing Systems (FMS).

The second period, however, is marked by a surge in research starting in the early 1990s that coincided with a rise in the vision of flexibility as a competitive weapon (De Meyer et al., 1989; Bolwjin & Kumple, 1990). Production in this period increased significantly but in an irregular pattern. During this second period, there was an emergence of the strategic perspective of flexibility as well as an increasing concern about its management. Thus, conceptual and review articles about the flexibility construct, as well as works that analyse different aspects, such as the fit between flexibility and environment, the effect of advanced manufacturing technologies or its relationship with supply chain, began to emerge.

Figure 1. Evolution of the field of study



Source: Authors

The analysis of Lotka's law allows us to determine whether most of the production within the analysed field is concentrated among a limited number of authors. In this case, the result 2.55 shows that, compared to other fields (such as the field of family businesses, with a value of 2.69 [Benavides-Velasco et al., 2011]), there is a greater concentration of articles by a small number of productive authors. According to these results, a total of 552 different authors have published 245 articles, of which 359 authors posted only a single article (65 percent of the total).

This analysis was also carried out on the productivity of authors and journals and its comparison with the average of references within the sample. This comparison shows that the most productive authors and/or journals are not always the most cited, as shown in Table 2. This conclusion could be biased by the fact that articles published earlier are likely to have received many more citations than more recently published papers. As a consequence, this ranking is more likely to include well-established scholars who began publishing their research some time ago. Thus, firstly, with respect to the productivity of the authors, it was found that the authors in our sample have each published 2.25 documents on average. Secondly, with respect to the productivity of the journals, it was found that the final sample used in this analysis has been published by 75 different journals.

Table 2. Activity Indicators

Evolution of the field of study	**2 research periods are identified (Figure 2)**	
	First period: 1978-1991	Second period: 1992- present
Lotka's Law	N=2.55	

Productivity of authors and most cited authors

Ranking of the most productive authors (number of articles per author)										**Ranking of the authors most cited (average of references per author)**	
MALHOTRA MK	6	BUZACOTT JA	3	BYRNE MD	2	HO JC	2	SHARMA S	2	SWAMIDASS P	51
BEACH R	4	CHANG SC	3	CAO M	2	IRAVANI SM	2	SHEWCHUK JP	2	GERWIN D	36
BENJAAFAR S	4	CHRYSSOLOURIS G	3	CHEN IJ	2	KOGUT B	2	SON YK	2	STECKE KE	25
CHAN FTS	4	GERWIN D	3	CHUNG CH	2	KOSTE LL	2	SUAREZ FF	2	BARAD M	22
DAS A	4	GUPTA YP	3	CHUU SJ	2	KULATILAKA N	2	TONCHIA S	2	GUPTA YP	19,3
GUPTA D	4	LLORENS-MONTES FJ	3	CUSUMANO MA	2	NOR NGM	2	VAN HOP N	2	HUTCHISON J	18
MUHLEMANN AP	4	MANDELBAUM M	3	DAS SK	2	OKE A	2	VAN OYEN MP	2	ZHANG YM	17
NARASIMHAN R	4	MOHAMED ZM	3	DE TONI A	2	OLHAGER J	2	VERDU-JOVER AJ	2	UPTON DM	16,6
PATERSON A	4	MOURTZIS D	3	DJASSEMI M	2	PARK CS	2	VONDEREMBSE MA	2	BOYER KK	16
PRICE DHR	4	PAPAKOSTAS N	3	FINE CH	2	PATEL PC	2	WAHAB MIM	2	SUAREZ FF	14
SHARP JA	4	UPTON DM	3	FISCH JH	2	PETRONI A	2	YANG CL	2	KOSTE LL	13,5
SHEU C	4	ZHANG QY	3	FISSCHER OAM	2	RAMAKRISHNAN R	2	ZHU XY	2	SLACK N	12,5
SLACK N	4	ABLANEDO-ROSAS JH	2	GAIMON C	2	REIMANN M	2	ZSCHOCHE M	2	DE TONI A	12,5
WADHWA S	4	BORENSTEIN D	2	GARAVELLI AC	2	RUIZ-TORRES AJ	2	ZUKIN M	2	KOGUT B	12,5
ALEXOPOULOS K	3	BRILL PH	2	GOYAL S	2	SCHILTKNECHT P	2				

Most productive journals in the area and most cited journals

Ranking of the most productive journals (number of articles per journal)				**Ranking of the journals most cited (average of references per journal)**	
INT J PROD RES	44	IEEE T ENG MANAGE	3	CALIF MANAGE REV	38,0
EUR J OPER RES	20	INT J SYST SCI	3	ORGAN SCI	35,0
INT J PROD ECON	17	PROD OPER MANAG	3	STRATEGIC MANAGE J	33,3
INT J OPER PROD MAN	16	OPER RES	**2**	MANAGE SCI	32,1
J OPER MANAG	13	SLOAN MANAGE REV	2	J PROD INNOVAT MANAG	32,0
OMEGA-INT J MANAGE S	9	IND MARKET MANAG	2	J INT BUS STUD	28,0
MANAGE SCI	8	LONG RANGE PLANN	2	OPER RES	27,5
J MANUF SYST	8	M&SOM-MANUF SERV OP	2	IIE TRANS	20,0
INT J FLEX MANUF SYS	8	FLEX SERV MANUF J	2	COMPUT OPER RES	17,0
PROD PLAN CONTROL	8	APPL ECON	2	IND LABOR RELAT REV	16,0
INT J COMP INTEG M	6	TOTAL QUAL MANAG BUS	2	ACCOUNT ORG SOC	13,0
COMPUT INTEGR MANUF	4	ECON MODEL	2	IEEE T ENG MANAGE	12,3
DECISION SCI	4	OPER MANAGE RES	2	SLOAN MANAGE REV	11,0
STRATEGIC MANAGE J	3			J OPER MANAG	10,3

Source: Authors. Note: We only represent authors and journals that have published more than 1 paper.

1.3.2 Results of the Relation Indicators

1.3.2.1 Network of Co-citation between authors

ACA allows us to identify the seminal documents as well as those that have contributed to the development of the field through the analysis of connections between joint references contained in scientific articles. Co-citation analysis is one of the most common and efficient tools for identifying central articles in a body of literature (Zitt & Bassecoulard, 1994). Because Web of Knowledge has historically excluded many journals that publish research in its early stages (Cornelious et al., 2006), this type of indicator allows us to identify important references that were not included in the initial sample of documents.

Given that the number of cited references that are usually handled in this type of indicator analysis is very high, this procedure requires the use of a cut-off or citation threshold. In this particular case, and according to previous studies (Ramos-Rodríguez & Ruiz-Navarro, 2008), this threshold implies the selection of papers with more than 10 citations.[2] According to Sanz (2003), to measure the structure, organisation and level of integration of this indicator, two aspects must be considered.

The first aspect is the density, expressed as a percentage of the ratio between the number of existing relationships with the maximum number of relationships that could exist if all nodes were connected directly with all others. In this case, the 84.21 percent density calculated reveals high connectivity among authors.

The second aspect refers to the centrality, which is based on the percentage of connections that a node has within the entire network (Freeman, 1979). Centrality can be measured through the range,[3] proximity[4] and mediation.[5] Analysing the centrality

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[2] Similar to Ramos-Rodríguez & Ruiz Navarro (2008), we have selected the necessary and sufficient papers to reach the 2 percent of the total citations of the papers used in ACA analysis.

[3] Centrality measured through the range is the ratio of real relationships over all possible links.

$$CD\,(n_i) = \sum x_{ij}$$

[4] Centrality measured through proximity is the average distance from influence domain actors *j* to actor *i*. It reflects how proximate actor *i* is to the set of all actors.

through the range, one can appreciate articles that allow greater access to information, identifying the best connected articles in the network. The measure of proximity identifies articles that allow access to the rest of the referenced articles, considering the quality of information when analysing not only the number of references but also which references they are. With mediation, one identifies the articles that are most intermediate between articles that have been referenced, allowing us to know which articles are unrelated to each other.

In Table 3, the results of centrality through the three measures are presented. This table shows the existence of several articles that allow greater access to information, identifying those that are best connected in the network.

In analysing the 20 most influential references identified, it is important to highlight the high theoretical, conceptual and review components of these works. Of these 20 papers identified, 75 percent belong to the initial database, while the remaining 25 percent are references to books or journals not classified as JCR and therefore not available in the ISI database.

In addition, among the journals that have published these papers, the most prolific journals include the *International Journal of Production Rese*arch (4) followed by the *European Journal of Operational Research* (3). These journals rank first and second, respectively, in the journal productivity ranking shown in Table 3.

$$D_i = \sum_{j=1}^{n} D_{ij}$$

[5] Centrality measured through mediation is the proportion of actors in the influence domain to the average distance of these actors to actor *i*.

$$C_B\,(k) = \frac{2\sum_{i=1}^{n}\sum_{i=1}^{n}\left(\frac{g_{ij}(k)}{gij}\right)}{n^2 - 3n + 2}$$

Table 3. ACA analysis results

References identified using a citation threshold of 2 percent	Ranking PROXIMITY	Ranking MEDIATION	Ranking RANGE
Cox, T. (1989). Toward the measurement of manufacturing flexibility. *Production and Inventory Management Journal*, *30*(1): 68-72.*	1	1	7
Swamidass P.M. & Newell W.T. (1987). Manufacturing Strategy, Environmental Uncertainty and Performance: A Path Analytical Model. *Management Science,* 33(4):509-24	2	2	2
Browne, J., Dubois, D., Rathmill, K., Sethi, S.P. & Stecke, K.E. (1984).Classification of flexible manufacturing systems. *The FMS magazine*.*	3	3	4
Gerwin, D. (1993). Manufacturing flexibility - a strategic perspective. *Management Science,* 39(4): 395-410	4	4	1
Slack, N. (1983). Flexibility as a Manufacturing Objective. *International Journal of Operations & Production Management* 3 (3): 4-13.*	5	5	3
De Toni, A. & Tonchia, S. (1998).Manufacturing flexibility: a literature review. *International Journal of Production Research,* 36(6): 1587-1617.	6	6	5
Chen, I. J., Calantone, R. J., & Chung, C. H. (1992). The marketing-manufacturing interface and manufacturing flexibility. *Omega*, *20* (4): 431-443.	7	7	12
Suarez, F., Cusumano, M. & Fine, C. (1996). Empirical study of manufacturing flexibility in printed circuit board assembly. *Operations research,* 44, (1): 223-240.	8	8	8
Beach, R., Muhlemann, A., Price, D., Paterson, A. & Sharp, J. (2000) A review of manufacturing flexibility. *European Journal of Operational Research,* 122 (1): 41-57.	9	9	11
Kumar, K., & Vannelli, A. (1987). Strategic subcontracting for efficient disaggregated manufacturing. *International Journal of Production Research*, *25*(12): 1715-1728.*	10	12	18
Barad, M. & Sipper, D. (1988). Flexibility in Manufacturing Systems: Definition and Petri Net Modelling, *International Journal.of Prod.Research,* 26, (2): 237-248.	11	14	15
Gupta, Y. P., & Goyal, S. (1989). Flexibility of manufacturing systems: concepts and measurements. *European journal of operational research*, *43*(2): 119-135.	12	13	9
Koste, L.L. & Malhotra, M.K. (1999,). A theoretical framework for analyzing the dimensions of manufacturing flexibility. *Journal of Operations Management,* 18(1): 75-93.	13	15	10
Gupta, D., & Buzacott, J. A. (1989). A framework for understanding flexibility of manufacturing systems. *Journal of manufacturing systems*, *8*(2): 89-97.	14	10	17
Churchill Jr, G. A. (1979). A paradigm for developing better measures of marketing constructs. *Journal of marketing research*, 64-73.*	15	16	14
Gupta, Y.P. & Somers, T.M. (1996). Business strategy, manufacturing flexibility, and organisational performance relationships: a path analysis approach. *Production and Operations Management,* 5(3): 204-233.	16	11	6
Gerwin, D. (1987). An agenda for research on the flexibility of manufacturing processes, *International Journal of Operations and Production Management,* 7(1): 38-49.	17	18	13
Gustavsson, (1984). Flexibility and productivity in complex production processes**.** *International Journal of Production Research*, 22: 801–808	18	17	16
Hutchinson, G. K., and Sinha, D. (1989). A quantification of the value of flexibility. *Journal of Manufacturing Systems*, *8* (1): 47-57.	19	19	19
Upton, D.M. (1995). Flexibility as process mobility: the management of plant capabilities for quick response manufacturing. *Journal of Operations Management,* 12 (3-4): 205-224.	20	20	20

Source: Authors Note: *Outsider references

1.3.2.2 Co-word analysis

The co-word analysis approach is based on a simple principle: a research specialty can be identified by the particular associations established between its keywords (Callon et al., 1995). While the analysis of citations, and especially ACA, involves an intrinsic delay, co-word analysis does not suffer from this limitation; therefore, it does not exclude more recent works. For the articles that did not contain keywords, we assigned keywords based on the titles, abstracts and full texts of the documents. To perform such a task in a consistent and homogeneous mode, we created a list of keywords using terms that appeared in other articles and established new keywords based on their content.

When adding up all joint appearances and representing their relationships graphically, it is possible to identify various thematic groups or *clusters.* In these cases, the strength of the union of the words that comprise them is measured by a normalised index[6] whose value depends on both the appearance of the words individually as well as their joint appearances. The co-word analysis made it possible to obtain two types of results: 1) the definition of the themes present in the field and their classification within the strategic matrix in terms of their different levels of development, and 2) the networks of keywords associated with each thematic cluster (Table 4).

Table 4. Keywords associated with each identified cluster

Clusters	Co-words
Performance	Performance, supply chain, supply chain management, management, manufacturing flexibility, flexibility, manufacturing strategy, strategy, environmental uncertainty, framework, model, system, capability, dimensions, impact and firm
Pespective	Perspective, success, empirical research, industry, uncertainty, structural equation model, resource based view, human resource management, competitive advantage, competence, dynamic capability, environment, taxonomy, operation management, fit and organization
Technology	Technology, mass customization, strategic perspective, time, flexible automation, operations strategy, performance evaluation, integration, design and knowledge
Simulation	Simulation, group technology, shop, just in time, cellular manufacturing, cell, routing flexibilility and machine flexibility
Scheduling	Scheduling, machine and heuristics
FMS	FMS, flexibility and measure

Source: Authors

The co-word analysis carried out over the 245 articles in our database identified a total of seven clusters we called Performance, Perspective, Technology, Simulation, Real Option, Scheduling and FMS, as shown in Figure 2. We defined the names of the clusters by the main keywords, which are the main nodes and are therefore better

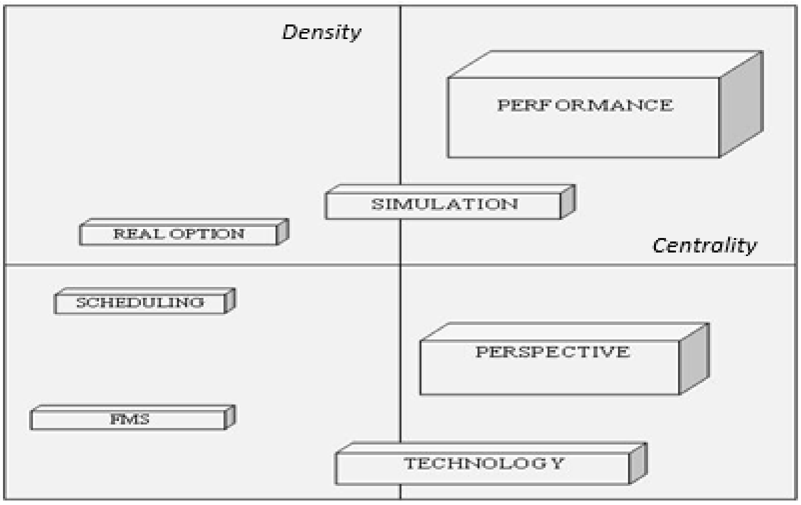
[6] The normalised index is calculated as :

$$e_{ij} = \frac{c_{ij}^2}{c_i c_j}$$

Where C_{ij} measures the strength of association between two words *i* and *j,* and *Ci* and *Cj* the absolute frequency of occurrence of the words *i* and *j,* respectively.

connected with the rest of the cluster keywords. The sizes of the clusters in Figure 2 represent the number of papers in each cluster.

Figure 2. Strategic matrix



Source: Authors

The results of the strategic matrix correspond to a field whose structure is distributed around the different quadrants, indicating that the field has an important dynamic and a rich and complex structure, given that we found all the branches of the topics and their different levels of development.

Thus, the first quadrant (upper right) defines the widely developed central themes. Within the same, we located the Performance and Simulation clusters. The second quadrant (lower right) defines themes that are important for the development of the field. Here, we located the Perspective and Technology clusters. The third quadrant (upper left) defines the themes that are considered specialisations within the field. Within the same, we located the Real Option cluster. The fourth quadrant (lower left) defines the peripheral and developed themes, and here we located the Scheduling and FMS clusters.

The analysis of co-words yielded networks of keywords associated with each of the previously identified clusters in the field (Table 4). These networks of co-words group those keywords that best describe each of the themes present in the field. This information may be particularly valuable in helping future researchers define the most important search keywords depending on the specific topic that they seek to address, because they represent the most important words that relate articles to each other and provide more information on the subject.

Thus, we proceed to describe the main lines of research identified in each cluster:

Performance cluster: The Performance cluster is one of the two largest clusters identified. The cluster is composed of 110 articles (44.90 percent). The relevance of the cluster is determined not only by the number of items within it but also because most of them are conceptual, theoretical or review papers (81 percent), and therefore can contribute more significantly to the development and consolidation of the research. Within the same, it is possible to identify seven lines of research.

The first group of published studies comprises general review articles of the field. Specifically, this group can be broken down into two subgroups. The first encompasses reviews whose main goal is to critically discuss the state of the art within this topic, establishing a research agenda for it (Gerwin, 1993; Bolwijn & Kumpe, 1990; De Meyer et al., 1989; Vokurka & O'Leary-Kelly, 2000; Beach et al., 2000). The second subgroup brings together papers dealing with the theoretical conceptualisation and identification of the dimensions integrating the flexibility construct (Xu, et al., 2011; Gerwin, 2005; De Toni & Tonchia, 1998; Gupta, 1993; Gupta & Goyal, 1989).

The second and largest group of studies is related to the design of tools for the operationalisation of the flexibility construct as a whole (Koste & Malhotra, 1999; D'Souza & Williams, 2000; Shewchuk, 1999; Gupta & Somers, 1992; Kahyaoglu & Kayaligil, 2002; Brill & Mandelbaum, 1989) as well as several of its dimensions (Wahab et al., 2008; Wahab, 2005; Batteman, 1999). Typically, researchers have used pre-existing scales or have developed scales based on underlying theoretical perspectives applying confirmatory factor analysis. However, since 2008, it seems that researchers have attempted to develop scales that can be used across groups to reach valid, scientific and sound conclusions using generalisability theory (Malhotra & Sharma, 2008).

The third area of interest is the analysis of the integration of manufacturing flexibility with supply chain activities as a result of increased dynamic competitive markets. In particular, this research has focused on three aspects. Mainly through case study, the first aspect tests the effect that different flexibility types have on the operations planning performance of a supply chain (Chan & Chan, 2010; Aprile et al., 2005; Nair, 2005). The second quantifies the effect of contractual flexibility, which is related to the effect of suppliers´ relationships on supply chain performance (measured in terms of flexibility) in different sectors and geographical contexts (Bigsten et al., 2000; Chang et al., 2006; Yang Lin & Sheu, 2007). Finally, the third block examines whether the simultaneous utilisation of both internal and external flexibilities create synergies that can improve a firm's delivery performance, drawing upon the theory of complementarity (Malhotra & Mackelprang, 2012; Rogers et al., 2011).

A fourth group of articles places special interest in analysing the decision-making process of strategic flexibility design. Specifically, this decision-making process has focused on four aspects. The first is the construction of theoretical and empirical models through case studies to help managers identify and analyse the best type and level of flexibility for their organisations' strategy, taking into account the requirements of the manufacturing system (Upton, 1994; Ketokivi, 2006; Slack, 2005; Chen et al., 1992; Olhager & West, 2002; Chang, 2012). The second aspect is the analysis and development of models to quantify opportunity costs and incentives to acquire manufacturing flexibility by considering industry characteristics (Son & Park, 1990; Huchzermeier & Cohen, 1996; Waller & Christy, 1992). A third group is composed of articles that develop analytical approaches to quantify manufacturing system flexibility. Among them, we can highlight the development of petri net models (Kochikar & Narendran, 1992; Barad & Sipper, 1988), entropy measures (Shuiabi et al., 2005; Kumar, 1987) or fuzzy models (Wang & Chuu, 2004; Beskese et al., 2004). Finally, other authors have focused on analysing decision-making processes in FMS environments, developing mechanisms for FMS performance evaluation (Benjaafar, 1994; Chan et al., 2006; Chandra et al., 2005; Gupta & Goyal, 1992). In a more precise manner, these authors have developed control and management mechanisms that study the relationship between the degree of routing, process, product mix or machine flexibility types and the performance level obtained by the system in an individual (Mohamed et al., 2001) or combined manner (Das & Nagendra, 1993; Benjaafar & Ramakrishnan, 1996).

A fifth line of research analyses the specific problems faced by small- and medium-sized enterprises in obtaining flexibility. In particular, the studies identify the best practices of flexibility (Petroni & Bevilacqua, 2002), the fit between manufacturing flexibility and business strategy (Chang et al., 2003) and the relationship between technology and flexibility (Dodgson, 1987; Wadhwa, 2012).

A sixth line of research is composed of papers analysing flexibility in the services sector. Most of these papers are theoretical or review articles that provide guidelines, principles, taxonomies and suggestions for the development of future research in this line, which is much less developed than research on manufacturing (Xu et al., 2011; Buzacott & Mandelbaum, 2008; Iravani et al., 2005; Arias-Aranda, 2003; Guo et al., 2012; Arias-Aranda et al., 2011; Slack, 2005).

Finally, within this cluster, there are studies that focus on the analysis of specific problems of flexibility in different geographical contexts. Namely, they have focused on the study of real wage flexibility in Finnish and American manufacturing industries (Nymoen, 1992; Brush & Crane, 1989) or the manufacturing strategies for quality in American and Japanese companies (Daniel et al., 2009).

Simulation cluster: This cluster comprises 22 articles (8.97 percent). All of these articles are qualitative studies with experimental methods and case studies. Within this cluster, two research lines can be identified.

A first group of articles investigates the problem of the design and management of cellular manufacturing systems through the development of simulation tools. In particular, the specific issues discussed are: 1) the introduction of routing flexibility in the system to allow cellular manufacturing systems to operate in a continuous manner

(Ahkioon et al., 2009; Albino & Garavelli, 1999; Dahel & Smith, 1993; Singh et al., 1992), 2) machine utilisation and the deterioration of the performance of cellular manufacturing systems under variable product mix situations (Djassemi, 2005; Seifoddini & Djassemi, 1997), and 3) the specific problem of Virtual Cellular Manufacturing, which is a dynamic structure that will enable future competitiveness in the fast-changing business environment (Wadhwa et al., 2009; Kannan, 1998; Nomden & Van der Zee, 2008).

The second group of articles focuses on the development of tools (algorithms, graph-based models, digital simulation modelling, or intelligent decision support systems, among others) to enable decisions about different aspects of flexibility. Specifically developed tools have been applied to decisions about buffer sizes (Sheikhzadeh et al., 1998; Gultekin, 2012), capacity planning (Alexopoulos et al., 2011), the determination of computer-integrated manufacturing system flexibility (Galbraith, 1993), real time control (Shirazi et al., 2012), a reduction in lead times (Byrne, 1992) or the technological flexibility requirements of Just-In-Time manufacturing (Garg et al., 2001).

Perspective cluster: This is one of the two major clusters identified, grouping 47 articles (19.18 percent). This high number of studies, coupled with their location in the second quadrant of the strategic matrix, indicates that the cluster contains topics that are likely to become central and developed in the literature. That is, the cluster includes important issues for the development of the field. In addition, 68 percent of the works are empirical. We have identified three research lines within this cluster.

The largest group of studies deals with the analysis of the fit between flexibility and the environment. In this line of research, we find on the one hand studies that focus on how a firm’s strategic choice of flexibility can be affected by the interpretation and perception of the environment (De Treville et al., 2007; Smith & Zeithami, 1996; Zukin & Dacol, 2000; Crowe & Nuno, 1991). On the other hand, we find empirical studies analysing the importance of fit between flexibility and environment to predict and improve both internal (Patel, 2011; Liker et al., 1999;

Upton, 1997) and external (Correa & Slack, 1996; Chang et al., 2002) performance. Finally, a third block of papers focuses on the analysis of a particular problem, the fit between flexibility, the supply chain and performance in different contexts (Sawhney, 2006; Avittathur & Swamidass, 2007; Lao & Rao, 2010; Merschmann & Thonemann, 2011).

The second body of works theoretically and empirically examines the strategy integration process. In this way, these studies intend to analyse how key resources affect the development of operational flexibility capability (Grawe et al., 2011), using theories that are widely used in other fields of research but underdeveloped in the field of operations management (Resource Based View or Knowledge Based View theories). These studies identify how the determinants of manufacturing flexibility affect the flexibility-performance relationship. Among the variables analysed, the most highlighted include innovation (Camison & López, 2010), the implementation of quality improvement (QI) (Llórens-Montes et al., 2004), organisational attributes (Swink et al., 2005; Llórens-Montes et al., 2005), technology (Hutchison & Das, 2007) or organisational characteristics such as size (Bosch & Blandon, 2011; Nor et al., 2007; Young, 1994). In addition, a group of researchers has focused on the moderating effect of human resource management practices within the flexibility-performance relationship on a micro-enterprise level (Huang & Cullen, 2001; Benson et al., 2000; Kathuria & Partovi, 1999; Grenier et al., 1997) as well as from a macroeconomic perspective in different geographical contexts (Jin et al., 2010; Fedderke & Hill, 2011; Chen et al., 2011).

The third and final group of works encompasses papers that analyse the flexibility construct according to competence and capability theory. Of particular importance is the distinction between the consideration of flexibility as an internal competence or as an external demand and the relationships between these perspectives of flexibility and manufacturing performance. Although this line mostly includes theoretical papers (Ling-Yee & Ogunmokun, 2008; Bordoloi et al., 1999; Bernardes & Hanna, 2009), there are some studies that have attempted to empirically demonstrate these relationships (Zhang et al., 2003; Patel et al., 2012). Similarly, another group of studies focuses on the development of partial (Van Hop, 2004) or total (Koste, et al., 2004; Narasimhan, et al., 2004) measurement scales of the flexibility construct in terms of both capability and competence approaches.

Technology cluster: This cluster comprises twenty-six articles (10.6 percent), indicating that the aspects investigated in this cluster are limited. Most of the articles in this cluster are qualitative (69.3 percent). It should be noted that much of the empirical studies present here (30.7 percent) have been tested in the automotive industry. We can identify five research lines, presented below.

The largest group of studies comprises works that have studied the effect of technology implementation on manufacturing flexibility, mostly from models or case studies. We find that the technological resources analysed have varied according to the evolution of the technology itself. Thus, while in the 1990s computer-aided machines or computer-aided design (CAD/CAM) (Buxey, 1992; Acaccia et al., 1993; Gola & Swic, 2011), advanced manufacturing systems (AMT) (Lei, et al., 1996; Pyoun & Choi, 1994), or computer-based manufacturing technologies (CBTM) (Pal & Saleh, 1993) were analysed, these mechanisms have more recently been replaced by information systems (IS) or dual-head placement machines (DHPMs) (Beach et al., 1998; Asif et al., 2010).

The second line of research identified focuses on the development of analytical models to test the implications of specific flexibility types for customer satisfaction. Specifically, these studies have analysed the individual effect of product flexibility (Zhang et al., 2009), mix flexibility (Muriel et al., 2006), process flexibility (Jordan & Graves 1995) and the joint effect of mix and volume flexibilities (Skarlo, 1999).

The third body of work brings together theoretical articles that develop frameworks for the analysis of linkages between the different flexibility types. Some of them adopt a broader perspective of the flexibility construct (Suarez et al., 1995; Parker & Wirth, 1999; Pereira & Paulre, 2001; Francas et al., 2011), while other authors reduce the number of types included in the flexibility construct (Boyer & Leong, 1996).

The analysis of the tradeoffs associated with determining the best level of flexibility under lifecycle considerations through case studies is the central theme of the fourth line of research identified (Gaimon & Singhal, 1992; Aurich & Barbian, 2004 or Alexopoulos et al., 2007).

The fifth and final line of research identified relates to the cost of flexibility in specific contexts, such as developing economies. This line of research is very limited in terms of the number of studies within it (Kaluwa & Reid, 1991; Frantzen, 1985).

Real option (quadrant 3): The Real Option cluster brings together 14 articles (5.71 percent). Articles in this quadrant can be considered to be specialised, with weak interaction with other clusters. With regard to the methodologies used, the vast majority are qualitative studies (72.4 percent). More specifically, two research lines can be identified within this cluster, which are analysed below.

The largest group of studies adopts the traditional real options analysis to theoretically and empirically address three specific aspects: 1) the option value of a multinational network (Kogut & Kulatilaka, 1994; Tang & Tikoo, 1999; Allen & Pantzalis, 1996) evaluating the net present value, the growth option value, and the operational flexibility value of the existing production network to predict the establishment of a new site, 2) the study of the role of risk preferences for optimal investment, demonstrating how this effect can be mitigated by incorporating operational flexibility (Chronopoulos et al., 2011), and 3) the value of seasonal energy storage, finding thresholds for energy prices for which it is optimal to enter into an investment (Fleten & Nasakkala, 2010; Wu et al., 2012).

The second line of research identified is related to the review and discussion of the problems and benefits of the traditional real option analysis. Thus, it develops valuation approaches that modify the traditional discounted cash flow methodology (Karsak & Ozogul, 2005; Bengtsson, 2001).

Scheduling cluster: This is one of the three minority clusters identified, and it groups together 9 items (3.67 percent). This presence indicates that this issue has its own clear definition, although due to its size, the issues that have been investigated are limited in number. Papers focused on scheduling were particularly prevalent in earlier years (66.66 percent), and with regard to the methodologies used, all studies in this cluster are quantitative.

Within this cluster, one can identify two research phases. One of these phases is concentrated in the period 1988-1996, focused on the problems of procedures and practices of the day-to-day operation of these systems. Therefore, we find studies that have concentrated on the analysis through experimental tools of the impact of scheduling rules on performance or other factors as shop load, shop configuration, system breakdowns, inventory levels or split production (Daniels, et al., 1996; Ghosh & Gaimon, 1992; Mahmoodi et al., 1999). However, a more recent second line of research seems to focus on the development of heuristics tools, which allow the optimisation of the flowshop and the minimisation of the makespan, workstation or sequence dependent inter-task times (Ruiz-Torres et al., 2011; Nazarian, et al., 2010; Ruiz Torres et al., 2010).

Flexible Manufacturing System cluster: This cluster is composed of 17 items (7 percent). The vast majority (88.23 percent) are theoretical articles. The works contained in this cluster analyse the implementation of an FMS. More specifically, they have tried to address this issue using a double perspective. The first group of articles tries to develop flexibility measures to evaluate and justify investments in this type of manufacturing system (Gupta & Buzacott, 1989; Bernardo & Mohamed, 1992; Das, 1996). In some cases, this analysis has focused on the development of frameworks to quantify the effect of routing flexibility or the measurement scheme for sequencing flexibility (Benjaafar & Ramakrishnan, 1996) applying Taguchi or Markovian methods (Ali & Wadhwa, 2010; Chan, 2001; Upton & Barash, 1988). The second group has focused on the theoretical analysis of the introduction of an FMS into an industry based on cost justification (Feurstein & Natter, 2000; Kulatilaka, 1988; Kreng & Wu, 2000) or testing the operational flexibility effect on the individual parameters of the capacity of an FMS (Mohamed, 1995).

1.4 Conclusions

This first chapter of this dissertation has carried out a comprehensive, systematic and objective review of academic research on the subject of manufacturing flexibility by applying bibliometric indicators. It uses as its basis the literature published on these topics in the ISI Web of Knowledge database. A number of conclusions can be drawn from the analysis.

Firstly, the information provided by the activity indicators confirms that the topic of manufacturing flexibility is a relatively long-standing topic, as the first documents on this subject date from the late 1970s. We have identified two periods: the first (1978-1991) is characterised by low output and the second (1992-present) is characterised by clear growth production levels. This analysis verifies compliance with Lotka's law, indicating that there is a higher concentration of items by a few productive authors compared to other disciplines.

The analysis of activity indicators also reveals that the most productive authors and journals are not necessarily those that are most cited. Thus, the most productive journal in the field of flexibility in Operations Management is the *International Journal of Production Research*. Although the production of this journal is twice that of those following it, other journals that stand out include the *European Journal of Operational Research*, the *International Journal of Production Economics,* the *International Journal of Operations & Production Management* and the *Journal of Operations Management*, all of which have published more than 10 articles on the topic of manufacturing flexibility and are clearly focused on this line of research.

However, the most prominent journals in terms of the average numbers of citations are the *California Management Review* and *Organisation Science*, given that while they may not be deemed as reference journals or those specialising in the area of operations, these journals have published two of the most cited works in this area (Upton, 1994 and Adler et al., 1999). As for the authors, the most productive authors in this field of research include Malhotra, Beach, Benjaafar, Chan, Das and Gupta; however, the most cited authors are Swamidass and Gerwin.

This study has similarly demonstrated that this topic is highly interconnected with high co-citation between authors, enabling us to identify the 20 most influential articles that have consequently become important references in this line of research. These articles also contain a high theoretical element, and all those belonging to the database are largely classified within the performance cluster, a cluster in which the most established review works are concentrated. Likewise, this analysis has allowed us to further identify the reference works not included on the Knowledge Website (i.e., Browne et al., 1984 or Cox, 1989).

The co-word analysis and the construction of diagrams or clusters to define and classify research subjects indicate that the topic of manufacturing flexibility is structured around the different quadrants, indicating that the topic reveals important dynamics and a rich, complex structure, given that we found all the branches of the topics and their different levels of development. We found widely developed themes, such as *Performance* and *Simulation*; emerging themes, such as *Perspective* and *Technology*; developed-peripheral themes, such as *Scheduling* and *FMS*; and specialisation themes, such as *Real Option*.

Thus, among the central aspects that have been analysed within this area of study, we can highlight those that conceptualise and identify the flexibility types that make up the flexibility construct, similarly identifying the work geared to their operationalisation via attempts at the development of reliable and generalisable scales. A second aspect that has been analysed is the issue of the integration of the flexibility of manufacturing operations with the global supply chain, with a special focus on the possible influence that factors such as the sector or geographical context may have on the findings obtained. Similarly, we observe a significant development of the work focused on the application of diverse tools and methods, whether heuristic, simulation, and so on, for the analysis of the decision-making processes related to the most convenient types of flexibility to be implanted in terms of the objectives to be reached in the area of operations. Some of these tools, such as in the case of real options, can even become specialisations within the line of research. Other widely studied aspects include the analysis of decisions of a more operative nature, such as the programming of production and its effect on the results of operations (including the flexibility of the system as such) or the incorporation of the FMS in a company or even in a specific sector. Nevertheless, and unlike the previous topics considered to be central, these elements have a more peripheral character in terms of the development of this line of research.

Along with these most researched aspects, the analysis carried out has also revealed the existence of certain questions that may be relevant for the future development of this line of research. Especially relevant is the need for a strategic analysis of the importance of the coupling between the type of flexibility to implant within a company and the prevalent environmental conditions as a determinant of business results and, in addition, an analysis of the factors that may influence such relationships.

Along the same line, we observe that the need for an analysis of the role that technological development may play in the internal flexibility of operations as well as in external variables, such as customer satisfaction, will continue to be present in the future. Finally, a third relevant factor consists of the issue of analysing possible complementary elements between the different flexibility types.

All these results suggest that the evolution of the themes that make up the topic of the flexibility of manufacturing has been in accordance with the development of the field of Operations Management described by Pilkington (2009). Thus, we find that through this study, we have moved from a fragmented, tactical analysis towards the demand for the study of manufacturing flexibility from a more strategic perspective (Serrano-Bedia et al., 2013). For these reasons the strategic analysis of manufacturing flexibility construct and its impact on performance will be the main objective of this dissertation.

However, the results of this review suggest that in order to attain this goal it is necessary previously to define the concept and the flexibility types that make up manufacturing flexibility construct, because the literature has been ambiguous about its definition and the aspects that constitute it. Therefore, the first step is to review the vast literature available in an attempt to address the terminological and conceptual ambiguity associated with manufacturing flexibility that will be discussed in the next chapter of this dissertation.

CHAPTER 2

SYSTEMATISING THE MANUFACTURING FLEXIBILITY CONSTRUCT: A REVIEW

2.1 Introduction

As it was previously explained, flexibility is a broad concept, with its meaning varying from context to context (Sawhney, 2006). In a manufacturing context, it represents the ability of the manufacturing function to make adjustments needed for coping with environmental changes (He et al., 2014; Groote, 1994) with little penalty in time, effort, cost or performance (Upton, 1994). In spite of the potential benefits provided for company survival, a review focused on the manufacturing area (Jain et al., 2013) published in the *International Journal of Production Research* made it clear that several future research issues on manufacturing flexibility still remain open. Among these is the need to clarify the existing controversy around its conceptualisation, a problem which has hampered achieving consensus on its operationalisation, and therefore, comparing results of empirical studies (Shewduck & Moodie, 1998). That is because manufacturing flexibility is a complex and multidimensional construct (Mendes & Machado, 2015), and the literature has been ambiguous about its definition and the aspects that constitute it.

To begin with, ambiguity can be identified in the terminology -types, elements, dimensions, parameters and others- used to refer to the aspects which integrate the manufacturing flexibility construct. Specifically, the literature has used terms interchangeably to define two separate issues of the construct: the different flexibility forms (i.e., the variety of flexibility names which appear in the literature (Wadhwa, 2012; Shewchuk & Moodie, 1998) and the scope of each form (i.e., the metrics for measuring each flexibility form which capture the flexibility response in terms of the full range and diversity of options that the organisation can attain (Koste et al., 2004; Bernardes & Hanna, 2009). A second concern is related to the identification in the papers researching this topic (Singh et al., 2013; Brill & Mandelbaum, 1989) of more than fifty different flexibility forms (De Toni & Tonchia, 2005) under different names and definitions, indicating that the construct is poorly understood (Xu et al., 2011; Shi & Daniels, 2003; D'Souza & Williams, 2000), and common definitions and shared concepts remain elusive (Jain et al., 2013; Gottfried & Winkler, 2013; Cousens et al., 2009). Diverse causes have given rise to this situation.

Firstly, “identical flexibility related terms used by more than one writer do not necessarily mean the same thing” (Ramasesh & Jayakumar, 1991, p. 447). In other words, “even when different researchers use the same term to define flexibility they may attach entirely different meanings to it” (Swamidass, 1988, p. 5-6). Secondly, “there is the overlap in the scope of terms used by different authors to define this variety of flexibilities” (Xu et al., 2011, p. 13536) due to the fact that “some flexibility terms are aggregates of other flexibility terms used” (Xu et al., 2011, p. 13536). Another reason is that authors consider different temporal horizons (such is the case of expansion (long term flexibility) and volume (short term flexibility) (Rogers et al., 2011). Thirdly, in the words of Gerwin (1993, p. 398) “most treatments of flexibility assume it is a multidimensional concept but provide no theoretical basis for finding its relevant flexibility forms”. Finally, researchers have defined the forms of flexibility based upon a limited view of the manufacturing system, reflecting their own particular areas of interest and biases (Sawhney, 2006). This situation has made it difficult to use multi-item generalised sets of measures that span multiple industries, to identify the trade-offs among the various forms of flexibility, or to compare the results obtained in different studies as well as industries.

For these reasons, the main goal of this second chapter is to respond to the call for research made in Jain et al., (2013) by carrying out a systematic analysis of the names and definitions of the different forms of the manufacturing flexibility construct to be able to identify the existing similarities and differences among them, be they obvious or not at first glance. In this way, the chapter would contribute to the conceptual systematisation of the manufacturing flexibility construct by synthesizing the vast literature available in an attempt to address the terminological and conceptual ambiguity associated with it. This conceptual systematisation is a necessary preliminary step which will permit to advance in the homogeneous operationalisation of the construct.

The remainder of this second chapter is organised as follows. Section 2 presents the methodology of the literature review and clarifies the terminology used in this chapter. Section 3 describes the theoretical perspectives that underlie the manufacturing flexibility construct. Section 4 presents the systematisation of the flexibility definitions within each of the theoretical perspectives previously identified. Section 5 carries out a comparison between both perspectives. Finally, conclusions are drawn from this paper, and important future research issues are identified in section 6.

2.2 Methodology and terminology justification

Over the final sample of articles identified on the bibliometric analysis developed in chapter 1 the first step was to address the ambiguity identified in the terminology referring to the aspects of the manufacturing flexibility construct (see Appendix II). By doing so, we reviewed all the documents in the sample in order to identify: a) review articles of the manufacturing flexibility field; b) articles that discuss manufacturing flexibility conceptualisation; and c) articles that discuss manufacturing flexibility operationalisation. With these criteria the sample was reduced to 62 documents. These articles were analysed in an exhaustive manner in order to determine the terminology used to refer to: 1) the variety of flexibility forms and 2) the scope of each flexibility form.

The analysis showed that, related to the terms used to refer to the flexibility forms, the literature presents high agreement. In terms of frequency, 97.2% of the works which conceptualise the construct and 89.7% of the works which discuss its operationalisation use the term “type” for referring to the different flexibility forms. The second most frequent term, “dimension”, is used in 69.4% and 37.9% of the works, respectively. In the vast majority of cases, “dimension” is used along with “type”, employing both as synonyms. Only in three documents (Malhotra & Sharma, 2008; Cao & Zhang, 2008; and Tamayo-Torres et al., 2011) is “dimension” used in an independent manner. Other terms identified in the literature can be considered of marginal importance. Examples include “component” or “kind”, which are only used in two and one work, respectively.

Related to the terms used to define the scope of each flexibility form, the literature is less clear as two terms, “dimension” and “element” have been employed with practically the same frequency (around 30% in each case). Far from both of these are found the remaining terms identified: “component”, present in the works of Koste et al., (2004), Ling-Yee & Ogunmokun (2008) and Slack (1983, 1987, 1988), and "parameter", used in three works. Moreover, we find that the terms "dimension" and "component" have been used interchangeably in both groups, defining both the variety of flexibility forms and the scope of each flexibility form (Slack, 1983; Upton, 1997; Batteman, 1999; Van Hop, 2004; Gupta & Goyal, 1989; Xu et al., 2011). Thus, they represent the main terminology controversy. In order to avoid this terminological problem, and taking into account only the frequency in the use of different terms in each group, we propose throughout this paper the use of the term "type" to identify the different forms of the construct and the term "element" in order to refer to the scope of each flexibility type.

After clarifying the terminology, we proceeded to the systematic analysis of the number, the names and definitions of the variety of flexibility types identified in the literature review, which is the main objective of this chapter. To this end, the 62 papers from the sample were reviewed in order to select the articles, both theoretical and empirical, which included a wide discussion section on the composition of the flexibility construct, giving reasons for the identification of flexibility types and their relationships. As a result of this filtration process, a final sample of 26 articles was obtained. Further analysis of these articles allowed us to identify that, in some cases, authors directly ascribe their taxonomy to one of two main perspectives (hierarchical and strategic) in the literature. In other cases, authors sustain clear foundations which permit classification into one of these perspectives. After this process we obtained that the hierarchical perspective covers 41.7% of the sample and the strategic perspective accounts for 58.3% of the sample. Both approaches are described in the next section.

2.3 Theoretical perspectives in the development of the manufacturing flexibility construct

The two different but overlapping perspectives identified could be the result of the traditional division between researchers from the engineering and business school of the operations management field, as Ling-yee and Ogunmokun (2008) have noted. The main difference between these two approaches is on the basis adopted for the analysis of manufacturing flexibility, which is the result of defining flexibility types that reflect their own areas of interest. Briefly, the first approach could be more related with engineering researchers, who define manufacturing flexibility from a more internal view. They consider manufacturing flexibility as the ability of a firm to change operations management activities both economically and effectively given a certain capacity, analysing the flexibility of alternative process technologies with particular references to FMS contexts. On the other hand, the strategic approach could be more related with management researchers. It arose at practically the same time as the hierarchical approach, but it attempts to classify manufacturing flexibility by taking into account a broader perspective. Researchers within this approach classify the manufacturing flexibility types depending on if they can be visible and perceived by customers or not. The individual evolution of each approach is explained below.

2.3.1 Hierarchical perspective

The argument sustained by this perspective is that manufacturing flexibility is a construct that is built on a base of flexibility types of a lower level, giving rise to a hierarchical structure composed of various flexibility types which have mainly been identified through observation in case studies. Notwithstanding the above, the synthesis provided in Table 5 reveals that consensus appears elusive both on the number of levels in the hierarchy, and on the types that make up the levels themselves.

The precursor and the most widely recognized taxonomy was Browne et al., (1984) who, based on informal observation of ten enterprises in a FMS context, proposed a classification of eight different flexibility types structured in three levels (basic, system and aggregate levels). For quite some time, this classification was considered one of the most comprehensible in the literature, and was fully accepted by various authors such as Gupta and Goyal (1989) and Parker and Wirth (1999), among others. In addition, it has been extended by Sethi and Sethi (1990) and Chang (2012) who incorporated three new types to the eight initially proposed.

Other relevant taxonomies based on observing case studies have been those proposed by Slack (1987, 1988), who presented a classification of seven flexibility types structured in two levels (resource and system levels), and Dooner (1991), who proposed a three-level taxonomy (production, design and base levels) but considered only five flexibility types. At the end of the 90's, there begin to appear taxonomies within this perspective based on a theoretical review of the academic literature. Koste and Malhotra (1999) propose a taxonomy composed of a total of ten flexibility types structured in five levels (individual resource, shop floor, plant, functional and strategic business levels) while Narasimhan and Das (1999) reduce the hierarchical structure to three levels (basic, tactical and strategic levels) while they increase the number of flexibility types to eleven. Finally, Sawhney (2006) extends the horizon for the taxonomies developed up until that time in the direction of the supply chain. In this way, he sustains the existence of three levels (input, process and output levels) composed of eleven flexibility types identified through observation in ten case studies.

Table 5. Literature review of flexibility types identified in hierarchical perspective

References	Levels \ Types	Input or supplier	Machine and system configuration data	Operation	Material	Machine	Routing	Programme	Technology	Labour	Infrastructure	Process	Expansion	Product	Volume	Mix	Delivery	Control	Product mix	Modification	New product	Market	Manufacturing	Organisational	System	R&D	Marketing	Production	Strategic
Browne et al., (1984); Gupta & Goyal (1989); Parker & Wirth (1999)	**3**			**1**		**Component or basic level 1**	**2**					**System level 2**																**Aggregate level 3**	
Slack (1987)	**2**	**1**							**Resources level 1**					**Manufacturing level 2**															
(Slack 1988)	**2**	**1**							**Resources level 1**					**Manufacturing level 2**															
Sethi & Sethi (1990); Chang (2012)	**3**			**Component or basic level 1**			**2**	**3**				**System level 2**										**3**						**Aggregate level 3**	
Dooner (1991)	**3**		**Base level 1**			**Design level 2**									**Production level 3**														
Narasimhan & Das (1999)	**3**				**Operational level (shop level) 1**								**2**		**Tactical flexibility 2**					**2**	**Strategic level (firm level) 3**								
Koste &Malhotra (1999)	**5**			**1**	**Individual resource level 2**		**Shop floor level 1**			**2**			**3**		**Plant level 3**					**3**	**3**	**Functional level 4**							**Strategic business level 5**
Sawhney (2006)	**3**	**Input stage level 1**			**Process stage level 2**					**2**			**2**		**3**		**Output stage level 3**		**3**		**3**								

Source: Authors. *NOTE: We arrange flexibility types in the upper row by hierarchical level order. The number within the cells indicates the level to which belongs each flexibility type within the hierarchical structure (1=lowest level to 5= highest level). Also we list in the same cell multiple references when they have the same classification.

2.3.2 Strategic perspective

The fourteen papers included in this perspective analyse flexibility by taking into account the interaction between firms and their environment, as well as the level to which consumers perceive the effects of this interaction. External flexibility types are taken to be those that are directly related with the capability to cope with dynamic market changes and that directly affect the competitive position of a firm in a market. Internal flexibility types, on the other hand, deal with the flexibility inherent in manufacturing resources and management. In spite of the effort apparent in the papers which make up this approach, the synthesis presented in Table 6 shows that, in this case as well, there does not appear to be a clear consensus on the flexibility types that make up each of the two levels (internal / external) identified.

The origins of this perspective are to be found in the works of Slack (1983) and Gerwin (1987) who were the first to argue that flexibility types arise as a response to specific types of uncertainty. An initial classification of flexibility types as internal and external was subsequently carried out. As this perspective evolved, various authors began to argue that internal uncertainty is not independent of external uncertainty. Based on this, a large number of studies (Ramasesh & Jayakumar, 1991; Chen et al., 1992; Suarez et al., 1996; D'Souza & Williams, 2000; Oke, 2005) began to establish theoretical relationships between both types of uncertainty. Internal flexibility types, also known as *manufacturing based flexibilities* or *lower order flexibilities*, it was proposed, support external flexibility types, also known as *marketing based flexibilities* or *first order flexibilities*.

In the face of the proliferation of flexibility types developed under this perspective, the most recent papers have tried to either develop taxonomies applicable to specific sectors, e.g. the service sector or small and medium-sized enterprises (SMEs) (Arias-Aranda, 2003; Arias-Aranda et al., 2011; Braglia & Petroni, 2000), or to synthesize the flexibility types previously identified, and thereby reduce their number. This is done both from a theoretical perspective – based on the

Resource Based View (Zhang et al., 2003; Rogers et al., 2011)– as well as an empirical one – through the use of statistical techniques (D'Souza & Williams, 2000).

Based on this description, we can conclude that although the literature has suggested that the strategic approach arises in order to address the limitations of the hierarchical approach (Gerwin, 1993; Oke, 2005), both perspectives have common limitations in at least two aspects: 1) they have led to a proliferation of flexibility types and levels; and 2) sometimes, taxonomies are not easily transferable to manufacturing systems in general because they have been developed in particular contexts such as FMS or specific sectors.

Table 6. Literature review of flexibility types identified in strategic perspective

<table>
<tr><th>Flexibility types
References</th><th>Quality</th><th>Delivery</th><th>Volume</th><th>Product</th><th>Modification</th><th>Changeover</th><th>Expansion</th><th>Mix</th><th>New product</th><th>Variety flexibility (mix and new product)</th><th>Product mix</th><th>Supplier flexibility</th><th>Distribution of information</th><th>Market</th><th>Sequencing</th><th>Material</th><th>Routing</th><th>Machine</th><th>Labour</th><th>Programme</th><th>Process</th><th>Operation</th><th>System</th><th>Component</th><th>Layout</th></tr>
<tr><td>Slack (1983)</td><td>I</td><td colspan="3">E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>I</td><td></td><td>I</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Gerwin, (1987), (1993), (2005)</td><td></td><td></td><td colspan="4">E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">I</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ramasesh & Jayakumar (1991)</td><td></td><td></td><td colspan="2">E</td><td></td><td></td><td>E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="7">I</td><td></td><td></td><td></td></tr>
<tr><td>Chen, Calantone, & Chung (1992)</td><td></td><td></td><td colspan="2">E</td><td></td><td></td><td colspan="2">E</td><td></td><td></td><td></td><td></td><td></td><td>E</td><td></td><td colspan="6">Manufacturing based flexibilities
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<tr><td>Suarez, Cusumano, & Fine (1996); Oke (2005)</td><td></td><td colspan="2">First order flexibilities
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<tr><td>D'Souza & Williams (2000)</td><td></td><td></td><td>E</td><td></td><td></td><td>I</td><td></td><td></td><td></td><td>E</td><td></td><td></td><td></td><td></td><td></td><td colspan="2">I</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Braglia & Petroni (2000)</td><td></td><td></td><td colspan="2">E</td><td></td><td></td><td>E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">I</td><td></td><td></td><td>I</td><td></td><td></td><td colspan="2">I</td></tr>
<tr><td>Arias-Aranda (2003); Arias-Aranda, Bustinza & Molina (2011)</td><td></td><td></td><td>I
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<tr><td>Zhang, Vondemberse &Lim (2003); Cao & Zhang (2008)</td><td></td><td></td><td>Flexibility capabilities
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<tr><td>Rogers, Ojha,& White (2011)</td><td></td><td></td><td>E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Flexibility capabilities
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I</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Source: Authors. *NOTE: we arrange flexibility types in the upper row taking into account their external/internal character. We indicate within the cells "E" when flexibility type is considered external or "I" if it is considered internal. Also we list in the same cell multiple references when they have the same classification.

2.4 Systematising the names and definitions within each perspective

After classifying the papers in one of the two theoretical approaches, the original names and definitions of the manufacturing flexibility types that appear in the 26 papers included in Tables 5 and 6 were exhaustively reviewed for each perspective independently. The process followed is presented below, and the results are summarised in Tables 7 and 8. Though agreement both in content and name for the flexibility types is to be expected, our analysis shows that this is not always the case. For this reason, in order to systematise the construct a first step was to establish a "consensus definition". We began by reviewing the content of the definitions in order to identify the different flexibility realities that authors propose, and classified them together with the definitions which refer to the same reality. Then, we obtained the consensus definition, selecting for this purpose the one that appeared with the greatest frequency amongst those that refer to the same reality. The consensus definitions obtained through this process can be found in the column headings of Tables 7 and 8.

Secondly, we completed the rows of Tables 7 and 8 with the names employed by the various authors for the flexibility types analysed in each paper. These were grouped according to their agreement with the consensus definitions previously identified. By way of example, within the hierarchical perspective, the definition for the *product flexibility* type proposed by Parker and Wirth (1999) as the "ability to change the mix of products in current production" coincides with the consensus definition identified for the *mix flexibility* type as the "ability to change the mix of products". For this reason, *product flexibility* appears reclassified under the column for *mix flexibility*.

In the third place, after carrying out the reclassification of names according to the consensus definitions, a further step was required. While an initial group of flexibility types was identified in which the name employed is the same in all the papers, sometimes different names are used in the literature to refer to the same reality. In these cases, it was necessary to identify a "consensus name". The selection criterion proposed and employed in this work is greatest frequency of appearance in the studies (Tables 7 and 8 present these greatest frequency names). The resulting consensus names for each perspective independently can be found in the last row of both Tables 7 and 8.

The columns in Tables 7 and 8 are grouped according to the following criteria. First, the manufacturing flexibility types with full consensus in their names across the literature reviewed. Then, the flexibility types with discrepancies, and finally the flexibility types analysed in only one paper. The process followed allowed us to identify three distinct types of discrepancies that are present within both approaches:

Type 1 Difference: consists of the use of different terms / names to refer to the same reality, which might be synonyms – as in the case of *machine / equipment* – or not, as with *operation / process / market flexibility*.

Type 2 Difference: the same name is employed but without consensus on the scope and content to which it makes reference. When this occurs, two definitions for the same flexibility type appear in the tables. This is the case for *supplier* in the hierarchical perspective, and *material* in the strategic perspective.

Type 3 Difference: greater ambiguity is to be found as differences exist both in terms of the name as well as the reality to which it refers. This is the case for all the flexibility types related to aspects of *product,* where up to four different flexibility types have been identified, with four names being used interchangeably: *mix, modification, new product* and *product*.

Lastly, flexibility types which appear in only one paper within the corresponding theoretical approach are also identified in the tables. These, of course, present no consensus problem. This is the case of *control flexibility* in the hierarchical perspective and d*istribution of information, layout, supplier* and *quality flexibility types* in the strategic perspective. All of them, except supplier, have also been analysed in only one approach.

Table 7. Conceptual systematisation of flexibility types under hierarchical perspective

Consensus definitions / References	Ability to vary delivery dates	Ability to easily add capability and capacity	Range of tasks that a person can perform	Ability to adapt to a changing market environment	Ability of the material handling system to move material effectively through the manufacturing system	The universe of part types that can be processed	Ability of the system to run virtually unattended	Ability of production to produce a part on different equipment or different sequences	Ability to operate profitability varying output levels	Ability to change the operations that a machine can execute	Ability to interchange the ordering of several operations for each part	Ability to change between the production of different products	The responsiveness enjoyed by a firm to desired changes in its mix, volume, delivery time and new product	The range of supply potential changes, both in terms of quantity and type, of material, labour or any input resource	Ability to change the mix of products	Ability to modify the design of a product	Ability of manufacturing system to introduce new products	Number and heterogeneity of products which can be produced	Range of states for which the system can effectively respond
	Flexibility types with consensus agreement									**Type 1 difference**			**Type 2 difference**		**Type 3 difference**				**One work**
Browne et al., (1984)		**Expansion**				**Production**		**Routing**	**Volume**	Machine	Operation				Process		Product		
Slack (1987)	**Delivery**		**Labour**						**Volume**			Process		Supplier	Mix	Product			
Slack (1988)	**Delivery**		**Labour**						**Volume**			Process		Supplier	Mix	Product			Control
Gupta & Goyal (1989)		**Expansion**						**Routing**	**Volume**	Machine	Sequencing	Process			Production		Product		
Sethi & Sethi (1990); Chang (2012)		**Expansion**		**Market**	**Material**	**Production**	**Programme**	**Routing**	**Voume**	Machine	Operation				Process		Product		
Dooner (1991)								**Routing**	**Volume**	Machine					Mix				
Parker & Wirth (1999)		**Expansion**				**Production**		**Routing**	**Volume**		Operation	Process			Product				
Koste & Malhotra (1999)		**Expansion**	**Labour**		**Material**			**Routing**	**Volume**	Machine		Operation				Modification	New Product	Product (new product and modification	
*Narasimhan & Das (1999)		**Expansion**		**Market**	**Material**		**Programme**	**Routing**	**Volume**	Equipment					Mix	Modification	New Product		
Sawhney (2006)	**Delivery**	**Expansion**	**Labour**		**Material**			**Routing**	**Volume**	Equipment			Supplier				New Product	Mix	
Consensus names	**Delivery**	**Expansion**	**Labour**	**Market**	**Material**	**Production**	**Programme**	**Routing**	**Volume**	**Machine**	**Operation**	**Process**	**Supplier**		**Mix**	**Modification**	**New Product**	**Product**	**Control**

Source: Authors *Empirical Works

Table 8. Conceptual systematisation of flexibility types under strategic perspective

Consensus definitions / References	Ability to vary delivery dates	Ease with which capacity can be added	The ability to vary the workforce	Ability to implement minor design changes in a given product	Capability of a system to operate unattended	Capability to use alternative sequences or routes to make a product	Capability to operate at different levels of output	Capability of machine to perform different operations	Capability to adapt to market changes	Capability to produce a given set of part types using different ways (process, material or sequences	Ability to make the parts with alternative composition	Ability to transport different work pieces between various processing centers	Capability to respond quickly and economically to different product mix	Ability to create or substitute new products quickly	Capability of a system to add or substitute product, new product or respond to customer request without major effort	Ability to distribute and share information through the delivery system	Ease with which internal layout can be modified	Ability to change the quality level of one or more of its products	Ability of suppliers to respond to changes requested by the customer
	Flexibility types with consensus agreement							**Type 1 difference**			**Type 2 difference**		**Type 3 difference**			**One work**			
Slack (1983)	**Delivery**		**Labour**			**Routing**	**Volume**						Product	New				Quality	
Gerwin (1987);(1993); (2005)				**Modification**		**Routing**	**Volume**			Sequencing	Material			Changeover	Product (mix and new product)				
Ramasesh & Jayakumar (1991)		**Expansion**	**Labour**		**Programme**	**Routing**	**Volume**	Machine		Operation	Material		Process		Product (mix and new product)				
Chen, Calantone, & Chung (1992)		**Expansion**	**Labour**		**Programme**	**Routing**	**Volume**	Machine	Infraestructural	Process		Material	Mix						
Suarez, Cusumano, & Fine (1996)*; Oke (2005)	**Delivery**					**Routing**	**Volume**						Mix	New product					
D'Souza & Williams (2000)*							**Volume**			Process (changeover		Material			Variety (mix and product modification)				
Braglia & Petroni (2000)*		**Expansion**				**Routing**	**Volume**	Machine		Process					Product (mix and new product)		Layout		
Arias- Aranda (2003)* Arias-Aranda, Bustinza & Molina (2011)		**Expansion**	**Labour**		**Programme**		**Volume**	Machine	Market				Process		Service and servuction (mix and new product)	Distribution of information			
Zhang, Vonderembse, & Lim (2003)*; Cao & Zhang (2008)			**Labour**			**Routing**	**Volume**	Machine				Material	Mix						
Rogers, Ojha,& White (2011)*			**Labour**				**Volume**	Equipment		Routing			Product-mix						Supplier
Consensus names	**Delivery**	**Expansion**	**Labour**	**Modification**	**Programme**	**Routing**	**Volume**	**Machine**	**Market**	**Process**	**Material**		**Mix**	**New product**	**Product**	**Distribution of information**	**Layout**	**Quality**	**Supplier**

Source: Authors. * Empirical Works. Note: Although Suarez, Cusumano and Fine (1996) work was attributed with 7 flexibility types in Table 6 they did not provide definitions for two flexibility types (System flexibility and Component flexibility). For this reason, it is concerned with only 5 flexibility types in Table 8.

2.5 Systematising the concept between perspectives

Once the flexibility types within each perspective have been systematically reviewed, analysed and classified, a comparison of the perspectives was undertaken. This comparison, summarised in Table 9, allowed us to identify that, in total, there are twenty one different flexibility types. A block of six flexibility types was identified that is specific to each approach – *control, production* and *sequencing* in the hierarchical perspective, and *distribution of information, layout* and *quality* in the strategic approach – and which, therefore, will not be compared.

In order to conclude our systematisation process, three aspects of the remaining fifteen flexibility types were reviewed: a) the levels at which each of these flexibility types are situated, according to each perspective (Tables 5 and 6); b) the consensus definitions presented in the column headings in Tables 7 and 8; and c) how the consensus names presented in the last row of Tables 7 and 8 were obtained.

With respect to the levels at which each of the flexibility types are situated, there is notable consensus between both approaches. The analysis shows that typically, when classifying flexibility types, researchers have developed frameworks (both hierarchical or strategic perspective) that are divided into stages (sometimes referred to as "levels" or "tiers"), with each stage consisting of associated flexibility types. In both perspectives there is a logical link between levels of decomposition which supports the view that lower levels, which also have a lower direct impact on performance (Buzacott & Mandelbaum, 2008), determine the degree of higher levels of flexibility (Slack, 1988). This sustains the view that flexibility moves in one direction within an organisation from the lower levels (which focus on issues concerned with maintaining process consistency, worker morale and trust between workers and management) to the higher levels (which focus on strategic aspects and have a more long term horizon) (De Treville et al., 2007). Additionally, this analysis show that correspondence can be seen between the hierarchical level 1 (component or basic level, or levels 1 (shop floor level) and 2 (individual resource level) in the breakdown of the 5 level structure of Koste and Malhotra (1999)) and the internal level of the strategic perspective. Similarly, correspondence is evident between levels 2 (system/manufacturing or tactical level) and above in the hierarchical approach (aggregate or strategic level, or levels 3 and above -plant/functional and strategic levels- in the case of Koste and Malhotra (1999)) and the external level in the strategic approach.

Problems are limited to four flexibility types – *programme, process, routing* and *supplier*. In the first three cases, the flexibility types are classified into more than one level within the analytic framework utilised (*programme* and *process)* classified as internal (Chen et al., 1992) or external flexibility types (Arias-Aranda, 2003; Arias-Aranda et al., 2011) in the strategic approach, or as shop floor level –level 1- (Narasimhan & Das, 1999) or aggregate level –level 3- (Sethi & Sethi, 1990; Chang, 2012) in the hierarchical approach; *routing* classified as shop floor -level 1- (Narasimhan & Das, 1999; Koste & Malhotra, 1999) or system level –level 2- (Browne et al., 1984; Gupta & Goyal, 1989; Parker & Wirth, 1999; Sethi & Sethi, 1990; Chang, 2012; Dooner, 1991) in the hierarchical perspective). In the case of *supplier*, the typical correspondence is not seen given that level 1 (input stage of Sawhney 2006) is considered to be an internal flexibility type. Instead, we found that supplier flexibility is considered external by Rogers et al., (2011) in the strategic perspective. This lack of agreement might be related with the fact that it is considered a supply-chain partner flexibility that isn’t within the organisation itself (Handfield & Nichols, 2002).

In terms of the second and third of the aspects reviewed, a comparison of the consensus definitions and names allowed us to identify various situations:

- **Flexibility types with total consensus agreement prior to the systematisation**: There are seven flexibility types which have been systematically defined and named in the same way in both approaches (*delivery, expansion, labour, programme, volume, machine*, and *material flexibility*). In the case of only one flexibility type, *material flexibility*, is it necessary to specify that the consensus in terms of the definition is limited to only one of the two definitions proposed within the strategic perspective. That definition refers to the ability to move material effectively through the manufacturing system (Sethi & Sethi, 1990; Chen et al., 1992; Koste & Malhotra, 1999; D'Souza & Williams, 2000; Zhang et al., 2003; Sawhney, 2006; Cao & Zhang, 2008 or Chang, 2012) instead of to the ability to make parts with alternative compositions, as suggested by Gerwin, (1987, 1993, 2005) or Ramasesh and Jayakumar (1991).

- **Flexibility types without consensus on the name prior to the systematisation**: There are five manufacturing flexibility types in which there is consensus on the definition, however, the names employed within each approach have been quite different (although the intensity of the lack of name consensus depends on the type of flexibility considered (*market, new product, modification, process, and mix)*). Notably, after the systematisation process, it has been possible to eliminate this difference. More specifically, the first three types – *market, new product* and *modification*- present more homogeneity in that we found less variety of terms for these flexibility types. *Market flexibility* has been named *infrastructural flexibility* in the work of Chen et al., (1992). *New product flexibility* has been named *product flexibility* by Slack (1987, 1988) and *modification flexibility* appears as *product / changeover flexibility* in the works of Gupta and Goyal (1989), Sethi and Sethi (1990), Chang (2012) or Gerwin (1987, 1993, 2005). The last two flexibility types –*process* and *mix*- present a more complex lack of agreement. A noteworthy example is the case of *mix flexibility* which is defined in both approaches as the capacity to vary the mix of products (Slack, 1987; Dooner, 1991; Narasimhan & Das, 1999; Suarez et al., 1996; Oke, 2005; Zhang et al., 2003; Cao & Zhang, 2008), yet referred to with terms as varied as *process* (Browne et al., 1984; Sethi & Sethi, 1990; Chang, 2012; Ramasesh & Jayakumar, 1991; Arias-Aranda, 2003 or Arias-Aranda et al., 2011*), production* (Gupta & Goyal, 1989*), product* (Parker & Wirth, 1999; Slack, 1983) and *product mix flexibility (*Rogers et al., 2011*)*. In the same line, *process flexibility,* defined as the ability to change between the production of different products (Slack, 1987; Gupta & Goyal, 1989; Parker & Wirth, 1999; Braglia & Petroni, 2000) has been referred to with terms such as *operation* (Koste &

Malhotra, 1999; Ramasesh & Jayakumar, 1991), *sequencing* (Gerwin, 1987, 1993, 2005) or *routing* (Rogers et al., 2011).

- **Flexibility types without consensus on the scope of the definition after the systematisation**: There are three flexibility types which varied, both in the name as well as the scope of the definition, according to the approach analysed. However, the types of discrepancies encountered differ in each of the cases.
    - *Product flexibility:* both perspectives coincide in defining it as an aggregate which is justified from a theoretical point of view due to the complexity of the concept. It can encompass such diverse aspects as changes in design, in the quantity offered, in the range of products available, etc. The problem in this case is limited to determining what flexibility types make up the aggregate. Thanks to the systematisation carried out, it has been possible to reach consensus on the names and definitions of these individual flexibility types. The result is that the differences between both perspectives are less than the literature review initially suggested. More specifically, by applying the consensus names, one observes that the individual flexibility types within the strategic perspective are *mix, modification*, and *new product* while in the hierarchical perspective they are *mix, modification* and *volume*. For this reason, and given the theoretical justification for maintaining the definition as an aggregate in both perspectives, we recommend clearly specifying the flexibility types that make up the aggregate in all research from among the four previously mentioned.

    - *Routing flexibility*: in this case the hierarchical perspective defines it as an aggregate of two previous independent flexibility types (*machine* and *operation*), while the strategic perspective conceives of it as an individual flexibility type (capability of using alternative sequences or routes to make a product). The lack of agreement about the nature of *routing flexibility*, coupled with the fact that the existence of aggregate flexibility types has traditionally constituted one of the principal causes of ambiguity in conceptualising the manufacturing flexibility construct (Xu et al., 2011) leads us to propose using the definition from the strategic perspective.

- *Supplier flexibility*: the scarcity of works which have analysed this type of flexibility within each perspective (two authors in the hierarchical perspective, and one author in the strategic perspective) together with the ambiguity of the definitions positions it closer to those that have been described in only one theoretical perspective and require further research to fully explain their definitions.

In summary, the level of consensus achieved after the systematisation process is much greater than that initially suggested by the literature review since in only two of the fifteen cases analysed do discrepancies remain after carrying out this process.

Table 9. Comparison of flexibility types identified in both perspectives

TYPE OF CONSENSUS	CONSENSUS NAME	CONSENSUS DEFINITION HIERARCHICAL PERSPECTIVE	LEVEL	CONSENSUS DEFINITION STRATEGIC PERSPECTIVE	LEVEL
TOTAL	Delivery	Ability to vary delivery dates	**2**	Ability to vary delivery dates	**External**
	Expansion	Ability to easily add capability and capacity	**2**	Ease with which capacity can be added	**External**
	Labour	Range of tasks that a person can perform	**1**	The ability to vary the workforce	**Internal**
	Volume	Ability to operate profitability varying output levels	**2**	Capability to operate at different levels of output	**External**
	Machine	Ability to change the operations that a machine can execute	**1**	Capability of machine to perform different operations	**Internal**
	Material	Ability of the material handling system to move material effectively through the manufacturing system	**1**	1-Ability to transport different work pieces between various processing centers 2-Ability to make the parts with alternative compositions	**Internal**
	Programme	Ability of the system to run virtually unattended	3	Capability of a system to operate unattended	Internal or external
WITHOUT CONSENSUS ON THE NAME PRIOR TO THE SYSTEMATISATION	Mix	Ability to change the mix of products	**2**	Capability to respond quickly and economically to different product mix	**External**
	Modification	Ability to modify the design of a product	**2**	Ability to implement minor design changes in a given product	**External**
	Market	Ability to adapt to a changing market environment	**3**	Capability to adapt to market changes	**External**
	New product	Ability of manufacturing system to introduce a new product	**3**	Ability to create or substitute new products quickly	**External**
	Process	Ability to change between the production of different products	2	Capability to produce a given set of parts types using different ways (process, material or sequences)	Internal or external
WITHOUT CONSENSUS ON THE SCOPE OF THE DEFINITION AFTER THE SYSTEMISATION	Product	Number and heterogeneity of products which can be produced	**2**	Capability of a system to add or substitute product, new products or customer request without major effort	**External**
	Routing	Ability of the production to produce a part on different equipment or different sequences	1/2	Capability to use alternative sequences or routes to make a product	Internal
	Supplier	1-The responsiveness enjoyed by a firm to desired changes in its mix, volume, delivery time and new product 2- The range of supply potential changes both in terms of quantity and type, of material, labour or any input resource	1	Ability of suppliers to respond to changes requested by customer	External
SPECIFIC OF ONE PERSPECTIVE	Control	Range of states for which the system can effectively respond	2		---
	Production	Universe of part types that can be processed by a manufacturing system	3		---
	Operation	Ability to interchange the ordering of several operations for each part	1		---
	Distr. of information		---	Ability to distribute and share information through the delivery system	External
	Layout		---	Ease with which internal layout can be modified	Internal
	Quality		---	Ability to change the quality level of one or more of its products	Internal

Source: Authors. Note: We identified level agreement in bold

2.6 Conclusions

This chapter responds to the call for research along these lines in Jain et al., (2013) by attempting to address the wide terminological and conceptual ambiguity associated with the manufacturing flexibility construct. This chapter first carries out an analysis of the terms -types, elements, dimensions, parameters and others- used to refer to the aspects which integrate the manufacturing flexibility construct. Then, we perform a systematic analysis of the names and concepts of the different flexibility types in each of the theoretical approaches (hierarchical and strategic) in the manufacturing flexibility literature, to later identify the similarities and differences among them. To the best of our knowledge, this is the first work to carry out a conceptual systematisation of the manufacturing flexibility construct considering, firstly independently and then in a comparative manner, the two theoretical approaches. It uses as its basis the literature published on these topics in the ISI Web of Knowledge database during the period 1900-2012. From the analysis performed, a number of conclusions can be drawn.

Firstly, with respect to the ambiguous terminology for referring to the aspects which integrate the construct (variety of forms and the scope of each flexibility form), the analysis has allowed us to identify the main controversy around the terms identified, and, taking into account the frequency, to propose the use of the term "type" for the former and the term "element" for the latter.

Secondly, the systematisation process performed, when necessary, in analysing the works in each perspective, led to the establishment of both consensus definitions and names for the flexibility types discussed. This allowed us to identify and classify the types of discrepancies alluded to in previous studies into three categories: Type 1 (name), Type 2 (definition / scope), or Type 3 (combination).

Thirdly, the comparison carried out between both theoretical approaches makes it clear that, despite the widespread belief in the field that there is a great degree of confusion and ambiguity in terms of terminology (Sawhney, 2006; Jain et al., 2013), consensus on this matter is much higher than would appear at first sight. In more specific terms, the analysis reveals: 1) a block of seven flexibility types exists for which total consensus is found, both in definition and name, regardless of the theoretical approach utilised; 2) that after applying the systematisation process described, consensus is extended to five additional flexibility types which refer to the same reality in both approaches despite the use of distinct names in each one; 3) equivalence is to be found, as well, regarding the level in which the majority of the flexibility types have been discussed in the literature – correspondence between levels 1 and 2 with internal flexibility types, and between levels 3 and higher with external flexibility types; 4) only in three manufacturing flexibility types has a partial discrepancy been detected related to the scope of the definition, and only in four of them is there no clear correspondence between levels.

The high degree of consensus identified after the process performed (summarised in Table 9) has some theoretical implications. Firstly, it suggests that both perspectives identified, hierarchical and strategic, could coexist provided that researchers employ consensus names and definitions in a systematic way for referring to the same flexibility reality. Thus, the conceptual systematisation proposed in this work appears to be a promising taxonomy/approach that enables a standardisation of the terms and definitions for the flexibility types that could be used in future studies. This would eliminate, to the degree possible, the historical lack of conceptual agreement that has resulted in the fact that research into manufacturing flexibility has been broadly fragmented and difficult to compare. It would also allow us to have a better understanding of the implications of acquiring and using manufacturing flexibility, enhancing the possibility of comparing the results obtained in various studies, within and between the two perspectives. Moreover, the conceptual systematisation proposed also allows future researchers to advance in the consensus operationalisation of the construct by developing multi-item scales according to the elements needed to measure the scope of each flexibility type identified. This is so specifically for the twelve individual flexibility types with consensus before and after the systematisation process. This conceptual and terminological systematisation is essential for the homogeneous development of the manufacturing flexibility field. Additionally, after applying the consensus definitions to the individual flexibility types, it has been possible to determine that the level of consensus regarding the aggregate *product flexibility* is very high. Discrepancies are limited to the individual types which in each case are considered to be part of the aggregate, and which raises questions that could be of interest to researchers within each specific current. In contrast, it has not been possible to provide a solution for the discrepancy in *routing flexibility* even though we opt for the strategic perspective in order to determine the scope that this flexibility type should possess. Lastly, the still scanty research in the case of *supplier flexibility* makes it impossible to analyse this construct, and positions it closer to the group of six dimensions which have been proposed and developed in only one perspective.

In summary, this conceptual systematisation published in *International Journal of Production Research* (Pérez-Pérez et al., 2016) solves the first controversy around the conceptualisation of the construct and constitutes the base for the discussion of the operational systematisation that is presented in the next chapter of this dissertation.

CHAPTER 3

OPERATIONAL SISTEMATISATION

3.1 Introduction

As it was previously mentioned in this dissertation, the literature review of manufacturing flexibility carried out by Jain et al., (2013) suggests that two main research issues in this field still remain open. Firstly, there is the need to clarify the existing controversy around its conceptualisation (Jain et al., 2013; Narain et al., 2000), a problem which has contributed to a second controversy, the difficulty for its homogeneous operationalisation (Pérez Pérez et al., 2016; Koste et al., 2004; Shewduck & Moodie, 1998).

The conceptual and terminological systematisation developed in chapter 2 which has been published in the *International Journal of Production Research* (Pérez Pérez et al., 2016) solves the first controversy by providing standardised terms and definitions for the homogeneous conceptualisation of flexibility types identified in the literature. However, it only constitutes a necessary preliminary step that enables us to advance, in this chapter, on their homogeneous operationalisation. More specifically, three aspects should be studied together as long as they have been identified as the main causes of the lack of a "well accepted operationalisation" of the flexibility concept (Jain et al., 2013; Gerwin, 1993). Firstly, the controversy around the individual/aggregate nature of some flexibility types (Xu et al., 2011; Rogers et al., 2011). Secondly, the lack of agreement for determining the number and the names of the elements needed for measuring the scope of each flexibility type (Jain et al., 2013). Thirdly, the proliferation of items and partial scales without a consistent and structured approach for operationalising each flexibility type (Jain et al., 2013; Parker & Wirth, 1999; Beskese et al., 2004).

For these reasons, the main goal of the present chapter is to advance in the homogeneous operationalisation of the flexibility types conceptually systematised in chapter 2. More specifically, the objective is to create generalisable, structured, homogeneous and simplified measures that could be easily and consistently applied in future studies. In this way, the work would contribute to the systematisation of the flexibility types operationalisation by synthesising the vast empirical literature available in an attempt to solve the main ambiguities associated with it.

The remainder of the chapter is organised as follows. Firstly, section 2 presents the discussion of the individual or aggregate nature of flexibility types identified in chapter 2. Section 3 reviews the different elements proposed by the academic literature for operationalising the scope of each individual flexibility type. Thirdly, the methodology followed for the operational systematisation process will be presented in section 4, in order to describe in section 5 the discussion of the results that permit us to conclude with our operationalisation proposal.

3.2 Nature of flexibility types

We begin with the discussion of the individual/aggregate nature of the flexibility types. We define an aggregate of flexibility as a result of grouping various individual flexibility types (Xu et al., 2011). Their existence leads to a first problem for the construct operationalisation because the literature has shown inconsistencies when defining the specific individual flexibility types that make up an aggregate (Pérez Pérez et al., 2016), increasing the ambiguity of manufacturing flexibility operationalisation (Xu et al., 2011).

As a base for the identification of aggregates we use the conceptual systematisation developed in chapter 2 (see Table 9 of Chapter 2). The comparison carried out between the flexibility types defined by strategic and hierarchical theoretical approaches makes it clear that, despite the widespread belief in the field that there is a great degree of confusion and ambiguity in terms of terminology, consensus on this matter is much higher than would appear at first sight. More specifically, we found that consensus exists between both perspectives with respect to the definition of 15 flexibility types (*delivery, expansion, labour, volume, machine, material, programme, mix, modification, market, new product, process, routing, product and supplier).* After the systematisation process it was found that both perspectives only differ on the identification of a last group of flexibility types which were considered specific to each perspective *(control, operation and production flexibility types* within the hierarchical perspective and *distribution of information, layout and quality flexibility types* within the strategic perspective*).*

The operational systematisation proposed in this chapter will be focused on the 15 flexibility types with total consensus between both theoretical perspectives and the 3 flexibility types identified under the strategic perspective. That is because, according to the emerging research issues identified in Chapter 1, the strategic perspective matches better with the necessity of studying flexibility from a strategic point of view. This selection shows 18 potential flexibility types for the analysis.

For these 18 flexibility types two specific aspects were reviewed in order to identify aggregates: 1) the consensus definitions in order to analyse their scope and identify possible conceptual overlap among them that could be redundant; 2) the operationalisation proposals developed in the empirical literature in order to find measures that combine items from different flexibility types.

The analysis of these two aspects allowed us to identify the existence of 7 flexibility aggregates (see Table 10). These aggregates were excluded from the process of operational systematisation because we understand that the homogenisation of the measures of each flexibility type should be carried out, in the first place, at the individual level. Only after completing this phase it would be possible to work on the construction of aggregates in a consistent form, as well as to avoid ambiguities. Adopting this criterion reduced to 11 the total number of flexibility types considered for the operational systematisation of this chapter -*delivery, labour, volume, machine, material, programme, mix, modification, new product, routing* and *quality.*

Table 10. Flexibility types identified as aggregates

Name	Consensus definition identified in Chapter 2	Conceptual overlap identified	Operationalisation as an aggregate of….
Expansion	Ability to easily add capability and capacity/Ease with which capacity can be added	It is defined throughout the literature as a mid-range or long-range increase in capacity. Capacity is only expanded if the organisation needs to increase overall output volume or products, thus expansion flexibility was simply determined aggregating these two flexibility types (Rogers et al., 2011, Arias-Aranda et al., 2011; Koste & Malhotra, 1999; Gupta & Somers, 1992).	VOLUME + PRODUCT (Koste & Malhotra, 1999) VOLUMEN + NEW PRODUCT (Gupta & Somers, 1992; Arias- Aranda et al., 2011)
Market	Ability to adapt to a changing market environment/ Capability to adapt to market changes	It was extensively defined as a strategic dimension, and related to the marketing function, implying it is an outcome of implementing other dimensions such as mix and volume or indeed as a performance measure (Kim et al., 2013; Chang, 2012; Rogers et al., 2011; Gupta & Somers, 1992; Ward et al., 1995; Narasimhan & Das, 1999; Koste & Malhotra, 1999; Sethi & Sethi, 1990).	MIX +VOLUME (Kim et al., 2013; Rogers et al., 2011)
Process	Ability to change between the production of different product/Capability to produce a given set of parts types using different ways (process, material or sequences)	The definition overlapped with those of routing and mix, (Rogers et al., 2011; Swamidass, 1988, Sethi & Sethi, 1990, Koste & Malhotra, 1999, Vokurka & O'Leary-Kelly, 2000), or indeed with product, volume and machine (Tamayo-Torres et al., 2011; D'Souza & Williams, 2000; Braglia & Petroni, 2000; Sawhney, 2006; Boyer & Leong, 1996) as they all capture the ability of a manufacturing system to use alternative manufacturing pathways making this dimension redundant. Also, some authors have suggested that it includes routing, machine and material (Zhang et al., 2003) or modification and routing (D'Souza & Williams 2000) or mix and machine (Boyer & Leong, 1996).	MIX+VOLUME+DELIVERY+PRODUCT (Tamayo-Torres et al., 2011; Swink et al., 2005) PROCESS+LABOR+MACHINE+ROUTING +MATERIAL+EXPANSION+QUALITY (Sawhney, 2006) DELIVERY+VOLUME (Nair, 2005) MACHINE+MIX (Browne et al., 1984; Brill & Mandelbaum, 1989; Sethi & Sethi, 1990; D'Souza & Williams, 2000; Braglia & Petroni. 2000)
Product	Number and heterogeneity of products which can be produced/ Capability of a system to add or substitute products, new products or customer request without major effort	It is a complex concept that involves some aspects related with products such as mix, modification, volume or new product (Slack 1988; Da Silveira, 2006; Azzone & Bertele, 1989; Chen et al., 1992; Hyun & Ahn, 1992;Pérez Perez et al., 2016)	NEW PRODUCT+MIX (D'Souza & Williams, 2000) MIX+MODIFICATION+NEW PRODUCT (Chiang et al., 2012; Van Hop, 2004)
Supplier	1-The responsiveness enjoyed by a firm to desired changes in its mix, volume, delivery time and new product 2-The range of supply potential changes both in terms of quantity and type, of material, labour or any input resource/ Ability of suppliers to respond to changes requested by customer	Supply chain flexibility, refers to the ability to re-configure some aspects of the supply chain, such as volume or adapting products in line with demand changing requirements of purchased components (Merschmann & Thoneman, 2011; Tachizawa & Gimenez, 2009; Seebacher & Winkler, 2013; Vickery et al., 1999)	VOLUME + DELIVERY (Rogers et al., 2011, Ojha et al., 2013)
Dist. Information	Ability to distribute and share information through the delivery system	The definition overlaps with supplier or delivery or indeed could be similar to the definition of one dimension of the strategic sourcing construct of supply chains "information sharing" defined as the ability of the organisation and its suppliers to share information on market place changes as well as current supply chain inventory levels (Chiang et al., 2012)	Not operationalised
Layout	Ease with which internal layout can be modified	It presents an overlap similar to process flexibility that makes this flexibility type redundant in the sense that they capture the ability of a manufacturing system to use alternative paths.	Not operationalised

Source: Authors.

3.3 Elements needed for measuring each flexibility type

We continue by determining how to consistently measure the scope of each flexibility type (Jain et al., 2013). Although many researchers have developed single-item measures for manufacturing flexibility types, their use is considered inappropriate (Jain et al., 2013) and could limit the generalisability of the statistical results (Chang et al., 2006; Flynn et al., 1999; Koste et al., 2004; Noble, 1995). That is because the academic literature of manufacturing flexibility agrees in that the scope of any flexibility type consists of various elements (Koste et al., 2004) that require the use of multi-item scales for measuring each individual flexibility type. However, there is a lack of agreement for determining the number and the names of the elements that must be considered for measuring the scope of each flexibility type (Jain et al., 2013).

This fact makes it necessary to perform a theoretical review of the elements which have been proposed in the academic literature to define the most appropriate scope in the operationalisation proposal developed in this chapter. To this end, Table 11 presents the review carried out of the works, both theoretical and empirical, that have incorporated a discussion of this aspect. This table provides, in the top row, the name and definition of the various elements identified, while the columns present, chronologically, the references found along with the specific proposals developed by each one of them.

An analysis of this information shows that the bulk of the academic literature is mainly concentrated around three proposals which diverge in terms of considering 2, 3 or 4 elements. Additionally, isolated proposals are observed that, even though they have been employed in only one study (see Table 11), maintain a conceptual correspondence with those which have received greater attention. For this reason, they will not be discussed in a detailed and individualized manner.

An exhaustive analysis of the most frequent proposals makes it clear that, in spite of the variety in the number, the elements defined do not differ much as far as conceptualisation is concerned. More specifically, the two initial elements proposed by

Slack (1983) – *range* – ability to take up different positions - and *response* – ability to move from one state to another, in terms of cost or organisational disruption – have evolved and grown in number as the definitions were being made more precise.

The first evolution appears when Upton (1994) explains the *response* element in finer detail. He suggests that although it is true that flexibility has an effect on cost and time (Slack´s element *response* that Upton renames as *mobility*) it also has an effect on different parameters of manufacturing systems that must be measured. Following this argument he divides the element *response* into two: *uniformity* (ability of the system to produce similar performance outcomes regardless of the state of flexibility measured through assessing productivity, efficiency or quality performance) and *mobility* (easiness with which the organisation moves from one state to another in terms of cost or time (quickness and response). This explanation involves the use of an intermediate proposal in which three elements are defined –*range, mobility and uniformity*- (Jack & Raturi, 2002, Zhang et al., 2003; Narasimhan & Das 1999; 2004; Das, 2001; Fantazy et al., 2009; Cao & Zhang, 2008 or Swink et al., 2005) where the definitions of the last two suggest multiple measurement options, with the most frequent ones being productivity, efficiency and quality in the case of *uniformity*, and cost, easiness and quickness in the case of *mobility*.

Later, Koste and Malhotra (1999) make a new contribution and incorporate a fourth element as a result of defining more precisely the element *range*. To be more precise, they propose breaking it down into two: a) *range-number* – that is a numerical count of the possible options – and b) *range-heterogeneity* – which tries to measure the degree of difference between the options. As a result of this contribution, a new proposal arises which measures the scope through four elements, and which has been employed in the most recent studies (Malhotra & Sharma, 2008; Tamayo-Torres et al., 2011; Patel et al., 2012 or Malhotra & Mackelprang, 2012).

Given this situation, the systematisation proposal to operationalise the different flexibility types presented throughout this Chapter 3 selects, from among the proposals that are most employed in the literature, the proposal that incorporates the largest number of elements to measure the scope of each flexibility type – *range-number, range-heterogeneity, uniformity* and *mobility*-. In this way, the widest and most precise vision is employed, with the understanding that should it be necessary to construct elements of a higher level – *range or response* – it would be possible by means of aggregating corresponding items in each case.

Table 11. Elements for defining the scope of each individual flexibility type

Elements described				RESPONSE		RANGE				
References	Number of elements for defining the scope	**RANGE:** Ability to take up different positions or alternatively the ability to adopt a range of states.	**RESPONSE:** Ability to move from one state to another, in terms of cost or time	**UNIFORMITY:** Captures the ability of the system to produce similar performance outcomes regardless of the state of flexibility measured through assessing productivity, efficiency or quality performance	**MOBILITY:** Represents the ease with which the organisation moves from one state to another in terms of cost or time (quick and easiness)	**RANGE-NUMBER:** Is a strict numerical count of the number of possible options that a system or resource can achieve	**RANGE HETEROGENEITY:** The degree of difference between different options.	**SCOPE:** Captures the scope of flexible response in terms of the full range and diversity of options (i.e., operations, products, etc.) that the organisation can attain	**ACHIEVABILITY:** It captures the short-term (transient) and long-term (duration) penalties that the organisation incurs in invoking the flexible response	**DISTENTION:** Time and cost needed to change the action space, for example expand or contract it
Slack (1983;1988); Rogers et al. (2011);Ojha (2013); Oke (2013); Chang et al., (2003)	2	**X**	**X**							
Upton (1994), Jack & Raturi (2002), Zhang et al., (2003); Narasimhan & Das (2004); Das (2001); Fantazy et al., (2009); Cao & Zhang (2008); Swink et al., (2005): Urtasun-Alonso et al., (2014)	3	**X**		**X**	**X**					
Koste & Malhotra (1999); Malhotra & Sharma (2008); Tamayo-Torres et al., (2011); Patel, Li & Tejeresen, (2012); Malhotra & Mackelprang (2012)	4			**X**	**X**	**X**	**X**			
D'Souza & Williams (2000)	2	**X**			**X**					
Olhager & West (2002)	3	**X**	**X**							**X**
Koste et al., (2004)	2							**X**	**X**	

Source: Authors. Note: this table shows works that have included a further theoretical discussion about elements needed to operationalise the scope of each flexibility type.

3.4 Systematising items per element within the scales

Once the individual flexibility types were identified, and the number of elements necessary for the measurement of the scope of each one was determined, the next step to operationalise the different flexibility types is to propose the items through which each one of these elements will be measured. Given the proliferation of scales used in academic literature, our first step involved a review of this literature in order to identify the items proposed in empirical studies that include multi-item scales of any individual flexibility type. The process followed is presented below, and the results of this review are summarised in Table 12. Though it is expected that works which justify the existence of different elements to measure the scope of each flexibility type should specify which items correspond to each one of the elements proposed, our analysis shows that this is not always the case. More specifically, only a reduced number of works (Koste et al., 2004; Malhotra & Sharma, 2008; Malhotra & Mackelpang, 2012 and Patel et al., 2012) provide a detailed classification of the items used for measuring each of the elements considered. For this reason it was necessary to identify which elements correspond to the items proposed by the studies which lack this level of detail. We classified them according to the similarities between the items of the scales proposed by the four works previously identified (Koste et al., 2004; Malhotra & Sharma 2008; Malhotra & Mackelpang, 2012; Patel et al., 2012).

It is relevant to highlight that during the process of assigning items to each element we found two special situations : a) in some cases it was not possible to classify an item exclusively under one element (an example of this case is the item for labour flexibility of Arias-Aranda et al., (2011) "The number of different operations an employee can perform without incurring in [sic] high changing costs is very high" which includes the *range-number* –number of options- and *mobility* –cost of the change- elements); b) in other cases, all the items used in the scale were classified under the same element (that is the case of Narasimhan & Das, 1999; Das, 2001; and Kim et al., 2013). The results of this first step are summarised in Table 12, while the specific items proposed in the literature for each element that defines the scope of each flexibility type are in the Appendix III.

Table 12. Specific items proposed in the literature for each element

References	Internal Flexibility types																								External Flexibility types																			
	Labour				Machine				Material				Routing				Programm				Quality*				Volumen				Mix				Modification				New product				Delivery			
	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M	RN	RH	U	M
Jayakumar (1984)																	x			x					x			x																
Slack (1988)																									x			x													x			x
Gupta & Somer (1996)									**				x			X									x		x																	
Narasimhan & Das (1999)***																									x			x								x				x				
D'Souza & Williams (2000)									**																x			x																
Das (2001)***																									x			x				x	x		x	x				x				
Jack & Raturi (2002)																									x		x	x																
Zhang et al., (2003)	x	x	x	x	x	x		x	x	x		x	x	x		x									x	x	x	x		x	x	x												
Arias-Aranda (2003)	**				x			x					x			x									x			x																
Koste et al., (2004)	x	x	x	x	x	x	x	x	x	x	x	x																	x	x	x	x	x	x	x	x	x	x	x	x				
Narasimhan & Das (2004)																									x			x								x				x				
Swink et al., (2005)																																					x			x				
Nair (2005)																																					x			x				
Fantazy et al., (2009)																																									x	x		x
Malhotra & Sharma (2008)	x	x	x	x	x	x	x	x	x	x	x	x																	x	x	x	x	x	x	x	x	x	x	x	x				
Cao & Zhang (2008)	x	x	x	x	x	x		x	x	x		x	x	x		x									x	x	x	x		x	x	x												
Chen et al., (2009)																																											x	x
Rogers et al., (2011)	x			x	x			x					x	x												x		x		x		x												
Tamayo-Torres et al., (2014)					x	x	x			x	x	x	x	x	x	x																	x			x								
Arias-Aranda (2011)	**																x			x					x			x																
Patel et al., (2012)	x	x	x	x	x	x	x	x	x	x	x	x																	x	x	x	x					x	x	x	x				
Malhotra & Mackelprang (2012)																													x	x	x	x	x	x	x	x	x	x	x	x				
Ojha et al., (2013)	x			x	x			x					x	x												x		x		x		x												
Oke (2013)	x	x	x	x																										x	x	x												
Kim et al., (2013)***	**				x			x																																x				
Urtasun-Alonso et al., (2014)																												x	x	x		x					x	x						
Mendes & Machado (2015)																									x			x				x					x			x				
Ojha et al. (2015)	x			x	x			x					x	x												x		x		x		x												
Total	**9**	**6**	**6**	**9**	**11**	**6**	**4**	**10**	**5**	**6**	**4**	**6**	**8**	**6**	**1**	**5**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**13**	**5**	**4**	**16**	**5**	**11**	**7**	**13**	**5**	**3**	**4**	**7**	**8**	**5**	**4**	**11**	**2**	**1**	**1**	**3**

Source: Authors. *Note: quality flexibility has never been operationalized. ** They provide items for this flexibility type but these items could not be classified under only one element.*** In some cases, although these works use scales, all the items used were classified under the same element

Table 12 shows a general view of the situation in which one finds the operationalisation of each flexibility type as well as the universe of items used to measure each element. More specifically, it reveals: a) that not all flexibility types have been operationalised with the same intensity. In this sense, worth noting is the absence of scales to operationalise *quality flexibility*, indicating that it has only been treated conceptually, and the reduced number of scales for *programme* and *delivery* flexibility types, which have been operationalised in only two (Jayakumar, 1984; Arias-Aranda et al., 2011) and three works (Slack, 1988; Fantazy et al., 2009 and Chen et al., 2009) respectively; b) there is great heterogeneity in the number of elements utilized to define the scope of each flexibility type.

In a second step, the classified items were reviewed in order to identify the most frequent item for each one of the four elements which define the scope of each flexibility type (see Tables 13a and 13b). However, as previously mentioned, the conceptual definitions of these elements are not homogeneous in terms of the measurement options that should be included. More specifically, the definitions of *range-number* and *range-heterogeneity* suggest only one measurement option – *number of options available* and *degree of difference between options* respectively- so we anticipate one most frequent item in each case. However, the definitions of *uniformity* and *mobility* elements suggest multiple measurement options, with the most frequent ones being *productivity, efficiency* and *quality* and *quickness, easiness and cost impact*, respectively -. As a consequence, in these specific elements we identify three different most frequent items. The results of this second step are presented in Tables 13a and 13b together with the numerical count (n/N) that each item (n) has been used within the scales previously analysed (N). This information shows:

- The greatest heterogeneity is found, as it was expected, around the items identified under the *uniformity* and *mobility* elements.
- Some flexibility types (*material, modification* and *delivery*) have more than one most frequent item - used with the same frequency- for measuring an element (*range-number* and *range-uniformity* in the first two cases, *mobility* in terms of cost in the latter).

- Some flexibility types present incomplete measures (that is the case of *new product, delivery, material, routing, programme* and *quality flexibility types*).

This situation shows that further discussion is needed in order to establish criteria to select the best items to measure the elements for each flexibility type or develop missing scales. This discussion is presented in the next section.

Table 13a. Most frequent item of internal flexibility

Element	RANGE NUMBER	RANGE HETEROGENITY	UNIFORMITY			MOBILITY		
Way of measure Flexibility type	Number of options	Degree of difference between options	PRODUCTIVITY	EFFICENCY	QUALITY	QUICKLY	EASILY	COST
Labour	Workers are cross-trained to perform many different tasks	Workers can perform tasks which differ greatly from one another	Workers are equally effective, in terms of productivity for all tasks	Workers are equally efficient for all tasks	Workers are equally effective, in terms of quality for all tasks	A short time delay occurs when workers are moved between tasks	Workers can move easily between different tasks	A small cost is incurred (in terms of lost productivity) when workers are moved between different tasks
n/N	6/9	3/6	2/6	5/6	1/6	2/9	5/9	3/9
Machine	The number of different operations that a typical machine can perform is high	Machines can perform operations which differ greatly from one another	Machines are equally effective, in terms of productivity, for all operations	Machines are equally reliable for all operations	Machines are equally effective, in terms of quality, for all operations	Machine set ups between operations are relatively quick	Machine set-ups are easy	**Cost of switching from one operation to another**
n/N	10/11	4/6	3/4	3/4	1/4	9/10	7/10	1/10
Material	There are many different material handling paths between processing centers	The material handling system can transport materials of different sizes	------------	The choice of material handling path does not affect the efficiency of material transfer	The quality of material is not affected by the material handling path	Changing a material handling path is quick.	Changing a material handling path is easy	1) Changing a material handling path is inexpensive. 2) The choice of material handling path does not affect the material transfer cost.
n/N	3/5	4/6	0/4	4/4	2/4	6/6	2/6	3/6
Routing	**A typical part operation can be routed to different machines**	**A route can process products/parts which differ greatly to one another**	------------	-----------	**Alternate routes do not decrease quality**	**Route changes can be made quickly**	**Route changeover are easy**	**Alternate routes do not decrease costs**
n/N	6/8	3/6	0/1	0/1	1/1	3/5	2/5	1/5
Programme	**Number of systems with unattended operations**	----------------	----------------	----------------	----------------	----------------	**Expected percentage uptime during second and third shift**	----------------
n/N	2/2	0/0	0/0	0/0	0/0	0/2	2/2	0/2

Source: Authors. Note: quality flexibility has never been operationalized. Note: bold items have been classified by authors. n= numerical count that the item has been used. N= Total of scales

Table 13b. Most frequent item of external flexibility

Element	RANGE NUMBER	RANGE HETEROGENITY	UNIFORMITY			MOBILITY		
Way of measure Flexibility type	Number of options	Degree of difference between options	PRODUCTIVITY	EFFIENCIENCY	QUALITY	QUICKLY	EASILY	COST
Volume	**The range of output volumes at which the firm can run profitably**	**We vary total output from one period to the next**	**We can operate profitably at different production volumes**	**We can operate efficiently at different production volumes**	**When we increase levels of output we do not experience quality problems**	**We can quickly change the quantities for our products produced**	**We easily change the output volume of a manufacturing**	**Cost of increasing or decreasing volume of output**
n/N	6/13	5/5	¾	2/4	1/4	5/16	6/16	4/16
Mix	A large number of product lines are produced in the plant	We can vary process requirements from one period to the next	Productivity is not affected by changes in product mix	The efficiency of the production process is not affected by changes in product mix	Product quality is not affected by changes in product mix	The time required to change to a different product mix is short	The product mix produced by the plant can be changed easily	The cost of changing to a different product mix is small
n/N	5/5	4/11	3/7	4/7	3/7	5/13	8/13	4/13
Modification	1)There are a large number of product modifications every year 2) Existing products lines are frequently modified. 3) The features of existing products are often modified	1)Modified products are very different from existing products 2) Modified products are very similar to existing products 3)The product modifications made are fairly similar to one another	Productivity levels are not affected when a modified product is introduced into the manufacturing system	Manufacturing system performance is not affected by the production of modified products	The quality of existing products is not affected when a modified product is introduced into the manufacturing system	Modified products can be made quickly	Product modifications are easy to make	Cost of accommodating minor design changes
n/N	4/5	3/3	¾	3/4	3/4	4/7	3/7	4/7
New Product	The number of new products introduced into production each year is high	New products are very different from existing products	Productivity levels are not affected when a new product is introduced into the production system	---------------	The quality of existing products is not affected when a new product is introduced into the production system	The time required to develop and introduce new products is extremely low	-------------	The cost (in dollars) required to design and develop new products is extremely high
n/N	8/8	5/5	¾	0/4	4/4	11/11	0/11	8/11
Delivery	**1) The extent to which delivery dates can be brought forward** **2) Managing the varying number of delivery modes available per product** **3) Managing small delivery order quantity form the customer**	**1) Delivering urgent request with different and faster modes of transportation** **2) Handling more or more delivery order of a customer from more than one warehouses, distribution channels or factories**	**Your company's delivery rate of products still stable when customers shorten delivery deadlines**	----------------------	--------------------------	**The time taken to reorganize the manufacturing system to re-plan for the new delivery date**	------------	**The cost implications of changing the delivery due dates**
n/N	1/2	1/2	1/1	0/1	0/1	2/3	0/3	1/3

Source: Authors Note: bold items have been classified by authors. n= numerical count that the item has been used. N= Total of scales

3.5 Systematisation proposal to operationalise flexibility types

Once the items within scales have been systematically reviewed and classified, a discussion of the most frequent items per element identified was undertaken in order to establish a criterion for developing the operationalisation proposal. This result is summarised in Tables 14a and 14b. The criterion adopted was to select the most frequently employed item.

However, the previous section shows two different situations that affects the application of this criterion: a) elements where the academic literature has been clear on the definition, suggesting only one measurement option –that is the case of *range-number* and *range-heterogeneity*-; and b) elements which appear more ambiguous as a result of the fact that the conceptual definition provided by academic literature has derived in multiple measurement options –that is the case of *uniformity* and *mobility* -.

With respect to the first case, -*range-number* and *range-heterogeneity*-, the suggestion of only one form of measurement -*number of options available in the first case* and *degree of difference between options in the second*- increased the level of consensus and the identification of a clear pattern as to the items identified as most frequent. In this sense, these most frequent items were selected for our operationalisation proposal, with two exceptions:

- *Modification* and *delivery flexibility types*: three different items have been used with the same frequency for measuring the elements *range-number* and *range-heterogeneity*. In these cases we opt to select the item which presents the greatest similarity to the items selected for the rest of the flexibility types.
- *Programme flexibility:* there was no item for measuring the *range-heterogeneity* element, so an item was proposed by the authors. The items previously selected for the rest of the flexibility types served as the point of departure which allowed us to identify a pattern for the development of this missing item.

With respect to the second case, the elements *uniformity* and *mobility*, we found that the multiple measurement options suggested in the works which had operationalised the flexibility types using these elements increased the heterogeneity between the items identified. This situation leads to the fact that the selection of the most frequent item results in a scale that is partial and unsystematic. Thus, further discussion of the information in Tables 13a and 13b is required, which is presented below:

- *Uniformity*: academic literature has suggested multiple measurement options, with the most frequent being those that measure the impact on productivity, efficiency or quality. However, Tables 13a and 13b show that not all these three options have been used for operationalising all the flexibility types, and secondly, when the three options were identified within a flexibility type they do not have the same intensity of use. More specifically, we found that all the flexibility types, with the exception of *routing* and *programme*, present items for measuring the impact on productivity and / or efficiency. However, the analysis of the effect on product quality has received greater attention in flexibility types of an external character. This difference in the usage intensity depending on the character of the flexibility type under consideration –internal or external- may have a theoretical justification in the strategic perspective. This perspective maintains that the internal flexibility types are linked to a greater degree to the production process, impacting in a more immediate way on efficiency or productivity of the production system. In contrast, external flexibility types, apart from affecting the efficiency and / or productivity of the system, also impact more directly on existing product quality, and thus, their effects are more easily perceived by consumers.

  Following this discussion, our systematisation proposal measures the element *uniformity* using different number of items depending on the flexibility type under consideration – internal vs. external -. In more specific terms, our proposal will include an item to measure the impact on productivity / efficiency for all flexibility types, independent of character, and following this template, "The productivity / efficiency of the manufacturing process is not affected by changes in …". On the other hand, for the external flexibility types, the impact on existing product quality will also be measured by selecting the most frequent item identified in Tables 13a and 13b.

- *Mobility*: in this case the conceptual definition provides two different options for measuring this element: cost and time. Furthermore, the latter could be measured through two concepts – easiness and quickness-. Tables 13a and 13b show that scales usually attempt to measure this element by focusing on the time impact. Empirical works have sometimes used both options suggested – quickness and / or easiness of change (i.e. Koste et al., 2004; Malhotra & Sharma, 2008) or only one of them (i.e. Patel et al., 2012; Tamayo-Torres et al., 2014). However, the items that measure the element *mobility* by means of the impact on cost have a lower frequency of use. Our proposal suggests that the items which measure quickness and easiness could turn out to be equivalent as put forward by Ling Yee & Ogunmokun (2008). However, that a change is easy or quick does not imply that there is no impact on cost. Given this situation, the proposal to measure the element *mobility* will incorporate two items. The first one will be the result of combining the items which measure quickness and easiness of change. The items will be adapted following this template, “It is quick and easy to carry out changes on …”. The second item will measure the impact on cost. In this case we select the most frequent item identified in Tables 13a and 13b.

The discussion presented in this section allows us to establish systematised criteria for reducing the ambiguity around the different items proposed in the literature, specifically for the *uniformity* and *mobility* elements. It also permits maintaining an equilibrium between the numbers of items utilized to measure each one of the elements, as Cupani (2012) or Clark (1999) suggests.

The final operational proposal developed and discussed on this chapter are summarised in Tables 14a and 14b.

Table 14a. Systematisation proposal to operationalise internal flexibility types

Element		Item	References
Labour	R-N	- Workers are cross-trained to perform many different tasks	- Koste et al., (2004); Malhotra & Sharma (2008); Rogers et al., (2011); Patel et al., (2012); Ojha et al., (2013); Ojha et al., (2015)
	R-H	- Workers can perform tasks which differ greatly from one another	- Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012)
	U	- *The productivity/efficiency is not affected by changes on the tasks of workers*	-Adapted from Zhang et al., (2003); Koste et al., (2004); Malhotra & Sharma (2008); Cao & Zhang (2008); Patel et al., (2012)
	M	- *It is quick and easy to move workers between different tasks* - A small cost is incurred when workers are moved between different tasks	-Adapted from Zhang et al., (2003); Koste et al., (2004); Malhotra & Sharma (2008); Cao & Zhang (2008); Patel et al., (2012); Oke (2013) - Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012)
Machine	R-N	-The number of different operations that a typical machine can perform is high	- Zhang et al., (2003); Arias-Aranda (2003); Koste et al., (2004); Malhotra & Sharma (2008); Cao & Zhang (2008); Rogers et al., (2011); Patel et al., (2012); Kim et al., (2013); Ojha et al., (2013); Ojha et al., (2015)
	R-H	- Machines can perform operations which differ greatly from one another	- Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012); Tamayo et al., (2014)
	U	- *The productive/efficiency is not affected by changes on operations of machines*	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012); Tamay-Torres et al., (2014)
	M	- *It is quick and easy to made changeovers between machines operations* - Cost of switching from one operation to another	- Adapted from Zhang et al., (2003); Koste et al., (2004); Malhotra & Sharma (2008); Cao & Zhang (2008); Rogers et al., (2011); Patel et al., (2012); Kim et al., (2013); Ojha et al., (2013); Ojha et al., (2015). - Arias Aranda (2003)
Material	R-N	- There are many different material handling paths between processing centers	- Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012)
	R-H	- The material handling system can transport materials of different sizes	- Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012); Tamayo-Torres et al., (2014)
	U	- *The productivity/efficiency is not affected by changes of material handling path*	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Patel et al., (2012); Tamayo-Torres et al., (2014)
	M	- *It is quick and easy to change the material handling path* - The choice of material handling does not affect the material transfer cost	- Adapted from Zhang et al., (2003); Koste et al., (2004); Cao & Zhang (2008); Malhotra & Sharma (2008); Patel et al., (2012); Tamayo-Torres et al., (2014). - Koste et al., (2004); Malhotra & Sharma (2008); Tamayo-Torres et al., (2014)
Routing	R-N	- A typical part can use many different routes	- Zhang et al., (2003); Cao & Zhang (2008); Rogers et al., (2011); Ojha et al., (2013); Tamayo-Torres et al., (2014); Ojha et al., (2015)
	R-H	- A route can process products/parts which differ greatly to one another	- Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)
	U	***- The productive/efficiency is not affected by changes on the routes***	**- Proposed by authors**
	M	- *It is quick and easy to change the routes* - Alternate routes do not increase costs	- Adapted from Zhang et al., (2003); Cao & Zhang (2008); Tamayo-Torres et al., (2014) - Tamayo-Torres et al., (2014)
Programme	R-N	- Number of systems with unattended operations	- Jayakumar (1984); Arias-Aranda et al., (2011)
	R-H	**- Manufacturing system programming is capable of running unattended, for a long enough time, a products/parts which differ greatly one to another**	**- Proposed by authors**
	U	**- The productivity/efficiency of the system is not affected by changes in the programme**	**- Proposed by authors**
	M	**- It is quick and easily to change manufacturing system programming** **-Alternate programme do not increase costs**	**- Proposed by authors**
Quality	R-N	**- The production system can work with a widely range of tolerances for the product specifications**	**- Proposed by authors**
	R-H	**- The range of tolerances for the product specifications differ greatly one to another**	**- Proposed by authors**
	U	**- The productivity/efficiency of the system is not affected by changes in the range of tolerances for the product specifications**	**- Proposed by authors**
	M	**- It is quick and easily to change the range of tolerance of specific products** **-Alternate range of tolerance do not increase costs**	**- Proposed by authors**

Source: Authors. NOTE: *Italic items are the result of combining two ways of measures after the discussion of uniformity and mobility elements*. **Bold items are created by authors**

Table 14b. Systematisation proposal to operationalise external flexibility types

Element		Item	References
Volume	R-N	- The range of output volumes at which the firm can run profitably	- Gupta & Somers (1996); Zhang et al., (2003); Cao & Zhang (2008); Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)
	R-H	- We can vary output levels from one period to the next	- Zhang et al., (2003); Cao & Zhang (2008); Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)
	U	*- The productivity/efficiency of the production process is not affected by changes in production volumes* - The quality of products is not affected by changes in production volumes	- Adapted from Zhang et al., (2003); Cao & Zhang (2008) - Jack & Raturi (2002)
	M	*- It is quick and easy to change the production volume of a manufacturing process* - Cost of increasing/decreasing production volume	- Adapted from Zhang et al.,(2003); Cao & Zhang (2008); Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015) - D'Souza & Williams (2000); Urtasun-Alonso et al., (2014); Mendes & Machado (2015)
Mix	R-N	- A large number of product lines are produced in the plant	- Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012); Urtasun-Alonso et a (2014)
	R-H	- We can vary product mix from one period to the next	- Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012)
	U	*-The productivity/efficiency of the production process is not affected by changes in product mix* - Product quality is not affected by changes in product mix	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012) - Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)
	M	*- It is quick and easy to change the product mix produced by the plant* -The cost of changing to a different product mix is small	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Rogers et al., (2011); Patel et al., (2012); Ojha et al., (2013); Urtasun-Alonso et al., (2014); Ojha et al., (2015). - Das (2001); Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)
Modification	R-N	- There are a large number of product modifications every year	- Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Tamayo-Torres et al., (2014)
	R-H	- Modified products are very different from existing products	- Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)
	U	*- The productivity/efficiency of the production process is not affected when a modified product is introduced into the manufacturing system* -The quality of existing products is not affected when a modified product is introduced	-Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012) - Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)
	M	*- It is quick and easy to introduce modified products* - Cost of accommodating minor design changes	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Tamayo-Torres et al., (2014) - Narasimhan & Das (1999); Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)
New product	R-N	- The number of new products introduced into production each year is high	- Koste et al., (2004); Swink et al., (2005); Nair (2005); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012); Urtasun-Alonso et al., (2014); Mendes & Machado (2015)
	R-H	- New products are very different from existing products	- Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012); Urtasun-Alonso et al., (2014)
	U	*- The productivity/efficiency of the production process is not affected when a new product is introduced into the production system* - The quality of existing products is not affected when a new product is introduced into the production system	- Adapted from Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012). - Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012).
	M	*- It is quick and easy to introduce the introduction of new products* - The cost required to design and develop new products is high	- Adapted from Narasimhan & Das (1999); Das (2001); Narasimhan & Das (2004); Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Patel et al., (2012). - Das (2001); Narasimhan & Das (1999); Narasimhan & Das (2004); Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012); Mendes & Machado (2015)
Delivery	R-N	- The number of delivery deadline options available per product is high	-Slack (1988)
	R-H	- Delivering urgent request with different and faster modes of transportation	- Fantazy et al., (2009)
	U	- The rate of wrong deliveries still stable when customers shorten the delivery deadlines	- Chen et al., (2009)
	M	**- It is quick and easy to made changes on delivery deadline changes** - The cost implications of changing delivery dates	- **Proposed by authors** - Fantazy et al., (2009)

Source: Authors. NOTE: *Italic items are the result of combine two ways of measures after the discussion of uniformity and mobility elements*. **Bold items are items created by authors**

3.6 Conclusions

This discussion presented within this chapter allows us to create generalisable, structured, homogeneous and simplified measures that could be easily and consistently applied in future studies. In this way, the work contributes to the systematisation of flexibility type operationalisation by synthesizing the vast empirical literature available in an attempt to solve the main ambiguities associated with it. To the best of our knowledge, this is the first work to carry out a systematisation of flexibility type operationalisation, responding to the recent call for research along these lines in Jain et al., (2013) and Pérez Pérez et al., (2016).

This chapter solves the second controversy around the operational systematisation of the construct. Together with the conceptual systematisation developed in chapter 2, it allows us to advance in a homogeneous manner on the main goal of this dissertation that is presented in the next chapter.

CHAPTER 4

EMPIRICAL REVIEW AND MODEL PROPOSAL

4.1 Introduction

The main objective of this doctoral thesis is to analyse the effect of the implementation of manufacturing flexibility practices on the performance of the organisation. We base our proposal on the strategic theoretical perspective. As we have identified in Chapter 2, the strategic theoretical approach contains three main premises:

1) There are two manufacturing flexibility levels. Internal flexibility constitutes the lower or basic level, and external flexibility constitutes the second or higher level (Chang et al., 2007; Lynch & Cross, 1991; Upton, 1994; Chang et al., 2003; Chang et al., 2005; Chang et al., 2006). The distinction between these two levels is based on the degree of perception of their effects by consumers (Pérez Pérez et al., 2016; Bernardes & Hanna, 2009).
2) Depending on the flexibility level considered, the implications on performance differ (Gaimon & Singhal, 1992; Urtasun-Alonso et al., 2014). More specifically, this theoretical approach sustains that external flexibility has a higher positive direct impact on performance (Buzacott & Mandelbaum, 2008; Pérez Pérez et al., 2016; Chang et al., 2007) than internal flexibility.
3) There is a logical link between levels of decomposition which supports the view that lower levels determine the degree of higher levels of flexibility (Pérez Pérez et al., 2016; Jain et al., 2013; Rogers et al., 2011; Oke, 2005; Slack, 1988). Thus, internal flexibility is essential for the development of external flexibility because the former allows a firm to combine, integrate, and reconfigure resources for developing external flexibility and improving performance (Zhang et al., 2003).

However, while these three premises are clearly identified by conceptual literature, empirical works which have tested them are scarce, fragmented and controversial with a proliferation of partial and heterogeneous models, which largely ignore the complexities inherent in the actual operationalisation and implementation of the manufacturing flexibility construct (Malhotra & Mackelprang, 2012) and its effects on performance. Given that, there are some open issues relating to the empirical validation of the premises of the strategic approach.

This chapter seeks to gain further insights into the existence of two flexibility levels, the linkage that exists among them, and the effects that they have on performance. In this way, we intend to provide empirical evidence to validate the premises suggested in the strategic theoretical framework, and at the same time, to respond to the recent call for a greater understanding of the interactive nature of internal and external flexibility types in the development of manufacturing flexibility in a company (Ojha et al., 2013; Jain et al., 2013). More specifically, firstly, our proposal involves empirically validating the existence of two flexibility levels –internal and external-. Secondly, we will analyse the individual and direct effects that these two manufacturing flexibility levels have on performance. And, thirdly, we will test if external flexibility constitutes a full or partial mediator variable between the internal flexibility – performance relationship.

The remainder of this chapter is organised as follows. Firstly, section 2 presents the integrative model proposal and hypotheses. Specifically, within this section firstly the creation of second order constructs will be discussed. Then the literature that suggests direct effects on performance will be presented. Finally the arguments for the mediation effect between internal and external flexibility will be discussed.

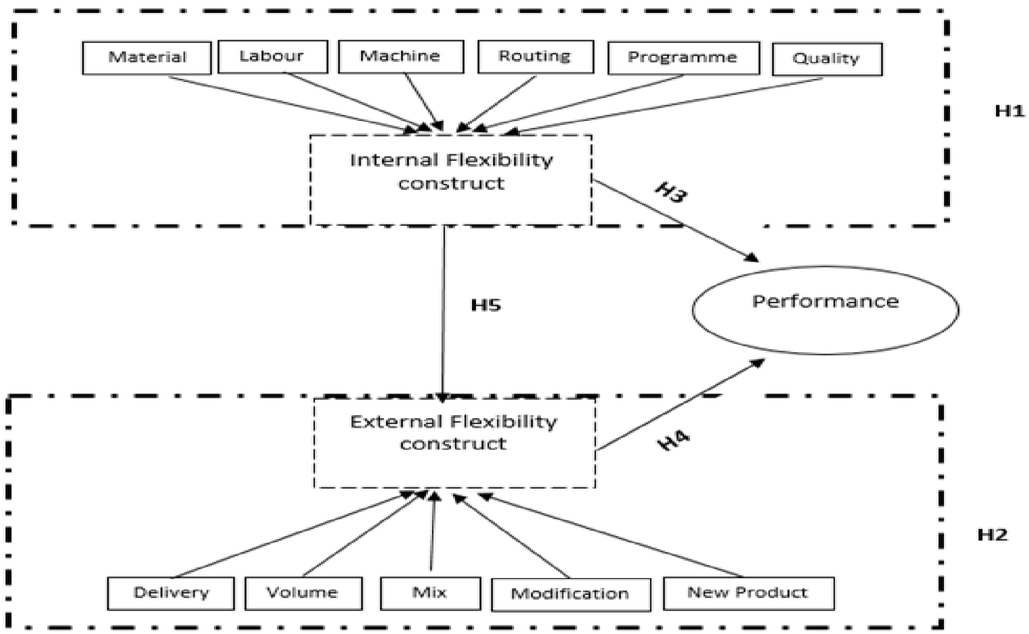
4.2 Theory development

Manufacturing flexibility is a vital tool in allowing the firm to respond appropriately to changes in the competitive environment. It will be essential if a firm is to succeed in this increasingly global marketplace (Mendes & Machado, 2015; D'Souza & Williams, 2000; Leong et al., 1990; Hill, 1994; Miller & Roth, 1994). It is therefore incumbent on managers and researchers to strive for a better understanding of the manufacturing flexibility construct. However, it is well known that over the last few decades the literature has been ambiguous about its conceptualisation and operationalisation (Jain et al., 2013) resulting in the fact that the construct was not well understood.

More specifically, although researchers agree that it constitutes a complex and multidimensional construct (Mendes & Machado, 2015; Francas et al., 2011; De Toni & Tonchia, 1998) composed of flexibility types that are developed at different levels– internal vs. external- (Pérez Pérez et al., 2016; Cao & Zhang, 2008; Braglia & Petroni, 2000), the absence of a well-accepted taxonomy has increased ambiguity as far as determining the number, name and level of development of the flexibility types involved (Pérez Pérez et al., 2016).

In order to unify theoretical research on manufacturing flexibility, the three premises put forward by the strategic perspective, together with the conceptual and operational systematisation of the manufacturing flexibility construct developed in previous chapters of this dissertation, are the base for the model proposal presented in Figure 3. The specific explanations for formulating the hypotheses developed within this model proposal are explained below.

Figure 3. An integrative framework of manufacturing flexibility and performance



Source: Authors

4.2.1 Internal and External flexibility constructs

As indicated previously, the first theoretical premise of the strategic approach suggests that manufacturing flexibility is multidimensional and consists of a number of flexibility types which are divided into two levels based on the degree of perception of their effects by consumers. Internal flexibility types respond to disturbances inside the organisation related with manufacturing resources and management (Bernardo & Mohamed, 1992), such as machine breakdowns or labour problems that are difficult to be perceived by consumers (D'Souza & Williams, 2000). External flexibility types, on the other hand, are introduced through changes in products, quantity demanded, delivery deadlines, etc., that are taken to be those that are directly perceived by customers outside the organisation.

Currently, from a theoretical point of view, it is widely accepted that it is feasible to conceptualise and operationalise manufacturing flexibility constructs by analysing these two broad levels –internal and external- separately (Malhotra & Mackelprang, 2012, Chang, 2012; Zhang et al., 2003; D'Souza & Williams, 2000). This is because it has been suggested that there are inherent trade-offs associated with the "internal" and "external" level of a flexible response (Malhotra & Mackelprang, 2012), and a better understanding is needed about how these two different levels fit and impact on performance (Zhang et al., 2003).

However, though the existence of these two flexibility levels has been accepted theoretically, empirical testing of this assumption is practically non-existent in the literature, thus constituting a research gap. This circumstance is driven by two main causes: a) problems associated with the conceptualisation of the manufacturing flexibility construct which have made it difficult to identify the number and names of the flexibility types within each level; b) the complexity related with operationalisation of a complex construct that requires higher levels of abstraction.

In this regard, the conceptual and operational systematisation developed in chapters 2 (Pérez Pérez et al., 2016) and 3 of this dissertation enabled us to identify 11 individual flexibility types that make up this multidimensional construct as well as to obtain a detailed classification of the level – internal and / or external - to which each one of them belongs (see Table 9, Chapter 2). Specifically, the systematisation process carried out made it clear that:

- There are five flexibility types – *labour, machine, material, routing* and *quality* – which have been considered as belonging to the internal level by the academic literature in a unanimous way.
- There are five flexibility types- *volume, mix, modification, new product* and *delivery* - which have been considered as belonging to the external level by the academic literature in a unanimous way.
- Only one flexibility type, *programme* flexibility, requires further discussion as the literature has not provided clear consensus about its character – internal or external. In relation with this individual flexibility type, theoretical studies argue that higher levels of programme flexibility result in procedures that increase the effective capacity of the production system (Sethi & Sethi, 1990). These procedures are developed inside the organisation, improving productivity of the manufacturing process, and are not directly perceived by customers. Following this premise, we consider it appropriate to classify *programme* as an internal flexibility type.

In summary, we propose that the internal flexibility level is composed of 6 flexibility types -*labour, machine, material, routing, quality* and *programme*-. In addition, the external flexibility level is composed of five flexibility types - *volume, mix, modification, new product* and *delivery*-.

Once the number and names of the flexibility types that are classified within each level have been clarified, the next step is to analyse how to operationalise them independently.

As we discussed in Chapter 3 of this dissertation, each individual flexibility type identified must be measured through different elements –*range number, range* *heterogeneity, uniformity, mobility-*, and consequently they are considered latent variables or single constructs. That is because a single construct is an underlying variable that cannot be observed directly and is hard to measure (Wong, 2013) because its scope can be represented by a variety of items (Saghiri, 2011) that can be formative or reflective[7] (Peng & Lai, 2012).

Measurement of individual flexibility types as single constructs, instead of as single indicators, has formed an important building block of the empirical literature in manufacturing flexibility (see Table 15), capturing the individual flexibility impact on performance of each flexibility type. However, the distinction made by the strategic perspective on the existence of two flexibility levels leaves the door open to the interpretation that each one of the flexibility levels could be treated in an independent way as a combination of the individual flexibility types that are classified within each level. In this way it would be necessary to employ more complex constructs termed multidimensional or second order constructs.

A multidimensional or second order construct is a theoretical concept consisting of a number of interrelated dimensions (Trumpp et al., 2015; Edwards, 2001), where each dimension can be measured through independent scales. These constructs refer to a single theoretical concept, and from multiple dimensions regarded as distinct but related concepts rather than a single overall concept (Hattie, 1985). In other words, these dimensions are grouped under the same multidimensional construct and each dimension represents some portion of the overall latent construct (Podsakoof et al., 2006; Bollen & Lennox, 1991; Law et al., 1998).

From an empirical point of view, various works in the literature could be considered antecedents, or exponents, of the treatment of flexibility as a multidimensional construct (see Table 16). However, an analysis of the construction of

[7] The fundamental difference between reflective and formative constructs is that the latent variable determines the indicators for reflective constructs whereas the indicators determine the latent variable for formative constructs. Researchers can refer to Chin, (1998), Diamantopoulos & Winklhofer, (2001) and Petter et al., (2007) for in-depth coverage of reflective versus formative constructs.

these works provides evidence of certain limitations indicating that the theoretical premises of the strategic approach were not being fully transferred to practice (De Treville et al., 2007), and thus, calling for further research. In more specific terms, we found:

1) On the one hand, there are a group of works which create latent constructs through multi-item scales. However, the construction of these constructs has two limitations (Chang et al., 2003; Pagell & Krause, 2004; Camison et al., 2010; Patel et al., 2012; He et al., 2014; Llórens-Montes et al., 2005; Ling Yee et al., 2008; Malik & Kotabe, 2009; Grawe et al., 2011). Firstly, authors mix together flexibility types that are considered as belonging to different levels. Secondly, they assign one unique item for the measurement of each flexibility type. The use of one unique item for measuring manufacturing flexibility types is considered inappropriate (Jain et al., 2013) because academic literature of manufacturing flexibility agrees in that the domain/scope of any flexibility type consists of various elements (Koste et al., 2004) that make necessary the use of multi-item scales for measuring each individual flexibility type. Therefore, it seems that these constructs have been incorrectly operationalised.
2) On the other hand, there is another block of works which has created second order constructs measuring individual flexibility types through single constructs. This block of works empirically justifies the possibility of creating multidimensional constructs of flexibility. However, they do not provide a full view of manufacturing flexibility for various reasons:
    - They include a limited number of flexibility types that varies from a minimum of 3 to a maximum of 6. Thus, it could be considered that this block of works approaches the study in a partial and incomplete way, without taking into account all the flexibility types identified, either in terms of a global consideration of flexibility (which would include 11 flexibility types) or one based on level (6 flexibility types for the internal level and 5 for the external level).

- Most of the works have not based the creation of the construct on a clear theoretical framework. Thus, we find that in some cases they have created a second order construct combining internal and external flexibility types (Narasimhan et al., 2004; Cao & Zhang, 2008; Patel et al., 2012; Ojha et al., 2013 and Purwanto et al., 2015), contradicting in this way the theoretical premises of flexibility which make a distinction between the different flexibility levels (see the levels proposed by the hierarchical and strategic perspectives in Chapter 2).
- Even when the studies theoretically acknowledge the existence of various flexibility levels, later empirical validation of each level as an independent construct is only partial. In more specific terms, the majority of these studies have limited themselves to validate only one of the levels. The external construct is the one which has received greater attention in the empirical literature although its validation could be considered partial given that all the flexibility types identified in the literature have not been incorporated (Slack, 1988; Malhotra & Mackelprang, 2012 and Chang, 2012). Only one work (Zhang et al., 2003) empirically validates the existence of the internal construct as well as the independent existence of both constructs – internal and external-. However, this work also turns out to be limited since it only considers 4 of the 6 internal flexibility types identified – *machine, labour, material* and *routing* – and only 2 of the 5 external flexibility types – *volume* and *mix*-.

This theoretical and empirical support leads us to formulate that both levels of flexibility –internal and external- can be operationalised independently as two second order constructs. More specifically, attending to the conceptual systematisation of Pérez Pérez et al., (2016), we propose to extend to 11 the model of 6 flexibility types developed by Zhang et al., (2003). As a consequence, we hypothesize that:

Hypothesis 1: Internal flexibility is a second order construct composed of six individual flexibility types, namely labour, material, machine, quality, routing and programme.

Hypothesis 2: External flexibility is a second order construct composed of five individual flexibility types, namely volume, mix, new product, modification and delivery.

4.2.2 Direct effects on performance

Theoretical arguments provided by the second premise of strategic perspective suggest a positive flexibility-performance relationship. However, the empirical evidence about the impact of the internal/external constructs are partial, unbalanced and scarce (see Tables 15 and 16). This situation suggests that more research is needed about the impact that both constructs have on performance in an independent manner. The theoretical arguments and empirical review for each of these independent constructs are discussed below:

4.2.2.1 Internal flexibility

Internal flexibility allows manufacturing organisations to adapt quickly to any changes in relevant internal factors such as process, workload or machine failure (Purwanto et al., 2015). These flexibility types play a vital role in most manufacturing sectors because they are considered key variables in the production process (Cao & Zhang, 2008) that directly affect organisational costs and consequently performance (Ojha et al., 2013; Oke, 2013; Hyun & Ahn, 1992; Ramasesh & Jayakumar, 1991; Upton, 1995; Jack & Raturi, 2002).

On the one hand, *machine* and *labour flexibility types* make it possible to perform different tasks economically and effectively (Oke, 2013). They increase productivity, allowing for higher machine utilization (Ojha et al., 2013) that permits reducing time resulting in lower per unit cost for manufactured products. On the other hand, *routing, material, programme* and q*uality flexibility types* act as workflow regulators to allow firms to find alternative processing centres for a particular product when needed (Gerwin, 1993; Koste & Malhotra, 1999; Zhang et al., 2003; Rogers et al., 2011) in case of system overloads that can cause delays and increase costs (Sethi & Sethi, 1990).

In sum, the internal flexible response allows firms to handle uncertainty in production processes and to respond to changes in demand (Hyun & Ahn, 1992; Upton, 1994), increasing system efficiency (Ojha et al., 2013) and reducing variation in workflow, leading to lower quality costs (Flynn et al., 1995), inventories and consequently, manufacturing costs (Arnheiter & Maleyeff, 2005; Ojha et al., 2013). So it is expected that such responses positively affect performance.

However, the empirical evidence which has tested the direct effect of the internal flexibility construct on performance is very scarce (see Table 16). Only one work has built an internal flexibility construct (Zhang et al., 2003). However, its goal was to test how the external flexibility construct mediates the internal flexibility/performance relationship, and as a consequence it only reports the indirect and positive effect that the internal flexibility construct has on performance.

However, although no empirical evidence exists for the direct effect from the internal flexibility construct, there is partial empirical evidence on the direct effect from some internal flexibility types at the individual level (see Table 15). For example, most of the empirical evidence reports positive results for *machine, labour, material* and *routing flexibility types* (Gupta & Somers, 1996, Mohamed et al., 2001; Francas et al., 2011 among others). Only in some cases was a negative impact on performance detected for two specific flexibility types -*machine* and *programme*- (Chan et al., 2006, Arias-Aranda, 2003) arguing that at times the implementation of these flexibility types requires changes in the physical and operating characteristics of a system (such as processing time, machine setting, tool changing time, tooling cost, job transportation time, performance of scheduling rule, etc.) in order to obtain a positive impact (Chan et al., 2006). Lastly, there is no empirical evidence for the impact of *quality flexibility* on performance.

This situation suggests a research gap relating to the real effect of the internal flexibility construct on performance when all the individual internal flexibility types are considered. Based on the previous theoretical arguments, and on the fact that most of the empirical findings suggest a positive impact of some individual internal flexibility types on performance, we propose the following hypothesis:

Hypothesis 3: Internal flexibility, defined as a second order construct, has a positive effect on performance.

4.2.2.2. External flexibility

External flexibility responses such as the introduction of new products, changes in delivery dates, changes/fluctuations in the level of production, or changes in product features usually are included by the firm to respond to different customers' demands (Malhotra & Mackelprang, 2012). The introduction of these flexibility types usually may be made in a short period of time, requiring a few engineering changes, and consequently, it is expected that they involve a moderate degree of commitment and effort (Malhotra & Mackelprang, 2012).

More specifically, on the one hand, *modification, mix* and *new product flexibility types* provide the kinds of products that customers request in a timely manner, including minor design changes such as colour or size, providing the product with the features that customers want without an excessive time delay or declines in quality or pre-empting market demand (Tamayo-Torres et al., 2014; Cao & Zhang, 2008; Swink et al., 2005; Chang et al., 2003; Zhang et al., 2003; Das, 2001; Malhotra & Sharma, 2012; Narasimhan & Das, 1999). On the other hand, *volume* and *delivery flexibility types* satisfy customers' requests by producing the exact amount of product ordered and reducing uncertainty in deadline delivery (Suarez et al., 1996; Vickery et al., 1997; Wadhwa & Rao, 2003; Zhang et al., 2003; Fantazy et al., 2009).

These flexibility types enable a firm to provide products to meet customer expectations, reducing the waiting time for special orders that customers value highly (Kathuria, 2000; Malhotra & Mackelprang, 2012). These flexibility types also permit a firm to raise prices and simultaneously to improve its competitive position and increase sales in different market segments (Francas & Minner, 2009; Chang et al., 2006; Etzel et al., 2001). So, theoretically, it is expected that external flexibility positively affects performance.

Empirical evidence confirms this expected positive effect. Only a reduced number of empirical studies have an unexpected non-significant, or negative, result of the individual effect of some specific flexibility types been reported (i.e. modification (Das, 2001), *mix* (Upton, 1995; Vickery et al., 1997; Swink et al., 2005), *new product* (Narasimhan & Das, 1999; Vickery et al., 1997; Gaimon & Singhal, 1992, Gupta & Somers, 1996), *volume flexibility* (Arias-Aranda 2003) or *delivery* (Fantazy et al., 2009). They suggest that market conditions and the maturity of the firm can explain these unexpected results.

The empirical literature which has developed an external flexibility second order construct is scarce and heterogeneous (i.e., they consider different numbers of flexibility types to make up the second order construct). However, these studies always report a positive impact of this construct on performance (Slack, 1988; Chang, 2012; Zhang et al., 2003 and Malhotra & Sharma, 2012).

Taking into account the theoretical arguments, and that most of the empirical findings that develop an external flexibility second order construct suggest strong positive relationships of flexibility on performance, we propose the following hypothesis:

Hypothesis 4: External flexibility, definded as a second order construct, has a positive effect on performance.

4.2.3 The mediation effect of external flexibility on the internal flexibility-performance relationship

In light of the theoretical arguments presented in the third premise of the strategic approach, it is theoretically expected that the internal flexibility construct has a strong positive effect on the external flexibility construct. That is because it is suggested that internal flexibility provides the necessary flexible response to develop external flexibility (Buzacott & Mandelbaum, 2008; Zhang et al., 2003). It's said that taken alone, internal flexibility is not adequate to build a substantial competitive edge because customers do not value it directly (Zhang et al., 2003). They are unwilling to pay more because machines and workers are flexible in responding to equipment breakdowns, variable task times, queuing delays, rejects and reworks, material changes, among others. Thus, although internal flexibility affects the efficiency of the system by reducing costs, customers value the manifestation of external flexibility that is the capability of the firm to provide products with features that customers want, at the right time, and in the correct quantity and deadline. This premise suggests that when internal and external flexibilities are invoked in a coordinated, systematic, and integrated fashion, positive synergies may exist (Singh et al., 2013; Malhotra & Mackelprang, 2012; Zhang et al., 2003). Consequently, external flexibility could be considered as a mediator variable of the internal flexibility-performance relationship.

More specifically, internal flexibility impacts on external flexibility in different ways such as providing the capacity to adjust quickly and easily to make other products, altering the operating rate of equipment, reducing down time caused by set-up delays, maintenance, or failures, adjusting quickly and easily to new tasks, reducing the time it takes to get up to speed or varying the speed of delivery as well as the ability to move a variety of products without impacting costs or quality (Ojha et al., 2013; Zhang et al., 2003).

However, there is little empirical evidence on the relationship between internal and external flexibility. More specifically, although there are some studies that provide empirical evidence on the positive relationship between some individual flexibility types (i.e. Francas et al., (2011) or Kim et al., (2013) report positive effects of *machine* and *labour* flexibility types on *volume, mix* and *new product* flexibility types, whereas Parker and Wirth (1999) suggest a positive relationship between *routing* flexibility and *volume* flexibility) it could be considered that there is only one work which has reported a relationship between internal and external flexibility constructs (see Table 15).

Zhang et al., (2003) can be considered the study that provides a clearer and more detailed analysis of the relationship between internal and external flexibility types. More specifically, Zhang et al., (2003), using a sample of 273 plants and applying structural equation modelling for the analysis, argue that internally focused flexibility types provide the processes and infrastructure that enable a firm to achieve the desired level of external flexibility and positively affect customer satisfaction. The authors establish that internal flexibility is a relevant enabler of external flexibility that affects customer satisfaction performance in positive ways.

However, for testing this relationship Zhang et al., (2003) consider only 6 flexibility types that were divided into two constructs. Four of them - *machine, labour, material* and *routing flexibility types*- make up the internal flexibility construct, and the other two –*volume* and *mix* flexibility types- make up the external flexibility construct.

Based on the theoretical and empirical evidence, our model proposal tries to gain further insights into the relationship between manufacturing flexibility and performance by providing additional evidence for the premises suggested by the strategic approach. More specifically, the previous theoretical and empirical support leads us to formulate the following hypothesis:

Hypothesis 5: External flexibility mediates the relationship between internal flexibility and performance

Table 15. Empirical works that analyse the direct individual impact using single indicators or single constructs

References	FLEXIBILITY TYPES INCLUDED											Number of flexibility types considered within the model	FLEXIBILITY OPERATIONALISATION		Results
	External					Internal									
	Volume	Modification	New Product	Mix	Delivery	Machine	Labour	Material	Routing	Programme	Quality		Single indicator for measuring individual flexibility type	Single construct for each individual flexibility type	
Kekre & Srinivasan (1990)				x								1	x		+
Fiengenbaum & Karnani (1991)	x											1	x		+
Gaimon & Singhal (1992)			x									1	x		-
Upton (1995)				x								1		x	-
Tannous (1996)	x											1	x		+
Suarez et al., (1996)	x		x	x								3		x	+
Gupta & Somers (1996)	x		x			x		x	x	x		6		x	Mixed (+ exception New Product -)
Vickery et al., (1997)	x		x	x								3			0
Narasimhan & Das (1999)	x	x	x									3		x	Mixed: (Volume, New Product: 0;Modification +)
Parker & Wirth (1999)	x			x				x	x			4	x		+
Vickery et al., (1999)	x		x	x								3	x		Mixed: (Volume+; Rest of flexibility types 0)
Das (2001)		x	x	x								3		x	Mixed (Mix +;Modification, New Product 0)
Mohamed et al., (2001)						x						1	x		+
Chang et al., (2002)	x		x	x								3	x		+
Jack & Raturi (2002)	x											1		x	+
Arias-Aranda (2003)	x					x			x	x		4		x	Mixed (Finanancial Performance: - exception routing+) (Non Financial Performance +)
Swink et al., (2005)			x	x								2		x	Mixed (New Product+, Mix 0)

Table 15. Empirical works that analyse the direct individual impact using single indicators or single constructs (Continued)

References	FLEXIBILITY TYPES INCLUDED											Number of flexibility types considered within the model	FLEXIBILITY OPERATIONALISATION		Results
	External					Internal									
	Volume	Modification	New Product	Mix	Delivery	Machine	Labour	Material	Routing	Programme	Quality		Single indicator for measuring individual flexibility type	Single construct for each individual flexibility type	
Chang et al., (2006)	x		x	x								3		x	+
Fantazy et al., (2007)			x	x	x							3		x	Mixed New Product: + financial perforformance –customer satisfaction Mix: - financial performance + customer satisfaction Delivery: +customer satisfaction –financial performance
Hutchinson & Das (2007)	x			x								2		x	+
Hallgren & Olhager (2009)	x			x								2	x		+
Francas et al., (2011)	x			x		x	x					4	x		+
Rogers et al., (2011)	x			x		x	x		x			5		x	+
Oke (2013)				x			x					2		x	+
Kim et al., (2013)			x			x	x					3		x	+
Tamayo et al., (2014)						x		x	x			3		x	+
Mendes & Machado (2015)	x		x	x								3		x	+
Total	17	2	13	17	1	7	4	3	5	2	0				

Source: Authors. Note: In the table, a + denotes a positive relationship, a 0 denotes no relationship detected, and a – denotes a negative relationship

Table 16. Empirical works that use latent constructs

References	FLEXIBILITY TYPES INCLUDED (numerical count and name)											Number of flexibility types considered within the model	FLEXIBILITY OPERATIONALISATION				Results
	External					Internal							Global construct (one item per flexibility)	Second order construct	Use second order constructs distinguing		
	Volume	Modification	New Product	Mix	Delivery	Machine	Labour	Material	Routing	Programme	Quality				Intern al	External	
Slack (1988)	x		x	x	x							4				x	+
Chang et al., (2003)	x	x	x	x	x								x				+
Zhang et al., (2003)	x			x		x	x	x	x			6			x	x	+
Pagell & Krause (2004)	x	x		x	x							4	x				0
Narasimhan et al., (2004)	x		x	x		x						4		x			+
Llorens et al., (2005)	x		x						x			3	x				+
Cao & Zhang (2008)	x			x		x	x	x	x			6		x			+
Ling Yee et al., (2008)				x			x	x				3	x				Mixed (Innovative Performance +, financial performance 0)
Malik & Kotabe (2009)	x							x				2	x				+
Camison et al., (2010)	x	x		x								3	x				+
Grawe et al., (2011)	x								x			2	x				+
Patel (2011)		x	x	x								3	x				+
Patel et al., (2012)			x	x		x	x	x				5		x			+
Malhotra & Mackelprang (2012)*		x	x	x								3				x	Mixed (Modification +; New Product and Mix 0)
Chang et al., (2012)	x		x	x	x							4				x	+
Ojha et al., (2013)	x			x		x	x		x			5		x			+
Tamayo et al., (2014b)				x		x		x				5		x			+
He et al., (2014)	x	x		x	x							3	x				+
Purwanto et al., (2015)	x		x			x	x		x			5		x			+
Total	15	6	9	14	5	7	6	6	6	0	0						

Source: Authors. Note: In the table, a + denotes a positive relationship, a 0 denotes no relationship detected, and a – denotes a negative relationship. *It is a special work because it creates three second order constructs. More specifically it combines each individual flexibility type with inbound and outbound supplier flexibilities

CHAPTER 5

DATA COLLECTION, METHODOLOGY AND ANALYSIS

In this Chapter, the results of this study are presented while using Structural Equation Modeling (SEM) for data analysis and assessment. IBM SPSS version 21 software was used for the initial evaluation of the data collected. Subsequently, partial-least squares or PLS path modeling SEM (PLS-SEM) followed to perform the comprehensive data analyses and assessments of the three different models in this study. The validation of the structural models was attained using SmartPLS version 3 (Ringle et al., 2015). The assessment and refinement of adequacy of the measurement models was first completed in order to proceed with the final assessment and evaluation of the structural models.

This Chapter is organized as follows: the first section includes a brief discussion regarding the sampling method and the design of the questionnaire. The second section presents an introduction to the methodology used, implications for the use of formative multidimensional constructs and descriptive statistics. Finally the third section presents the assessments of the three models proposed, internal flexibility, external flexibility, and the integrative model including both internal and external flexibility.

5.1 Scale development

The initial survey instrument was reviewed by a panel of academic and practitioner experts in operations management for content, clarity and understanding. The review was conducted by 3 academics familiar with the constructs employed in this research. Additionally, 11 practitioners, with titles such as general manager or operations manager, reviewed the instrument. Their responses provided written qualitative feedback on the clarity of both the instructions and the survey items. More specifically, the respondents provided notes and comments on any words or items that were ambiguous or imprecise. These comments were reviewed and the survey instrument was modified accordingly. Multiple items were used for evidence of internal consistency, and all the scales used in the study employed a 7-point Likert scale. The end points were labeled ‘Strongly Disagree’ (1) to ‘Strongly Agree’ (7). Additionally, several items were reverse coded to foster reliability of the scales.

5.2 Sampling issues

The manufacturing plant was chosen as the unit of analysis because it should provide enough variance to create and test the proposed measures. Two main reasons sustain this decision. Firstly, the use of plant level analysis is consistent with the focus of recent empirical flexibility research (Urtason-Alonso et al., 2014; Oke, 2013; Malhotra & Mackelprang, 2012; Koste et al., 2004). Secondly, it has been shown that different plants within the same division or strategic business unit may achieve different levels of flexibility (Koste et al., 2004; Dixon, 1992; Upton, 1995, 1997).

The targeted survey respondent should possess adequate knowledge to accurately complete the instrument. So the targeted respondent for this study was "someone who was very knowledgeable" about operations at the plant. The flexibility types included in our study were within the responsibility of top management. Consequently, Plant Managers were the targeted respondents. This selection is likely to be involved with the topic, thereby increasing accuracy (Huber & Power, 1985).

A convenience sample of plants, with the desired characteristics, was selected for the pretest from the SABI[8] database. Potential respondents were contacted, told the subject of the study, and requested to participate. For doing it a database of 2,462 manufacturing plants were obtained from the SABI database. The sample should also provide a variety of flexibility values over the measures being developed (Gerwin, 1987) but we also cautioned, however, that the population must not be so diverse that a scale is not applicable to the entire population. To meet these conflicting needs, we selected organisations in a limited number of industries. More precisely, those manufacturers within industries such as metal products (SIC 34), machinery (SIC 35), electronics (SIC 36), transportation equipment (SIC 37), and measuring, analysing and controlling instruments (SIC 38), which have been deemed likely candidates for flexibility research (Gerwin, 1987; Gupta & Somers, 1992, 1996; MacDuffie et al., 1996), thereby prompting their inclusion in our research as well.

The sample was then randomly selected from the five SIC groups. The representation of each SIC group in the sample was proportionated to its

[8]Sistema de Análisis de Balances Ibéricos/ Analysis System of Spanish Balance Sheets

representation in the sample frame. For example, if 30% of the organisations in the sample frame were electronics manufacturers, then 30% of the surveys were sent to randomly chosen organisations in this industry (Koste & Malhotra, 1999).

The telephone structured questionnaire survey conducted took place from April of 2015 to May of 2015. The survey was completed by a total of 277 organisations. Moreover, 11 were found to have incomplete information and were subsequently removed from the sample. In all, 266 surveys were returned, resulting in a 10.8% response rate. The sample error, taking an infinite population, is 5.68%, providing a confidence level of 95%. This response rate is consistent with other empirical research (Tamayo Torres et al., 2014; Ojha et al., 2013; Fricker et al., 2005; Klausch et al., 2013; Cao & Zhang, 2008; Llorens-Montes et al., 2005) and considered acceptable in Operations Management survey research (Malhotra & Grover, 1998).

Finally, a profile of the responding firms is provided in Table 17. As can be seen from the table, one third of the sample comes from SIC 34, 21.4% from SIC 35, 15% from SIC 36, 23.7% from SIC 37 and 4.7% from SIC 38. With respect to the number of employees, it ranged from less than 50 to greater than 250, with the majority having between 50 and 249 employees (73.3%). Finally, 59.4% of the plants use batch production process instead of discrete production, and 96.6% of the sample has international activity.

Table 17. Sample characteristics

		Frequency	**%**	**Total**
Industry type	SIC 34	95	35,7%	35,7%
	SIC 35	57	21,4%	57,1%
	SIC 36	40	15,0%	72,2%
	SIC 37	63	23,7%	95,9%
	SIC 38	11	4,1%	**100,0%**
	Total (N)	**266**	**100%**	
Number of employees	0-49	42	15,8%	15,8%
	50-249	195	73,3%	89,1%
	250 or more	29	10,9%	**100%**
	Total	**266**	**100%**	
Process type	Batch production	158	59,4%	59,4%
	Discrete production	101	38%	97,4%
	Other	7	2,6%	**100%**
	Total	**266**	**100%**	
International activity	Yes	257	96,6%	96,6%
	No	9	3,4%	**100%**
	Total	**266**	**100**	

Source: Authors

5.3 Structural equation modeling (SEM)

Structural Equation Modelling (SEM) is a second-generation multivariate data analysis method that theoretically supports linear and additive causal models (Wong 2013). For the past twenty years, scholars have increasingly been turning its use to overcome the limitations of first-generation techniques (Bagozzi & Yi, 1988). First-generation techniques, such as multivariate confirmatory (e.g. multiple regression, logistic regression, and analysis of variance) and exploratory (e.g. cluster analysis, exploratory factor analysis, and multidimensional scaling) methods, belong to the core set of statistical instruments which can be used either to identify or confirm theoretical hypothesis based on the analysis of empirical data (Palma Ruiz, 2015; Haenlein & Kaplan, 2004).

Compared to regression-based approaches, which analyse only one layer of linkages between independent and dependent variables at the same time, SEM allows the simultaneous modeling of relationships among multiple independent and dependent constructs (Gefen et al., 2000) called latent variables that are underlying variables that cannot be observed directly and are hard to measure (Wong, 2013). In addition, SEM provides more powerful tests and analyses in order to answer research questions in a single, systematic, and comprehensive analysis (Bagozzi & Yi, 1988; Gefen et al., 2000). There are several distinct approaches to SEM and it is necessary to consider their advantages and disadvantages to choose an approach to suit:

The first approach is the widely applied Covariance-based SEM (CB-SEM), using software packages such as AMOS, EQS, LISREL and MPlus. Although it has been widely applied in the social science field during the past, it must be used particularly when the sample size is large, the data is normally distributed, and the model is correctly specified (Wong, 2013). Based on covariance, the former is primarily used to confirm or reject theories (Hair et al., 2014).

The second approach is Partial Least Squares (PLS), which focus on the analysis of variance and can be carried out using PLS-Graph, Visual PLS, Smart PLS, AND WarpPLS. It can also be used employing the PLS module in the “r” statistical software package.

Based on variance it is typically used to develop theories in exploratory research (Hair et al., 2014). This approach, originally introduced by Wold in the 1960s (Wold, 1966), was recently revitalized by Chin et al., (2003) and has been deployed in many fields, such as marketing (Henseler et al., 2009), organisation (Sosik et al., 2009), operations management (Peng & Lai, 2012), management information system (Chin et al., 2003) and business strategy (Hulland, 1999). The main advantages of this approach is that it does not require normally distributed data, it can incorporate both formative and reflective indicators in the model (Hair et al., 2014; Wong, 2013) and it can be used when sample size is small. This last aspect is very relevant for operations management researchers who have difficulty in obtaining large samples because they typically examine phenomena at the firm or plant level (Peng & Lai, 2012).

The third approach is a component based SEM known as Generalized Structured Component Analysis (GSCA). It is implemented through Visual GSCA or a web based application called GesCA (Wong, 2013). This approach is relatively new, and it is difficult to locate examples to understand how it can be used in different research scenarios (Wong, 2013). In this research study, the methodology is based on PLS-SEM.

5.4 PLS-SEM

Partial-least squares modeling (PLS-SEM) is particularly suited to research in strategic management. As mentioned before, PLS-SEM is a strong approach for work intended to develop and refine theoretical and complex models (Robins, 2012) with constructs with many indicators. PLS-SEM has several advantages which are synthetised in Table 18.

Table 18. PLS-SEM advantages

	SEM using PLS	SEM using LISREL
Approach	Use the variance	Use the covariance
Relationship indicators and constructs	Formative and reflective	Only reflective
Model complexity	High (100 constructs and 1000 indicators)	Medium-Low (less than 100
Sample size	Small simple sizes (10 times rule of the largest formative indicator or the dependent latent variable)	Large sample sizes (5 to 20 times the number of parameters estimated)
Data	Do not need normally distributed data	Need normally distributed data

Source: Content adjusted from Hair et al., (2014) As we can see, PLS-SEM can analyse data without normally distribution assumptions and challenges scholars to think about theory in different ways. For example, while attempting to predict the effects of a set of independent variables on a dependent phenomenon, without assuming that all variables in a model provide full accountability of the dependent phenomenon. In addition, while uncovering different relationships among the variables that were not previously considered. Furthermore, PLS-SEM, unlike CB-SEM approaches, allows the measurement of formative indicators and a combination of reflective and formative measurements. This brings new possibilities for analysis, but it also demands that scholars make sure to use the appropriate domain of constructs and consider the larger context in which research is carried out. On this regard, a discussion of the importance of reflective and formative measurements is presented next, which also implies important considerations in the following sections in this study.

5.4.1 Reflective and formative measurements

There are two types of measurement scales in structural equation modeling; they can be reflective or formative (Wong, 2013).

Table 19. Reflective and Formative indicator characteristics

	Reflective construct	Formative construct
Direction of causality	From the construct to the measures	From de measures to the construct
Is the construct a trait explaining the indicators or rather a combination of the indicators?	Is a trait	Is a combination
The indicators represent	Consequences	Causes
Correlation among items	All items change in a similar manner. Measures expected to be correlated. Measures should possess internal consistency reliability.	Not all item change in a similar manner/Measures expected not to be correlated./ Internal consistency is not applied
Importance of items	Dropping an item from the scale does not change the meaning of the construct	Dropping an item from the scale may imply a change in the meaning of the construct
Measurement error **Interchangeability of items** **Covariation among items**	Accounted at the variable level Items are interchangeable Indicators are expected to co-vary with each other	Accounted at the construct level Items are not interchangeable Indicators are expected not to necessarily co-vary with each other
Nomological net (indicator has the same antecedents and consequences)	Should not differ	Differ
Multicollinearity	Required	It is a serious concern

Source: Content adjusted from De Giovanni, (2012) and Hair et al., (2014)

Table 19 synthetises the main differences between the two types of measurement scales. On the one hand, reflective construct refers to those indicators that are highly correlated and interchangeable. It has a long tradition in the social sciences and is directly based on classical test theory, which assumes that each measure is a reflection or manifestation of an underlying construct (Podsakoff et al., 2006). In this case their reliability and validity should be thoroughly examined (Hair et al., 2013; Petter et al., 2007). On the other hand, there is growing recognition that some measures may actually be determinants or causes of a construct, rather than manifestations of it (Podsakoff et al., 2006; Edwards & Bagozzi, 2000). These measures are referred as formative constructs. In this case, formative indicators are not interchangeable since they do not have the same or similar content, as is true with reflective indicators. Thus, each indicator for a formative construct captures a specific aspect of the construct domain that causes the construct (Petter et al., 2007).

The use of formative measures may represent a challenge for scholars. First, considering that many of the editors of major journals up-to-date lack the knowledge base to correctly evaluate a formative construct. Second, the use of other SEM softwares, such as LISREL, EQS, or AMOS has shown to lead to specification problems since they are not fully capable to estimate the models even when there is only one formative construct. However, the use of PLS-SEM software, such as Smart PLS (Ringle et al., 2015) allows researchers to estimate both reflective and formative measurement models, which has been very strongly recommended (Chin, 1998; Petter et al., 2007).

PLS-SEM assumes that formative indicators fully capture the content domain of the construct under consideration. Therefore, other criteria than the ones employed in reflective measures must be considered to assess the quality of these formative measurement models (Hair et al., 2012).

As a consequence of the statistical evaluation, criteria for reflective measurement scales cannot be directly transferred to formative measurement scales

(Diamantopoulus & Winklhofer, 2001; Peng & Lai, 2012). Table 20 summarises the criteria for evaluating reflective and formative indicators that are discussed following.

Table 20. Criteria for evaluating reflective and formative indicators

Criteria	Reflective constructs		Formative constructs	
Internal Consistency Reliability	Yes	Composite reliability > 0.7	N/A	
Indicator reliability	Yes	Outer loadings > 0.7 **If not:** *Outer loadings >0.4 and <0.7 could be retained (it depends of its effects on AVE) *Outer loadings < 0.4 must be dropped	N/A	
Convergent Reliability	Yes	AVE > 0.5	N/A	
Discriminant Validity	Yes	Square root of each construct´s AVE > its correlations with other constructs	N/A	
Multicollinearity	N/A		Yes	VIF < 3.3
Formative item contribution or importance to the formative index	N/A		Yes	Outer Weights : significant and > 0.1 **If not:** outer loadings significant and > 0.5

Source: Authors.

5.4.1.a Criteria for evaluating first order reflective constructs

We need to consider four elements:

1) **Internal consistency reliability:** for its evaluation Cronbach´s alpha is probably the most used and traditional parameter in social science research. It estimates the reliability based on the inter-correlations among the items within a scale (values range from 0 to 1). Thus, Cronbach´s alpha is sensitive to the number of items within a scale, and generally tends to underestimate the internal consistency reliability because it assumes that all items are equally reliable (i.e. all indicators have equal outer loadings in the construct). For this reason, it tends to provide a conservative measurement in PLS-SEM (Wong, 2013). In contrast to Cronbach´s alpha, the *composite reliability* does not assume equal factor loadings among the measures. Thus, prior literature highly suggests the use of composite reliability measure in PLS-SEM (Bagozzi & Yi, 1988; Hair et al., 2012). Consequently, it is more precise to apply a *composite reliability* measure of internal consistency than to evaluate the traditional Cronbach´s alpha (Chin, 2010). There may be researchers

more familiarized with traditional measures than with PLS-SEM, so both measurements are included in this dissertation as a reference point, although it is not required in PLS-SEM.

However, there are some disagreements over the minimum acceptable standards for scale reliability in Cronbach´s alpha. Some regard 0.70 as the minimally acceptable level (Nunnally, 1978), while others accept >0.50 as an indicator of good internal consistency reliability (Cronbach, 1951). Nunnally (1967) or Nunnally and Bernstein (1994) also argue that reliability value of 0.60 is sufficient to carry out an explorative study but a higher Cronbach´s alpha is always desirable (see Peterson, (1994) for an analysis on Cronbach´s alpha). On the other hand, *composite reliability* values of 0.60 to 0.70 are acceptable in exploratory research, values between 0.70 and 0.90 can be regarded as satisfactory (Hair et al., 2014; Nunnally & Bernstein, 1994), and values below 0.60 indicate a lack of internal consistency reliability.

2) **Indicator reliability:** In reflective measurement models, indicators are regarded as consequences of the latent variable to which they belong. In addition, the reflective indicators can be used interchangeably and even to a certain extent be discarded (Henseler & Fassott, 2010). Loading is the absolute contribution of an indicator to the construct; that is, it refers to the bivariate correlation between the indicator and the construct (Cenfetelli & Bassellier, 2009). The cut-off value for the loadings is 0.708 since that number squared equals 0.50. Therefore, the latent variable should explain a substantial part of each indicator variance, usually at least 50 percent. A value of 0.70 is considered close enough to 0.708 to be acceptable (Hair et al., 2014). Weaker outer loadings are usually observable in social science studies, and specifically when newly developed scales are used (Hulland, 1999). For this reason, Hair et al., (2014) recommend to carefully assess the reflective indicators loadings composite reliability and content validity rather than just directly eliminating those below the threshold of 0.70.

There are two main considerations. First, reflective outer loadings between 0.4 and 0.7 should be considered for removal only when deleting the indicator leads to an increase in composite reliability or in the average variance extracted (AVE) above the suggested threshold value. Second, weaker loadings are sometimes retained on the basis of their contribution to content validity (Hair et al., 2014). Indicators with outer loadings below 0.40 should always be eliminated (Hair et al., 2011).

3) **Convergent validity**: which usually is analysed through the average variance extracted (AVE). It refers to the sum of the square outer loadings of the indicators divided by the number of indicators in a construct. A value of 0.50 or higher indicates that on average the construct explains more than 50 percent of the variance of its indicators (Hair et al., 2014).
4) **Discriminant validity:** it refers to the extent to which a construct is truly different from other constructs by empirical standards (Hair et al., 2014). This means that the constructs are unique and do not capture the same phenomena than any other construct within the model. This particular approach compares the square root of the average variance extracted with the other constructs correlations within the model. Therefore, the square root of each construct AVE must be larger than its correlations with other constructs.

5.4.1. b Criteria for evaluating formative constructs

In the case of formative constructs there are two rules for their evaluation (Peng & Lai, 2012 or Hair et al., 2014).

1) **Collinearity**: The estimation of path coefficients in a formative structural model is based on OLS regressions of each endogenous latent variable on their corresponding predecessor constructs. Just as in a regular multiple regression, the path coefficients may be biased if the estimation involves significant levels of collinearity among the constructs. So, excessive collinearity among indicators makes it difficult to separate the distinct influence of the individual indicators on the latent variable, suggesting that some items may be redundant. To detect

collinearity, authors recommend assessing the *tolerance statistic* and *the variance inflation factor (VIF)*. *Tolerance* represents the amount of variance of one formative indicator not explained by the rest of the indicators in the same block (Hair et al., 2014). In the context of PLS-SEM, tolerance value lower than 0.20 indicates a potential collinearity problem. In addition to tolerance, the collinearity is also assessed through the variance inflation factor (VIF). General statistics theory suggests that multicollinearity is a concern if the VIF is less than 10 (Gruber et al., 2010), or less than 5 (Hair et al., 2011). According to some authors, a general cut-off value of 3.3 is recommended for identifying suspect variables, and values above 10 indicate a serious collinearity issue (Diamantopouluos & Siguaw, 2006; Petter et al., 2007).

2) **Evaluate each formative item contribution or importance to the formative index:** In formative measurement models, the latent variable or construct is regarded as a consequence of its respective indicators; therefore, changing indicators alter the meaning of the construct (Cenfetelli & Bassellier, 2009). The importance of a formative indicator is shown in its weight. This assessment involves examining each formative item weight, sign and significance (Gotz et al., 2010). In order to assess the significance of the weights and loadings, a bootstrap resampling procedure needs to be conducted in Smart PLS under the command bootstrapping routine (Benitez-Amado & Walczuch, 2012; Chin, 1998; Hair et al., 2014). Bootstrapping is a nonparametric procedure applied to test the significance of coefficients such as outer weights, outer loadings and path coefficients. Moreover, in bootstrapping, subsamples are generated with observations randomly drawn from the original set of data, which are then used to estimate the PLS path model. To ensure the stability of results, authors recommend the use of large subsamples (Hair et al., 2011; Preacher & Hayes, 2008; Ringle et al., 2015). The value of 5,000 was used as the recommended value for subsamples for final results preparation to the original number of observations. In addition, other authors' recommendations in bootstrapping were considered, such as allowing for individual sign changes (Hair et al., 2011;

Hair et al., 2012). The results obtained should be examined and the item would be retained if its weight is significant and the magnitude of the item weight is not less than 0.1 (Andreev et al., 2009 and Peng & Lai, 2012) or when its weight is non-significant but its loading is significant and above of 0.50 (Cenfetelli & Bassellier, 2009).

5.5 Multidimensional constructs

There are instances in which either reflective or formative constructs can be operationalised at a higher level of abstraction. Such models are referred to higher-order or hierarchical component models (HCMs) (Lohmoller et al., 1989). Most often these higher-order models involve testing second-order structures that contain two layers of constructs. For this reason, they are also referred in the literature as multidimensional constructs (Edwards, 2001; Polites et al., 2012). Thus, multidimensional constructs can be defined as a theoretical concept consisting of a number of interrelated dimensions, where each dimension can be measured using either reflective or formative indicators (Trumpp et al., 2015; Edwards, 2001). These constructs refer to a single theoretical concept, and from multiple dimensions regarded as distinct but related concepts rather than a single overall concept (Hattie, 1985). In other words, these dimensions are grouped under the same multidimensional construct and each dimension represents some portion of the overall latent construct (Podsakoof et al., 2006; Bollen & Lennox, 1991; Law et al., 1998).

The main reason for the inclusion of multidimensional constructs in PLS-SEM is that by establishing HCM, researchers can reduce the number of relationships in the structural model, making the PLS path model more parsimonious and easier to understand (Hair et al., 2014). The constructs of a multidimensional model can be conceptualised under an overall abstraction, and it is theoretically meaningful and parsimonious to use this abstraction as a representation of the dimensions (Law et al., 1998). Each dimension represents a unique content domain of the broader construct (Polites et al., 2012). This is to capture complex concepts in comparatively simple abstractions. Jarvis et al., (2003) determined four types of multidimensional constructs:

-Type I constructs (superordinate: reflective-reflective) refer to reflective first-order, reflective second-order. This type is the most used in the literature and has also received the most critical questioning due to its content, theoretical and practical contributions. One of the reasons for criticism relates to the limitations of the use of SEM software based on covariance such as AMOS or EQS, which does not allow change to multidimensional models from reflective to formative.

-**Type II constructs (aggregate additive: reflective-formative)** are reflective first-order and formative second-order. This type specifies dimensions that are related to each other, but are conceptually distinct. If a dimension is removed, it affects the model, contrary to the type I constructs.

-Type III constructs (superordinate: formative-reflective) are formative first-order and reflective second-order. In this case the dimensions are different manifestations of the same higher-order concept, but the indicators of each dimension combine to form their respective dimensions. Formative first order, reflective second-order constructs rarely appear in the literature, and even when they do, they are not explicitly identified as such (Polites et al., 2012; Diamantopoulos et al., 2008).

-**Type IV constructs (aggregate additive formative-formative)** are formative at first-order and second-order. In this form of aggregate construct, the dimensions are algebraically combined to form the overall representation of the construct (Wong et al., 2008), and the indicators of each dimension likewise form their respective dimensions (Polites et al., 2012).

Due to their potential to advance theory, multidimensional constructs have appeared more frequently in top journals in recent years as is shown below.

5.5.1 Reviews of multidimensional constructs in the Operations field

This section presents an overview of the frequency of appearance and types of multidimensional constructs published in the main journals in the field of operations management, published by Peng and Lai (2012). This review is useful in identifying the various forms of multidimensional constructs across journals and the relevance of SEM methodology for their assessment, which is particularly interesting denoting the opportunities for further PLS-SEM application.

Peng and Lai (2012) reviewed PLS use in Operations Management literature over the period 2000-2011. They consider Operations Management journals that are recognized as publishing relevant and rigorous empirical research together with several major journals in strategy management and organisation science that sometimes publish research related to operations management. In total 11 journal were analysed (*Journal of Operations Management (JOM), Management Science (MS), Decisions Sciences Journal (DSJ), Production and Operations Management Journal (POMS), the International Journal of Operations and Production Management (IJOPM), The International Journal of Production Economics (IJPE), the International Journal of Production Research (IJPR), IEEE Transactions on Engineering Management (IEEE), Strategic Management Journal (SMJ), Academy of Management Journal (AMJ) and Organisation Science)*. Their findings reveal that 42 OM-related articles used the PLS method. No articles using PLS method to examine OM topics were published in POM, AMJ and Organisation Science during 2000-2011 period. The distribution of the articles by journal and year is presented in Table 21.

Table 21. Distribution of empirical Operations Management articles that use PLS

		DSJ	IEEE	IJOPM	IJPE	IJPR	JOM	MS	SMJ	Total
Year	2000	0	1	0	0	0	0	0	0	1
	2001	0	1	0	0	0	0	0	0	1
	2002	0	0	0	0	0	0	0	0	0
	2003	0	0	0	0	0	0	1	0	1
	2004	1	0	0	0	0	1	1	0	3
	2005	0	0	1	0	0	0	0	0	1
	2006	1	0	0	0	0	0	0	0	1
	2007	2	1	0	0	0	2	1	0	6
	2008	0	0	2	0	0	0	1	0	3
	2009	1	0	0	2	0	2	0	0	5
	2010	3	2	2	2	3	1	0	1	14
	2011	0	0	0	2	3	0	0	1	6
Total		8	5	5	6	6	6	4	2	42

Source: Peng and Lai (2012)

Their findings revealed, firstly, that the number of Operations Management articles using PLS with multidimensional constructs has increased in last years. Among the 42 articles, 30 (75%) explicitly provide a rationale for using PLS. Not unexpectedly, small sample size was the most frequently cited reason for using PLS (n=14), followed by explanatory analysis (n=11), the use of formative constructs (n=8), non-normal data (n=6) and high model complexity (n=4). The median sample size is 126, with a range from 35 to 3,296. Only 13 articles (31%) have a sample size greater than 200. Interestingly, although 19 articles use formative constructs, only 8 articles state that the use of formative constructs is the reason for using PLS. Among 19 articles that use formative constructs, 3 do not perform any analysis on the measurement properties of the formative constructs, and 5 use techniques for evaluating reflective constructs which are considered inappropriate. Finally, 26 out of the 42 articles report which PLS software is used. 19 of them use PLS-Grapgh, however Smart PLS is gaining popularity, considering that 6 OM articles were published after 2009.

The previous overview to the literature in this field of study highlights the opportunities and challenges for scholars in applying multidimensional constructs. In methodological terms, this field provides great opportunities for advancement. The evidence of several sets of dimensions in the literature reflects the need to apply multidimensional constructs, and at the same time denotes limited knowledge and urges applications in PLS-SEM methodology. It is possible that the estimation of certain constructs is fairly unknown by researchers or the software techniques that have been used so far do not allow the estimation of multidimensional constructs, particularly formative or a combination of formative and reflective.

5.5.2 Approaches for estimating multidimensional constructs

The multidimensional types of constructs previously addressed, Type I to IV, can be estimated by using PLS-SEM software such as Smart PLS (Ringle et al., 2015). Although the quality criteria for evaluating multidimensional constructs are the same that the criteria used for first order reflective or formative constructs explained in sections 5.4.1.a and 5.4.1.b the literature documents two main approaches to estimate multidimensional constructs:

1) The first approach for measuring interaction is called PLS product-indicator or repeated-indicator (Chin et al., 2003; Wetzels et al., 2009). It is relatively an easy approach to implement. In one single step, first and second order constructs are estimated. However, its use is limited to the same number of indicators across lower-order components, otherwise the relationship between lower and higher order components will be significantly biased (Becker et al., 2012). In addition, this approach is recommended for Type I multidimensional constructs, since the same measurement model evaluation criteria apply to the higher-order component as for any other construct in the PLS path model (Hair et al., 2014).

2) The second approach is called the two-step or two-stage approach and represents the current dominant approach used in research (Chin et al., 2003). The procedure is more laborious than the repeated indicator approach. In a first step, the *Latent Variables Scores (LVS)* are obtained from the lower-order components. Then, in a second step, these *LVS* are used as indicators of the higher-order components (Chin, 2010). Thus, the use of this approach leads to suboptimal estimates by avoiding some inaccurate inferences, and provides the basis for making meaningful interpretations about theoretical constructs and their interrelations (Anderson & Gerbing, 1988). For these reasons, in this study a two-step approach is followed.

5.5.3 Minimum sample size

In general, one has to consider the background of the model, the distributional characteristics of the data, the psychometric properties of variables, and the magnitude of their relationships when determining sample size (Wong, 2010). Prior research suggests that a sample size of 100 to 200 is usually a good starting point to perform a path modeling (Wong et al., 2013; Hoyle, 1995). There is also known an acceptable rule of thumb, which suggests that the sample size should be at least 10 times the largest of two possibilities: (1) the construct with the largest number of formative indicators if there are any formative construct in the research model or (2) the dependent variable with the largest number of independent variables impacting it (Peng & Lai 2012; Chin, 1998). Therefore, for a more concrete sample size, the guidelines suggested by Marcoulides and Saunders (2006) were considered, depending on the maximum number of arrows pointing at a latent variable as specified in the structural equation model. In this case the largest formative construct is performance that could have the maximum of 13 indicators. Thus, the minimum sample size requirement for all the three models in this study is 13x10=130. The sample size (266) complied with the size requirements, as well as with the rule of thumb mentioned above. However the required sample should be also determined by means of power analysis based on the part of the model with the largest number of predictors.

In this sense, researchers can revert more differentiated rules of thumb such as those provided by Cohen (1992) (Hair et al., 2014) in his statistical power analysis for multiple regression models, provided that the measurement models have an acceptable quality in terms of its G power. For testing it, he provides the Table 22. In our case the maximum number of independent variables is ten, so we would need 256 observations to achieve a statistical power of 80% for detecting R^2 values of at least 0.10 (with a 1% of significance level).

Table 22. Suggested sample size for PLS-SEM

Minimum number of arrows pointing at a construct	Significance Level											
	1%				5%				10%			
	Minimum R^2				Minimum R^2				Minimum R^2			
	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75
2	158	75	47	38	110	52	33	26	88	41	26	21
3	176	84	53	42	124	59	38	30	100	48	30	25
4	191	91	58	46	137	65	42	33	111	53	34	27
5	205	98	62	50	147	70	45	36	123	58	37	30
6	217	103	66	53	157	75	48	39	128	62	40	32
7	228	109	69	56	166	80	51	41	136	66	42	35
8	238	114	73	59	174	84	54	44	143	69	45	37
9	247	119	76	62	181	88	57	46	150	73	47	39
10	256	123	79	64	189	91	59	48	156	76	49	41

Source: Cohen, (1992)

5.6 Empirical analysis

As previously discussed, PLS-SEM was employed to evaluate both the measurement and structural models. IBM SPSS version 21 and Smart PLS version 3 were used in this study for testing the integrative model proposed on chapter 4. More specifically as a consequence that we want to validate the existence of two independent constructs, and the direct impact of them on performance the integrative model proposed will be tested in three steps: .

-Model 1: effect of internal flexibility on performance

-Model 2: effect of external flexibility on performance

-Model 3: external flexibility partial/full mediate the link between internal flexibility and performance

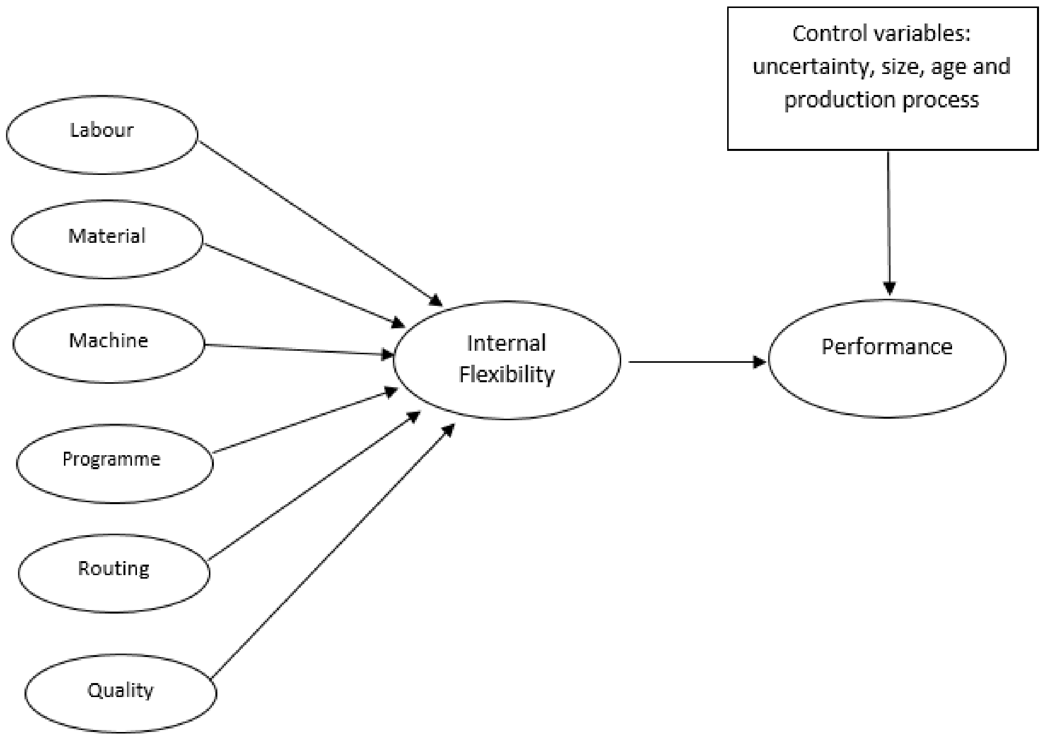
Smart PLS represents one of the leading software tools for PLS-SEM. It is appropriate to use the PLS-SEM technique to conduct this study for the following reasons. First, PLS is a variance-based SEM technique that has been used in previous research (Oke et al., 2013). Second, the use of PLS-SEM has been recommended when theoretical knowledge about a topic is scarce (Barroso et al., 2010; Petter et al., 2007). Third, to the extent that this study proposes multidimensional constructs that have not been examined before, and reveals the degree to which prior theory is limited by using traditional statistical models, hence PLS-SEM estimation is justifiable and relevant. Fourth, we combine first order reflective level and formative at second level with a formative measurement of results and PLS-SEM is more appropriate for estimating this type of model than for covariance-based SEM techniques, since the use of the latter has been shown to lead to identification problems (Chin, 1998). Fifth, the data do not follow a normal distributed data and finally, it is difficult to obtain large samples when working with firms.

For all the models presented bellow we will follow the same structure. Firstly, descriptive statistics analysis and construct validity measures are presented for first order reflective and formative constructs. In order to do that we will follow the quality criteria and rules for reflective and formative measures presented in section 5.4.1.a and 5.4.1.b. For reflective constructs we will present the results of internal consistency reliability, indicator reliability, convergent validity and discriminant validity. For formative constructs we will discuss collinearity and significance and relevance of outer weights. This process will let to purify the scales for each latent variable. After that, second order constructs are discussed and analysed in order to present thirdly the evaluation of the final structural model. In this final step the results of R^2, Q^2, f^2 and path coefficients will be discussed.

5.6.1 First model: internal flexibility – performance

In the first model of this research study, internal flexibility is the key endogenous variable and is operationalised as a multidimensional construct, type II reflective first-order and formative second-order construct. As discussed in Chapters 3 and 4, the six main latent variables or dimensions that define the internal flexibility construct are *labour, material, machine, quality, routing and programme flexibility types* (hypothesis 1). The internal flexibility ultimately has an effect on performance, which is the dependent variable in this study (hypothesis 3). Moreover, the characteristics of the dynamic environment (Ojha et al., 2015; Camison et al., 2010), production type (Patel, 2011; Patel et al., 2012; Chavez et al., 2013; Swink et al., 2005), age company (Patel, 2011; Patel et al., 2012; Camison et al., 2010) and size company (Oke, 2013; Zhang et al., 2003, Rogers et al., 2011, Malhotra & Mackelprang, 2012) are the main control variables affecting this relationship. Figure 4 shows the internal flexibility model.

Figure 4. The Internal Flexibility conceptual model



Source: Authors

5.6.1.1 Descriptive statistics

Dependent variable: Performance and descriptive statistics

Performance was measured as a formative first-order construct determined by thirteen indicators. Performance represents the dependent variable in this study. Operations management studies have frequently relied on subjective and partial performance indicators (financial, operational or customer satisfaction). Thus, the use of subjective measures has been justified by the difficulties in obtaining objective data (Dess & Robinson, 1984; Lubatkin et al., 2006; Schoenberg, 2006; Venkatraman & Ramanujam, 1987).

Our goal is to obtain a global vision of the impact of flexibility on performance, so we decided to use a global and formative performance measure following the criteria of Jarvis et al., (2003) and Diamantopouluos and Winklhofer (2001) and the recent contributions of Petter et al., (2007) or Peng and Lai (2012). These contributions claim the use of formative indicators is more appropriate to model performance because it is a multidimensional concept that typically includes, cost, quality, customer satisfaction or financial outcomes (De Giovanni & Espinoza, 2012; Johnston et al., 2004). Conceptually, researchers cannot expect that an underlying latent construct causes financial, operational (cost, quality, cycle time) and customers satisfaction performance all changing in the same direction and with the same magnitude. Secondly, the measurement items of a particular performance measure are not interchangeable with items measuring other performance dimensions. For example, items measuring customer satisfaction cannot be replaced by items measuring manufacturing cost and vice versa. Thirdly, a change in one performance measure is not necessarily associated with changes in other indicators.

We include subjective performance measures. The use of subjective measures is a valid alternative when objective measures are not obtainable (Lubatkin et al., 2006; Venkatraman & Ramanujam, 1987). As a result, the use of subjective evaluations regarding the domain of financial performance, operational performance and satisfaction performance are included in the scale. A seven-point Likert-type scale with values from 1 to 7 was used in order to resemble if the level of performance was smaller, or higher, than competitors, respectively. Table 23 shows the questions used in this section, as well as the descriptive statistics.

Table 23. Performance scale items and descriptive statistics

Performance		Min	Max	Mean	Std. Deviation	Variance
D1_1	Sales Growth	1,00	7,00	4,6203	1,50552	2,267
D1_2	Market Share	1,00	7,00	4,5263	1,33504	1,782
D1_3	Profitability	1,00	7,00	4,3383	1,26125	1,591
D1_4	Manufacturing cost	1,00	7,00	4,1090	1,06370	1,131
D1_5	Inventory turnover	1,00	7,00	4,4361	1,28182	1,643
D1_6	Cycle time (raw material to delivery)	1,00	7,00	4,6429	1,38328	1,913
D1_7	Conformance to product specifications	2,00	7,00	5,4286	1,17705	1,385
D1_8	Product innovativeness	1,00	7,00	4,5376	1,35162	1,827
D2_1	Our organisation satisfies the requirements and expectations of our customers	3,00	7,00	5,8571	,90818	,825
D2_2	Our organisation satisfies the quality requirements of our customers	3,00	7,00	6,1541	,81653	,667
D3_1	Our customers are loyal to our products	2,00	7,00	5,5940	1,04998	1,102
D3_2	Our customers are satisfied with the rate price/quality of our products	2,00	7,00	5,5414	,99061	,981
D3_3	Our customers think that our products have a good reputation	3,00	7,00	6,0526	,84510	,714

Source: Authors

Independent variables: Internal Flexibility scales and descriptive statistics

Each individual flexibility type was measured as a reflective first-order construct determined by five indicators, which represents the four elements needed to operationalise the scope of each flexibility type previously discussed in chapter 3 (*range number, range heterogeneity, mobility* and *uniformity*). Each of the items were measured in the questionnaire through a seven-point Likert-type scale with values from 1=totally false to 7=completely true. Table 24 shows the questions used in this section as well as the descriptive statistics.

Table 24. Internal Flexibility scale items and descriptive statistics

Items proposed				Min	Max	Mean	Std. Deviation	Variance
Labour Flexibility	R-N	B1_1	Workers are cross-trained to perform many different tasks	2,00	7,00	5,3271	0,98008	0,961
	R-H	B2_1	Workers can perform tasks which differ greatly from one another	1,00	7,00	5,0414	1,45699	2,123
	M	B3_1	It is quick and easy to move workers between different tasks	1,00	7,00	5,3571	1,33893	1,793
		B4_1	A small cost is incurred when workers are moved between different tasks	1,00	7,00	4,7180	1,75677	3,086
	U	B5_1	The productivity/efficiency is not affected by changes on the tasks of workers	1,00	7,00	4,5902	1,64183	2,696
Material Flexibility	R-N	B1_2	There are many different material handling paths between processing centers	1,00	7,00	4,8910	1,73731	3,018
	R-H	B2_2	The material handling system can transport materials of different sizes	1,00	7,00	4,6353	1,85679	3,448
	M	B3_2	It is quick and easy to change the material handling path	1,00	7,00	4,6165	1,71441	2,939
		B4_2	The choice of material handling does not affect the material transfer cost	1,00	7,00	4,3872	1,67908	2,819
	U	B5_2	The productivity/efficiency is not affected by changes of material handling path	1,00	7,00	4,4135	1,63512	2,674
Machine Flexibility	R-N	B1_3	The number of different operations that a typical machine can perform is high	1,00	7,00	4,2293	1,95902	3,838
	R-H	B2_3	The material handling system can transport materials which differ greatly from one another**	1,00	7,00	4,6617	1,77780	3,161
	M	B3_3	It is quick and easy to made changeovers between machines operation	1,00	7,00	4,5000	1,70294	2,900
		B4_3	Cost of switching from one operation to another	1,00	7,00	4,2143	1,65380	2,735
	U	B5_3	The productive/efficiency is not affected by changes on operations of machines	1,00	7,00	4,2143	1,56227	2,441
Routing Flexibility	R-N	G2_1	A typical part can use many different routes	1,00	7,00	5,2586	1,51130	2,284
	R-H	G2_2	A route can process products/parts which differ greatly to one another	1,00	7,00	5,1255	1,51942	2,309
	M	G5_2	Alternate routes do not increase costs	1,00	7,00	4,3992	1,59086	2,531
		G4_2	It is quick and easy to change the routes	1,00	7,00	4,9734	1,43938	2,072
	U	G3_2	The productive/efficiency is not affected by changes on the routes	1,00	7,00	4,3270	1,56766	2,458
Quality Flexibility	R-N	B1_4	The production system can work with a widely range of tolerances for the product specifications	1,00	7,00	4,6241	1,96613	3,866
	R-H	B2_4	The range of tolerances for the product specifications differ greatly one to another	1,00	7,00	4,3571	1,86636	3,483
	M	B3_4	It is quick and easily to change the range of tolerance of specific products	1,00	7,00	4,0075	1,88538	3,555
		B4_4	Alternate range of tolerance do not increase costs	1,00	7,00	4,1767	1,79590	3,225
	U	B5_5	The productivity/efficiency of the system is not affected by changes in the range of tolerances for the product specifications	1,00	7,00	4,1654	1,70982	2,923
Programme Flexibility	R-N	G1_1	Manufacturing system programming is capable of running unattended, for a long enough time, a high number of products/parts**	1,00	7,00	4,1069	1,94661	3,789
	R-H	G1_2	Manufacturing system programming is capable of running unattended, for a long enough time, a products/parts which differ greatly one to another	1,00	7,00	4,1374	1,87855	3,529
	M	G5_1	Alternate programme do not increase costs	1,00	7,00	4,3460	1,68911	2,853
		G4_1	It is quick and easily to change manufacturing system programming	1,00	7,00	5,0532	1,45840	2,127
	U	G3_1	The productivity/efficiency of the system is not affected by changes in the programme	1,00	7,00	4,3194	1,60768	2,585

Source: Authors. Discussion in chapter 3. NOTE: ** Items adapted during the pre-test

Control variables

According to the empirical review our proposal includes four control variables that offer alternative explanations of effects of flexibility on performance: size, age, production characteristics and uncertainty.

Firstly, we controlled for firm characteristics of size and age. In one hand, literature suggests that firm size affects firm ability to process information related to changing resource conditions that influence the way that manufacturing is organized. According to Lau Antonio et al., (2007), economies and diseconomies of scale, which are present in different sized companies, may have an effect on performance too (Mintzberg, 1979; Damanpour, 1991; Camison et al., 2004; Damanpour & Aravind, 2006). On the other hand, age is associated with the institutionalisation of routines and norms. Larger and older firms have greater inertia. While, smaller and younger firms are more likely to face resource constraints and lack organisational routines. Firm size is measured as a variable with three categories (less than 50, between 50-250, and more than 250 employees). Firm age is measured as the number of years since firm formation. Secondly, we incorporate two variables for controlling the effect of production process type on performance. Production process type can affect the impacts of flexibility on performance. For example batch manufacturing organisations produce multiple products in relatively small volumes, thereby requiring flexible resources (Koste et al., 2004; Hayes & Wheelwright, 1984). Organisations with an assembly/production line process also require a degree of flexibility, such as the flexibility to change product mix or to introduce new products. Continuous flow organisations, in contrast, produce a single or a limited number of products, and require less flexibility (Hayes & Wheelwright, 1984). Given this distinction, we controlled for two production process types: discrete and batch (Avittathur & Swamidass, 2007) that were included as dummy variables in the models, as done in previous studies (Patel et al., 2012). Finally, we included dynamic environment as a control variable. That is because literature has suggested that some flexibility types would yield greater performance improvements for those firms facing increased demand uncertainty versus those firms in more stable demand environments (Patel et al., 2012; Llórens-Montes et al., 2005; Pagell & Krause, 2004). This variable was measured using a Likert-type scale with values from 1=totally false to 7=completely true. Table 25 shows the questions used in this section as well as the descriptive statistics.

Table 25. Dynamic environment scale items and descriptive statistics

	Dynamic Environment	Min	Max	Mean	Std. Deviation	Variance
G1_2	Product and service obsolescence is very rapid in the sector	1,00	7,00	3,6353	1,81568	3,297
G1_3	It is difficult to predict the actions of our	1,00	7,00	4,3158	1,62234	2,632
G1_4	It is difficult to predict the demands and tastes of our customers	1,00	7,00	4,3233	1,66450	2,771
G1_5	Production/service technology changes rapidly and significantly	1,00	7,00	3,9248	1,68063	2,825

Source: Prepared by the authors based on Casillas, Moreno, and Barbero (2011)

5.6.1.2 Construct validity measures for first order reflective and formative constructs

Model assessment concentrates on the measurement models, in terms of evaluating the reliability and validity of the construct measures. For each of the constructs in this study, several variables were employed to indirectly measure a concept. These variables have been used before in the literature to assess a particular concept, as shown in the previous sections.

For an initial assessment of the PLS-SEM model, and by following Hair et al., (2014), an evaluation of the constructs included in the models is needed before proceeding to the evaluation of the structural model. In this case, all the individual flexibility types together with dynamic environment were measured as a first order reflective construct. The unique first order formative construct included in this first part is performance. The results of this evaluation are presented in Table 26. As can be seen on this table, all model evaluation criteria have been met, providing support for the measures reliability and validity. The criteria used for reflective and formative measures are explained bellow.

Table 26. Result summary for reflective and formative measurement models of internal flexibility

Latent Variable	Indicators	VIF	Weights	Loadings	Cronbach´s Alfa	Composite Reliability	AVE	Discriminant Validity?
Labour flexibility	B1_1	1.1552	0.544***	0.779***	0.553	0.767	0.53	Yes
	B2_1	**Dropped**						
	B3_1	1.2398	0.463***	0.772***				
	B4_1	**Dropped**						
	B5_1	1.1256	0.358***	0.614***				
Material Flexibility	B2_1	**Dropped**			0.661	0.7981	0.51	Yes
	B2_2	1.1061	0.219***	0.494***				
	B3_2	1.2459	0.3624***	0.7096***				
	B4_2	1.5368	0.4424***	0.7903***				
	B5_2	1.4966	0.3506***	0.7706***				
Machine Flexibility	B1_3	**Dropped**			0.6068	0.7910	0.5591	Yes
	B2_3	1.1720	0.4009***	0.6977***				
	B3_3	1.2632	0.5247***	0.8184***				
	B4_3	**Dropped**						
	B5_3	1.2148	0.4031***	0.7216***				
Quality Flexibility	B1_4	1.5442	0.2427****	0.6564****	0.7941	0.8559	0.5442	Yes
	B2_4	1.7323	0.2100***	0.7000***				
	B3_4	1.9618	0.2358***	0.7903****				
	B4_4	1.6217	0.2961***	0.7483***				
	B5_4	1.6433	0.3643***	0.7844***				
Routing Flexibility	G2_1	3.0688	0.2234***	0.7758***	0.8081	0.8688	0.6241	Yes
	G2_2	3.0509	0.2646***	0.7809***				
	G3_2	**Dropped**						
	G4_2	1.6237	0.4577***	0.8546***				
	G5_2	1.4671	0.3073***	0.7445***				
Programme Flexibility	G1_1	**Dropped**			0.7832	0.8726	0.6954	Yes
	G1_2	**Dropped**						
	G3_1	1.6711	0.3993***	0.8274***				
	G4_1	1.5050	0.4584***	0.8377***				
	G5_1	1.8429	0.3414***	0.8367***				
Performance	D1_1	**Dropped**			N/A	N/A	N/A	N/A
	D1_2	1.0706	0.3538***	0.5636***				
	D1_3	**Dropped**						
	D1_4	**Dropped**						
	D1_5	**Dropped**						
	D1_6	1.0363	0.1968**	0.3479**				
	D1_7	**Dropped**						
	D1_8	1.1902	0.5304***	0.7848***				
	D2_1	1.2265	0.2445**	0.6014***				
	D2_2	**Dropped**						
	D3_1	1.1372	0.3010**	0.5610***				
	D3_2	**Dropped**						
	D3_3	**Dropped**						
Dynamic Environment	C1_2	1.1392	0.4557***	0.7162***	0.5181	0.7969	0.6653	Yes
	C1_3	**Dropped**						
	C1_4	**Dropped**						
	C1_5	1.1392	0.7449***	0.9043***				
Batch	Dummy	1.000	1.000	1.000	1.000	N/A	1.000	N/A
Discrete	Dummy	1.000	1.000	1.000	1.000		1.000	N/A
Age	Age	1.000	1.000	1.000	1.000		1.000	N/A
Size	PC	1.000	1.000	1.000	1.000		1.000	N/A

t p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests), N/A=not applicable.

5.6.1.2.1 Results of reflective constructs evaluation

Reflective measures were evaluated according to the four criteria (internal consistency reliability, indicator reliability, convergent validity and discriminant validity) discussed in section 5.4.1.a.

Internal consistency reliability: As we can see in Table 26, values of composite reliability range from 0.7910 to 0.8726. Thus, high levels of internal consistency reliability are demonstrated among all latent variables in this model.

Indicator reliability: according to Hair et al., (2014) all the items loading below 0.4 were dropped from the scales. Outer loadings between 0.4 and 0.7 were removed only when deleting the indicator leads to an increase in composite reliability or in the average variance extracted (AVE) above the suggested threshold value, following the rules of previous studies (e.g. Braojos-Gomez et al., 2015). Following this criteria, Table 26 shows all the individual indicators outer loadings, some of which were dropped by following the discussion above. Moreover, all remaining but four indicators loadings (B5_1, B2_2, B2_3 and B1_4) were above the threshold value of 0.70. On these cases, when attempted to remove them the result did not increase the composite reliability and AVE, so the items were retained. In addition, their corresponding p-value was highly significant at <0.001.

Convergent validity: Table 26 shows that all AVE values are greater than the acceptable threshold of 0.5, so convergent validity, the third criteria, is also confirmed (Bagozzi & Yi, 1988; Chin, 2010). Overall, this analysis suggests good properties for the measures (Chin, 2010).

Discriminant validity: Table 27 shows the correlations and establishes that the final criteria, discriminant validity, was acceptable.

Table 27. Discriminant validity and inter-construct correlations of internal flexibility model

Latent Variables	1	2	3	4	5	6	7	8	9	10	11	12
1 Age	**1.000**											
2.Batch Production	-0.086	**1.000**										
3. Discrete Production	-0.0025	-0.622***	**1.000**									
4. Labour	-0.0087	-0.0996	-0.0493	**0.7254**								
5. Machine	-0.0522	-0.0615	-0.0350	0.5074***	**0.7477**							
6. Material	-0.0527	0.0134	-0.0858	0.6117***	0.6956***	**0.7106**						
7. Performance	-0.0211	-0.0943	0.0481	0.4439***	0.3158***	0.3183***	**n/a**					
8. Programme	0.0250	-0.1191[t]	-0.0983	0.4240***	0.4281***	0.5335***	0.3727***	**0.8339**				
9. Quality	0.0005	0.0016	-0.0620	0.4429***	0.5613***	0.5989***	0.2930***	0.3932***	**0.7377**			
10. Routing	-0.0384	-0.0926	-0.0635	0.4576***	0.4323***	0.5467***	0.3341***	0.7822***	0.4280***	**0.7900**		
11. Size	0.1695**	-0.0612	0.0005	-0.0332	-0.0241	-0.0817	0.0186	0.0366	-0.1451**	-0.0662	**1.000**	
12. Uncertainty	-0.0235	-0.0043	0.0333	0.2588**	0.2859***	0.3174***	0.3157***	0.2816***	0.2576***	0.2833***	0.0118	**0.8157**

N=266. Boldface values are the square root of the average variance extracted. It shows the variance shared between a construct and its measures. Boldface diagonal elements should be larger than off-diagonal elements in order to satisfy discriminant validity requirements. [t] p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests). n/a not applicable

5.6.1.2.2 Results of formative construct evaluation

Formative measures were evaluated according to the two rules (collinearity and significance and relevance of outer weights and loadings) explained in section 5.4.1.b. Table 28 summarizes the results obtained of multicollinearity and individual contribution of each individual indicator to the formative construct. Following both criteria we found that 8 items were dropped from the scale because their weights were not significant and the loadings are also lower than 0.5 although significant. The final scale of performance groups one financial item (market share), two operational measures (cycle time and product innovativeness) and two customers' satisfaction measures (satisfaction of the requirements and expectations of customers and loyalty of customer to the products).

Table 28. Results obtained of multicollinearity and individual contribution of each individual indicator to the formative construct

Performance		VIF	Weigths	Loadings
D1_1	Sales Growth	2,5042	-0,0026	0.4944**
D1_2	Market Share	2.025,16	**0,3379****	**0.5444*****
D1_3	Profitability	1,1352	0,1144	0.0519
D1_4	Manufacturing cost	2.020,16	0,1144	0.3272**
D1_5	Inventory turnover	1,1875	-0,0977	0.0498
D1_6	Cycle time (raw material to delivery)	1,4606	**0,1615^t**	0.3343^t
D1_7	Conformance to product specifications	1,2857	0,0119	0.4431**
D1_8	Product innovativeness	2,3201	**0,4780****	**0.7678*****
D2_1	Our organisation satisfies the requirements and expectations of our customers	2,2226	**0,2577****	**0.5847*****
D2_2	Our organisation satisfies the quality requirements of our customers	1,3465	-0,0579	0.4350***
D3_1	Our customers are loyal to our products	1,3304	**0,2595****	**0.5504*****
D3_2	Our customers are satisfied with the rate price/quality of our products	1,0545	0,1039	0.4119***
D3_3	Our customers think that our product have a good reputation	2,5042	-0,1810	-0.2283

Source: Authors

5.6.1.3 Second-order formative evaluation of measurement models

As previously stated, due to the nature of this study as a multidimensional construct, the evaluation of the formative measurement models was conducted before the evaluation of the structural model. So, by following Hair et al., (2014) an evaluation of the formative second-order constructs considers the same both elements explained before for first order formative construct (collinearity among indicators and significance and relevance of outer weights). The results of Table 29 shows that collinearity of the formative second-order construct is not a problem in the data. That is because the values range from 1.4847 to 3.0353 at second-order level and are lower than the cut off of 3.3 suggested by researchers.

Table 29. Tolerance and variance inflation factor results of formative second-order of internal flexibility construct

Latent Variable	R^2	Tolerance (1 - R^2)	VIF (1 / Tolerance)
Labour flexibility	0.326	0.674	1.4847
Material Flexibility	0.603	0.397	2.5166
Machine Flexibility	0.448	0.552	1.8110
Quality Flexibility	0.372	0.628	1.5918
Routing Flexibility	0.671	0.329	3.0353
Programme Flexibility	0.649	0.351	2.8457

Source: Authors

Additionally we present in Table 30 the second-order indicators in this model, where we found that all weights are significant, with the exception of routing flexibility. If we analyse the loading of this flexibility type we found that it is above of 0.5 cut off and significant so following the criteria for formative constructs this dimension was retained.

Table 30. Outer weights significance-testing results of formative second order of internal flexibility construct

Latent Variable	Outer Weights	p Value	T Statistics	Outer Loadings	p Value	T Statistics
Labour flexibility	**0.6744*** **	0.0000	4.9400	0.8352***	0.0000	9.2089
Material Flexibility	**-0.3437***	0.0423	1.7233	0.5755***	0.0000	4.7317
Machine Flexibility	**0.2689***	0.0265	1.9529	0.6168***	0.0000	6.0253
Quality Flexibility	**0.1975^t**	0.0625	1.5205	0.5551***	0.0000	4.4818
Routing Flexibility	-0.0251	0.4342	0.1666	**0.6450*** **	0.0000	5.5124
Programme Flexibility	**0.5226***	0.0110	2.3056	0.7180***	0.0000	6.1823

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (all tests are one tailed).

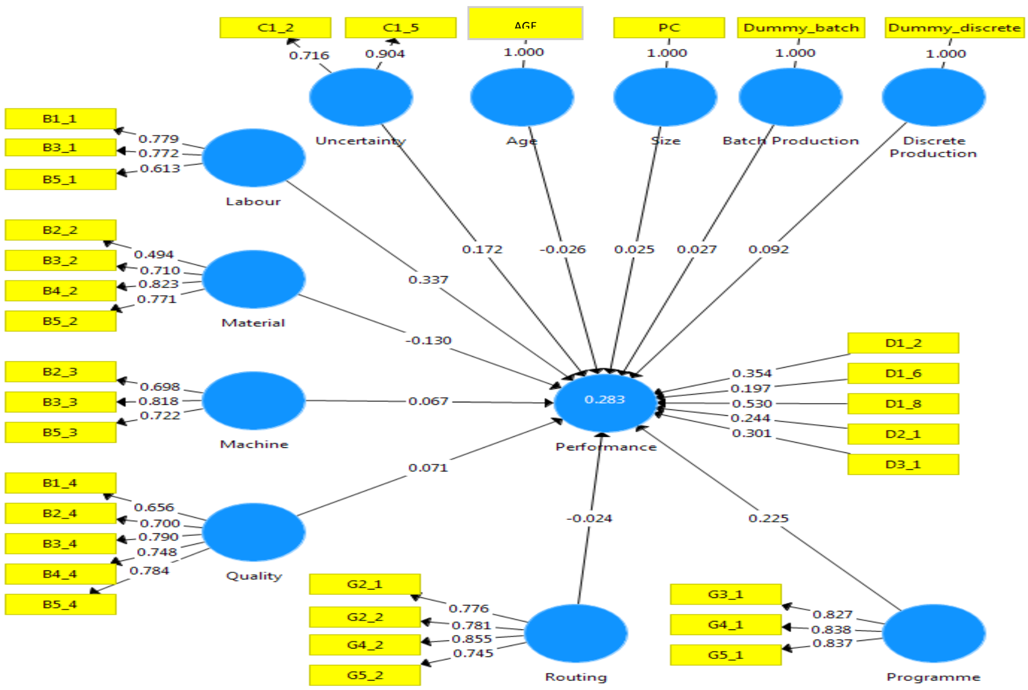
The previous results provide **support to Hypothesis 1,** the six latent variables or dimensions, *labour, material, machine, quality, routing* and *programme* flexibility types, belong to a second-order formative construct internal flexibility. These results provide empirical support to the formulation of the internal flexibility construct.

5.6.1.4 Evaluation of the structural model

Once the construct measures have been confirmed to be reliable and valid, an assessment of the structural model results followed. This assessment involves examining the model predictive capabilities, as well as the significance and relevance of the relationships among the constructs. The key criteria for assessing the structural model in PLS-SEM are to evaluate the significance of the path coefficients or the relationships among the constructs, the R^2 values, the effect size f^2, and the predictive relevance (Q^2), which are the measures of how well a model is performing (Chin, 1998). Applying the PLS-SEM algorithm can assess these criteria.

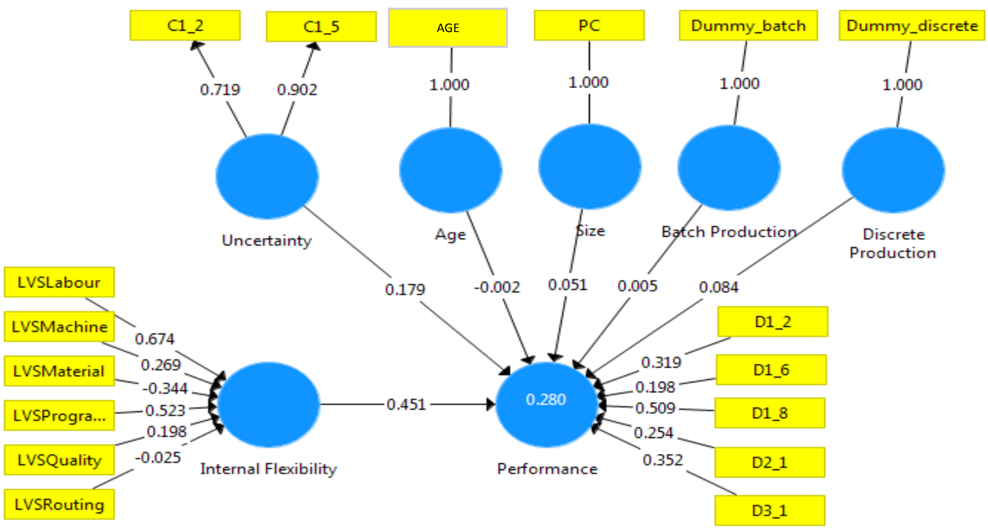
The PLS path modeling method was developed by Wold (1982) and the PLS algorithm is essentially a sequence of regressions in terms of weight vectors (Ringle et al., 2015). After applying the PLS-SEM algorithm, estimates are obtained for the structural model relationships or the path coefficients, which represent the hypothesized relationships between the constructs. The path coefficients for the structural model are shown in Figures 5 and 6. As previously discussed, the two-step approach was used to assess the measurement of the interaction among the constructs.

Figure 5. Internal Flexibility path modeling estimation (step 1 in the two-step approach)



Source: Authors

Figure 6. Internal Flexibility path modeling estimation (step 2 in the two-step approach)



Source: Authors

In general, for data set having up to 1,000 observations or samples, the “standardised” path coefficient should be larger than 0.20 in order to demonstrate its significance. However, in explanatory studies with reduced sample path coefficients are considered statistical significant when they are higher than 0.1 and their p-values are significant (Wong, 2013; Ringle, 2004; Heinecke, 2014). As shown in Table 31, the path coefficient of the key construct in the model, internal flexibility, is 0.451 with a p-value of 0.000 significant at the 0.05 level. With respect to the control variables we found that only two of them are significant: dynamic environment (0.179 highly significant) and discrete production (significant at the 0.10 level).

Table 31. Significance testing results of the structural model path coefficients of internal flexibility

Path	Path Coefficients	T Statistics	p Value
Internal Flexibility→ Performance	0.451***	7.8235	0.0000
Dynamic environment (control variable) →Performance	0.179**	2.5649	0.0052
Batch Production (control variable)→Performance	0.005	0.0918	0.4644
Discrete Production (control variable) → Performance	0.084^t	1.4338	0.0758
Age (control variable)→Performance	-0.002	0.0345	0.4862
Size(control variable)→Performance	0.051	2.5649	0.1289

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

These results **provide support to hypothesis 3**. Internal flexibility affects positively and highly significantly to performance (higher than 0.2 and p-value lower than 0.001). Additionally, we found that dynamic environment has a positive significant effect on the top internal flexibility-performance relationship. Besides, we found that the discrete production is a positive significant control variable at the level 0.10.

The R^2 values show the predictive quality of the model, values of 0.19, 0.33, and 0.67 are weak, moderated, and substantial (Chin, 1998). The R^2 value of performance is 0.28 with a p-value of 0.000. In addition to the R^2 values, the Stone-Geisser test of cross-validated redundancy measure Q^2 is used to assess the predictive validity of the exogenous latent variables and can be computed using the blindfolding procedure in Smart PLS software. In this case, values greater than zero imply that the independent variables have predictive relevance for the dependent variable under consideration (Chin, 1998). Table 32 shows the Q^2 values in the model. The Q^2 values are greater than zero as recommended, showing a satisfactory predictive power for the proposed model.

Table 32. Results of R^2 and Q^2 Values of internal flexibility

Endogenous latent variable	R^2 Value	p Values	Q^2 Value
Performance	0.28***	0.000	0.0669

^{t} $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$ (one tailed tests).

The f^2 effect size is a measure of the impact of a specific predictor construct on an endogenous construct. The f^2 effect size measures the change in the R^2 value when a specified exogenous construct is omitted from the model. The f^2 is very useful when evaluating whether the impact of a specific independent on a dependent variable is important. Values of 0.02, 0.15 and 0.35 depict a small, medium and large effect size respectively (Chin, 1998; Leal-Rodríguez et al., 2014). As shown in Table 33, the f^2 value in the proposed model for internal flexibility on performance was 0.243, and for dynamic environment, batch production, discrete production, size and age on performance were 0.041, 0.0000, 0.006, 0.004 and 0.000 respectively. Therefore, the effect size of internal flexibility on performance is medium, whereas dynamic environment has a small effect size and the rest of control variables were not significant. These results provide **additional support for hypothesis 3.**

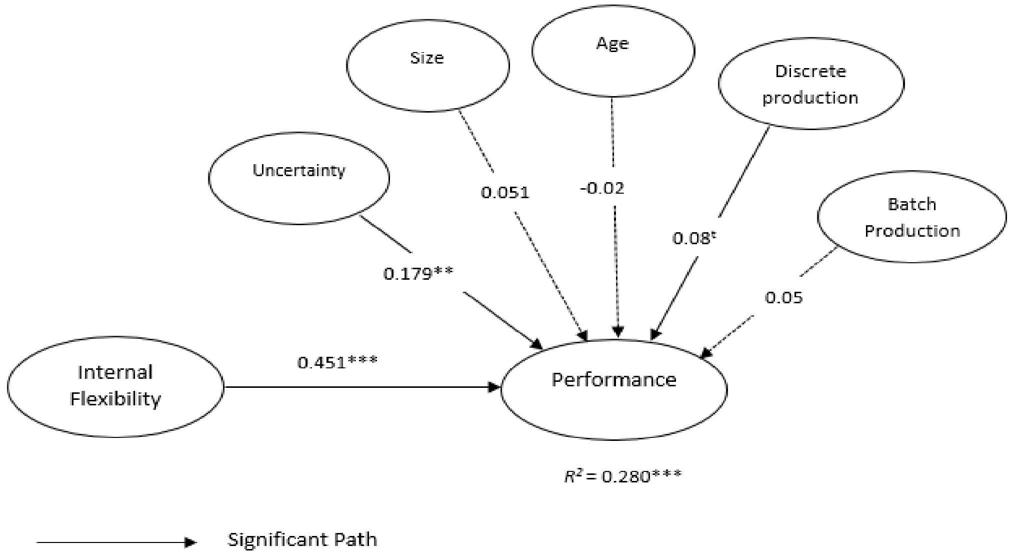
Table 33. Summary of results of internal flexibility

	Organisational performance	
	Path Coefficients	**f^2 Effect Size**
Internal Flexibility	0.451***	0.243**
Dynamic Environment	0.179**	0.041^t
Batch Production	0.005	0.000
Discrete Production	0.08^t	0.006
Size	-0.002	0.004
Age	0.051	0.000

^{t} $p<0.10$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$ (one tailed tests).

Figure 7 shows the final path analysis model and R^2 results.

Figure 7. Results of the path analysis for the internal flexibility model

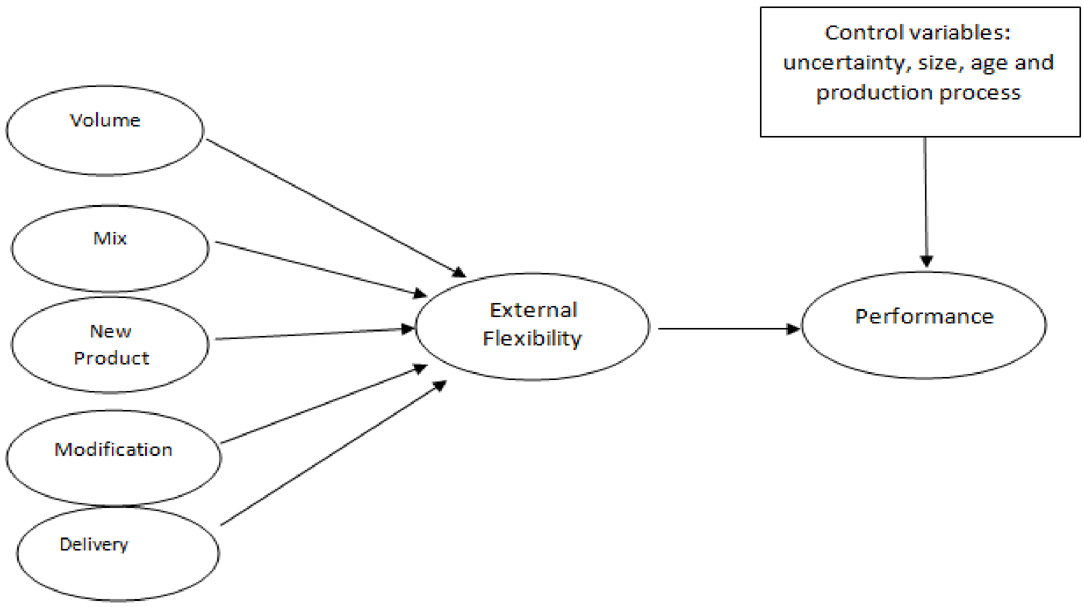


Source: Authors

5.6.2 Model 2: external flexibility-performance

In the second model of this dissertation, the external flexibility construct is the key endogenous variable and is operationalised as a multidimensional construct Type II, formative second order construct determined by four reflective first-order constructs. The dimensions incorporated in this formative construct are those discussed as action elements in Chapters 3 and 4. The explicit features, such as *volume, new product, mix, modification* and *delivery* flexibility types determine the external flexibility construct (hypothesis 2). The external flexibility has a direct effect on the performance (hypothesis 4). In addition, the dynamic environment, production type, age and size are also included in this model as control variables which affects this relationship. Please refer to Figure 8 for the external flexibility conceptual model.

Figure 8. The External Flexibility conceptual model



Source: Authors

5.6.2.1 Descriptive statistics

Dependent variable: Performance

Performance was measured as a formative first-order construct as previously discussed in Table 23 for the scale items and descriptive statistics respectively.

Independent variables: External flexibility types

In a similar manner to the previous model, each external flexibility type was measured as a reflective first-order construct determined by six indicators. This six indicators try to incorporate the four elements needed for operationalising each flexibility type discussed in chapter 3 *(range-number, range-heterogeneity, mobility* and *uniformity)*. The questionnaire examined the items through a seven-point Likert-type scale with values from 1=totally false to 7=completely true. Table 34 shows the questions used in this section as well as the descriptive statistics.

Table 34. External Flexibility scale items and descriptive statistics

Items proposed				Min	Max	Mean	Std. Deviation	Variance
Volume Flexibility	R-N	E1_1	The range of output volumes at which the firm can run profitably	2,00	7,00	5,7820	1,13496	1,288
	R-H	E2_1	We can vary output levels from one period to the next	1,00	7,00	4,6654	1,68369	2,835
	M	E3_1	It is quick and easy to change the production volume of a manufacturing process	1,00	7,00	5,1880	1,41235	1,995
		E4_1	Cost of increasing/decreasing production volume	1,00	7,00	4,3195	1,58750	2,520
	U	E5_1	Quality of products is not affected by changes in production volumes	1,00	7,00	5,1805	1,89671	3,598
		E6_1	The productivity/efficiency of the production process is not affected by changes in production volumes	1,00	7,00	4,7519	1,71302	2,934
Mix Flexibility	R-N	E1_2	A large number of product lines are produced in the plant	1,00	7,00	5,4436	1,56332	2,444
	R-H	E2_2	We can vary product mix from one period to the next	1,00	7,00	3,9925	1,58291	2,506
	M	E3_2	It is quick and easy to change the product mix produced by the plant	1,00	7,00	4,8835	1,59881	2,556
		E4_2	Cost of changing to a different product mix is small	1,00	7,00	4,3045	1,56655	2,454
	U	E5_2	Product quality is not affected by changes in product mix	1,00	7,00	5,0038	1,89836	3,604
		E6_2	The productivity/efficiency of the production process is not affected by changes in product mix	1,00	7,00	4,4962	1,68511	2,840
Modification Flexibility	R-N	E1_3	There are a large number of product modifications every year	1,00	7,00	4,6391	1,75838	3,092
	R-H	E2_3	Modified products are very different from existing products	1,00	7,00	3,9286	1,48406	2,202
	M	E3_3	It is quick and easy to introduce modified products	1,00	7,00	4,6541	1,51244	2,287
		E4_3	Cost of accommodating minor design changes	1,00	7,00	4,1955	1,42992	2,045
	U	E5_3	Quality of existing products is not affected when a modified product is introduced	1,00	7,00	4,8308	1,76911	3,130
		E6_3	The productivity/efficiency of the production process is not affected when a modified product is introduced into the manufacturing system	1,00	7,00	4,4624	1,58308	2,506
New Product Flexibility	R-N	E1_4	The number of new products introduced into production each year is high	1,00	7,00	4,1729	1,65295	2,732
	R-H	E2_4	New products are very different from existing products	1,00	7,00	4,1541	1,46233	2,138
	M	E3_4	It is quick and easy to introduce the introduction of new products	1,00	7,00	4,6165	1,47288	2,169
		E4_4	Cost required to design and develop new products is high	1,00	7,00	4,1917	1,48098	2,193
	U	E5_4	Quality of existing products is not affected when a new product is introduced into the production system	1,00	7,00	4,7143	1,71814	2,952
		E6_4	The productivity/efficiency of the production process is not affected when a new product is introduced into the production system	1,00	7,00	4,2895	1,61211	2,599
Delivery Flexibility	R-N	E1_5	The number of delivery deadline options available per product is high	1,00	7,00	4,4323	1,68823	2,850
	R-H	E2_5	Delivery deadlines available for customers differ greatly from one to another**	1,00	7,00	4,2105	1,71366	2,937
	M	E3_5	It is quick and easy to made changes on delivery deadline changes	1,00	7,00	4,7368	1,49916	2,247
		E4_5	Cost implications of changing delivery dates	1,00	7,00	4,2932	1,55543	2,419
	U	E6_5	The rate of wrong deliveries still stable when customers change the delivery deadlines	1,00	7,00	4,7030	1,73264	3,002
		E1_5	The number of delivery deadline options available per product is high	1,00	7,00	4,4323	1,68823	2,850

Source: Authors. Discussion in chapter 3 NOTE: ** Items adapted during the pre-test

Control variables

In this second model we included the same four control variables that offer alternative explanations of effects of flexibility on performance. These variables were operationalised as in model one (see section 5.6.1.).

5.6.2.2 Construct validity measures for first order reflective and formative constructs

As in the previous model, a systematic evaluation of PLS-SEM results was conducted by following Hair et al., (2014). First, an evaluation of the reflective and formative measurement models was needed before proceeding to the evaluation of the structural model. During this process we found that an individual flexibility type (*modification* flexibility) presents discriminant validity problems with *mix* and *new product flexibility types* that were only solved when modification flexibility was removed from the model.

The problem related to discriminant validity suggests that *modification* flexibility construct is not truly distinct from other constructs in accordance to empirical standards and consequently, this construct is not capturing a unique phenomenon not represented by other constructs. In this sense, some authors have addressed that the capacity to be able to make minor design changes in the product appears manifested in the ability to introduce new products rapidly (Suarez et al., 1996; Das, 2001). This may be because even though *modification, mix*, and *new product* flexibility types are all generally utilized to meet changing market demands, each flexibility type nevertheless has unique traits and usages that differ along the time horizon over which changes or adaptations are made, the frequency with which adaptations/changes are made, the degree of commitment and effort required to implement the changes, and finally the functional level within which the flexibility is utilized (Malhotra & Mackelprang, 2012). So taking into account these considerations we decided to remove *modification* flexibility from the model. The results of this evaluation are presented in Table 35. As can be seen, all model evaluation criteria have been met, providing support for the measures reliability and validity.

Table 35. Result summary for reflective and formative measurement models of external flexibility.

Latent Variable	Indicators	VIF	Weights	Loadings	Cronbach´s Alfa	Composite Reliability	AVE	Discriminant Validity?
Volume flexibility	E1_1	1.332	0.346***	0.692***	0.677	0.803	0.506	Yes
	E2_1		**Dropped**					
	E3_1	1.412	0.433***	0.790***				
	E4_1		**Dropped**					
	E5_1	1.434	0.284**	0.675***				
	E6_1	1.425	0.333***	0.681***				
Mix Flexibility	E1_2		**Dropped**		0.708	0.825	0.550	Yes
	E2_2	1.064	0.266**	0.481***				
	E3_2		**Dropped**					
	E4_2	1.502	0.389***	0.800***				
	E5_2	1.818	0.316***	0.785***				
	E6_2	2.060	0.370***	0.845***				
Modification flexibility	E1_3		**Dropped**					
	E2_3		**Dropped**					
	E3_3		**Dropped**					
	E4_3		**Dropped**					
	E5_3		**Dropped**					
	E6_3		**Dropped**					
New Product Flexibility	E1_4	1.407	0.390***	0.749***	0.719	0.825	0.542	Yes
	E2_4		**Dropped**					
	E3_4	1.536	0.339***	0.780***				
	E4_4	1.427	0.325***	0.732***				
	E5_4		**Dropped**					
	E6_4	1.366	0.303***	0.681***				
Delivery Flexibility	E1_5	1.564	0.351***	0.797***	0.737	0.835	0.560	Yes
	E2_5	1.334	0.310***	0.711***				
	E3_5	1.559	0.390***	0.815***				
	E4_5	1.264	0.276***	0.660***				
	E5_5		**Dropped**					
Performance	D1_1		**Dropped**		N/A	N/A	N/A	N/A
	D1_2	1.071	0.440***	0.623***				
	D1_3		**Dropped**					
	D1_4		**Dropped**					
	D1_5		**Dropped**					
	D1_6	1.036	0.275**	0.402**				
	D1_7		**Dropped**					
	D1_8	1.190	0.638***	0.822***				
	D2_1	1.227	-0.003	0.587**				
	D2_2		**Dropped**					
	D3_1	1.137	0.211	0.535**				
	D3_2		**Dropped**					
	D3_3		**Dropped**					
Dynamic Environment	C1_2	1.139	0.466***	0.723***	0.518	0.798	0.666	Yes
	C1_3		**Dropped**					
	C1_4		**Dropped**					
	C1_5	1.139	0.737***	0.900***				
Batch	Dummy	1.000	1.000	1.000	1.000	N/A	1.000	N/A
Discrete	Dummy	1.000	1.000	1.000	1.000		1.000	N/A
Age	Age	1.000	1.000	1.000	1.000		1.000	N/A
Size	PC	1.000	1.000	1.000	1.000		1.000	N/A

t p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests), N/A=not applicable.

5.6.2.2.1 Results of reflective constructs evaluation.

Reflective measures were evaluated according to the four criteria discussed in section 5.4.1.a.

Internal consistency reliability: Table 35 shows that composite reliability values range from 0.798 to 0.835. Composite reliability values between 0.70 and 0.90 are satisfactory (Nunnally & Bernstein, 1994). Thus, high levels of internal consistency reliability are demostrated among all latent variables in this model.

Indicator reliability: Table 35 shows all the individual indicators outer loadings, some of which were dropped by following the previous discussion. Moreover, all remaining but six indicators´ loadings (E1_1, E5_1, E6_1, E2_2, E6_4, E4_5) were above the threshold value of 0.70. On these cases, when attempted to remove them the result did not increase the composite reliability and AVE, so the items were retained. In addition, their corresponding p-value was highly significant at <0.001.

Convergent validity: Table 35 shows that all AVE values are greater than the acceptable threshold of 0.5, so convergent validity is confirmed (Bagozzi & Yi, 1988; Chin, 2010). Overall, this analysis suggests good properties for the measures (Chin, 2010).

Discriminant validity: Table 36 shows the correlation table that shows discriminant validity is acceptable because the square root of each construct´s AVE is larger than its correlations with other constructs.

Table 36. Discriminant validity and inter-construct correlations of external flexibility.

Latent Variables	1	2	3	4	5	6	7	8	9	10
1 Age	**1.000**									
2.Batch Production	-0.086	**1.000**								
3. Delivery	0.033	0.045								
4. Discrete production	-0.002	-	-0.103^{t}	**1.000**						
5. Mix	-0.025	-0.088	0.576***	-0.059	**0.742**					
6. New Product	-0.060	0.027	0.497***	-0.054	0.536***	**0.736**				
7. Performance	-0.024	-0.089	0.316***	0.049	0.312***	0.429***	**n/a**			
8. Size	0.169**	-0.061	-0.127**	0.001	-0.041	-0.010	0.014	**1.000**		
9. Uncertainty	-0.023	-0.004	0.192**	0.034	0.239***	0.349***	0.332**	0.011	**0.816**	
10. Volume	0.036	-	0.470***	0.024	0.654***	0.377***	0.256**	0.011	0.196***	**0.711**

N=266. Boldface values are the square root of the average variance extracted. It shows the variance shared between a construct and its measures. t p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests), N/A=not applicable.

5.6.2.3 Second-order formative evaluation of measurement models

Due to the nature of this study an evaluation of the formative second-order constructs was performed considering the two elements presented in section 5.4.1.b (Hair et al., 2014):

Collinearity among indicators: The values range from 1.647 to 2.322, suggesting that collinearity is not a problem in the data because they are not above of cut off of 3.3 (Table 37).

Table 37. Tolerance and Variance inflation factor results of external flexibility.

Latent Variable	R^2	Tolerance (1 - R^2)	VIF (1 / Tolerance)
Volume flexibility	0.480	0.520	1.924
Mix Flexibility	0.569	0.431	2.322
New Product Flexibility	0.393	0.607	1.647
Delivery Flexibility	0.423	0.577	1.734

Source: Authors

Significance and relevance of outer weights: Table 38 shows the second-order indicators. In one case (*new product* flexibility), the outer weights is significant. The outer loadings of the rest of flexibility types are above 0.50 and are highly significant, so all the indicators/dimensions were maintained (Hair et al., 2014).

Table 38. Outer weights significance-testing results of external flexibility.

Latent Variable	Outer Weights	p Value	T Statistics	Outer Loadings	p Value	T Statistics
Volume flexibility	0.168	0.180	0.914	**0.587******	0.000	3.573
Mix Flexibility	0.076	0.332	0.434	**0.696*****	0.000	5.178
New Product Flexibility	**0.767*****	0.000	4.665	**0.956*****	0.000	10.825
Delivery Flexibility	0.170	0.191	0.876	**0.675*****	0.000	4.268

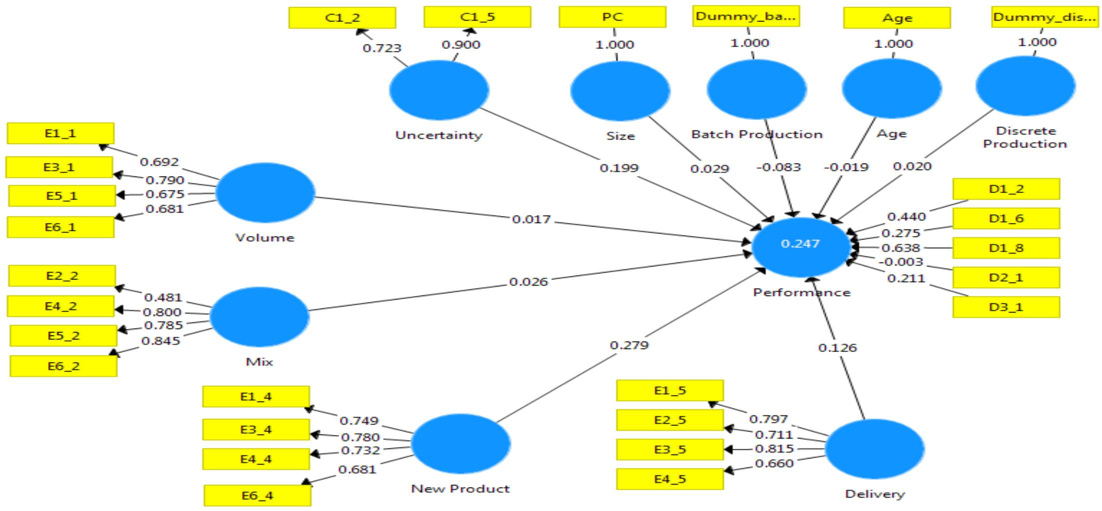
^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (all tests are one tailed).

The results provide partial **support to Hypothesis 2,** only four latent variables or flexibility types, namely *volume, mix, new product* and *delivery*, belong to a second-order formative construct external flexibility. These results provide partial empirical support to the formulation of the external flexibility construct.

5.6.2.4 Evaluation of the structural model

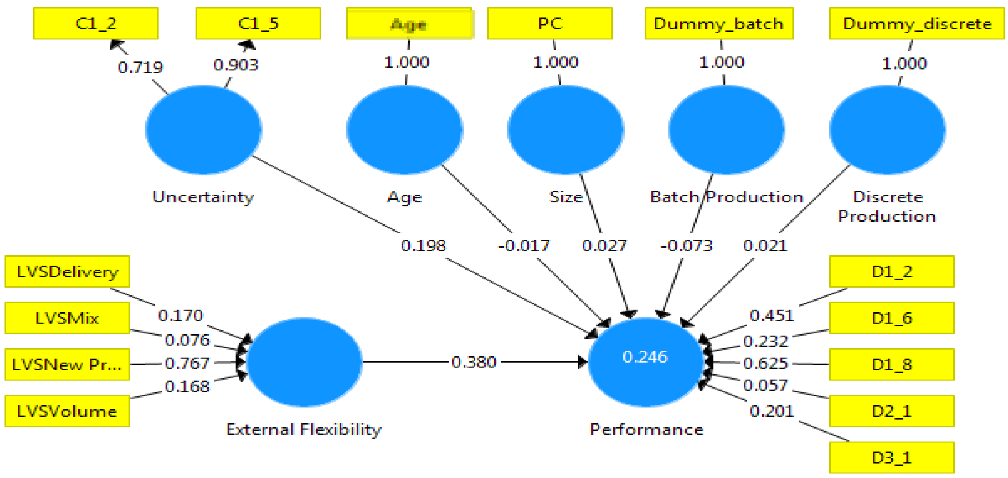
A bootstrap analysis with 5,000 subsamples was performed to estimate the significance of the path coefficients (Chin, 1998). The path coefficients for the structural model are shown in Figures 9 and 10.

Figure 9. External flexibility path modeling estimation (Step 1 in the two-step approach).



Source: Authors

Figure 10. External flexibility path modeling estimation (step 2 in the two-step approach).



Source: Authors

The results of Table 39 provide **support to hypothesis 4**, where the path coefficient of external flexibility to performance is 0.380 and highly significant at a 0.001 level. With respect to the control variables we found that two control variables are significant (dynamic environment and bath production).

Table 39. Significance testing results of the structural model path coefficients of external flexibility

Path	Path Coefficients	T Statistics	p Value
External Flexibility→ Performance	0.380***	6.132	0.000
Dynamic environment (control variable) →Performance	0.198**	2.777	0.003
Batch Production (control variable)→Performance	-0.073^{t}	0.343	0.098
Discrete Production (control variable)→Performance	0.021	0.455	0.324
Age (control variable)→Performance	-0.017	0.343	0.366
Size (control variable)→Performance	0.027	0.658	0.255

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

The R^2 values show the predictive quality of the model. The R^2 value of organisational performance is 0.246 with a p-value of 0.000, which shows a weak predictive quality.

Table 40. Results of R^2 and Q^2 Values of external flexibility

Endogenous latent variable	R^2 Value	p Values	Q^2 Value
Performance	0.246	0.000	0.051

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

Table 40 shows the Q^2 value in the model. The Q^2 values are greater than zero as recommended. These values show a satisfactory predictive power for the proposed model. As shown in Table 41 the f^2 value in the proposed model for external flexibility on performance was 0.166. Thus, the effect size of external flexibility on performance is medium since it is above the 0.15 limit (Chin, 1998; Leal-Rodríguez et al., 2014), whereas dynamic environment effect size on performance was small and significant at 0.10 level.

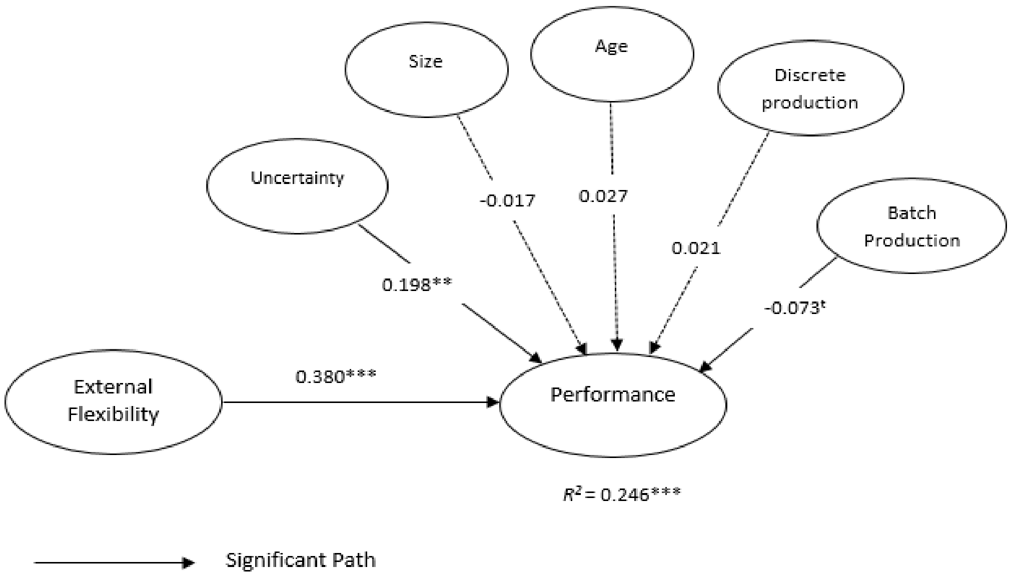
Table 41. Summary of results of external flexibility

	Organisational performance	
	Path Coefficients	**f^2 Effect Size**
Internal Flexibility	0.380***	0.166**
Dynamic Environment	0.198**	0.045^t
Batch Production	-0.073^t	0.004
Discrete Production	0.021	0.000
Size	-0.017	0.001
Age	0.027	0.000

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

These results provide **additional support for hypothesis 4**, where the effect of the external flexibility on performance is medium and significant (Figure 11).

Figure 11. Results of the path analysis for the external flexibility model

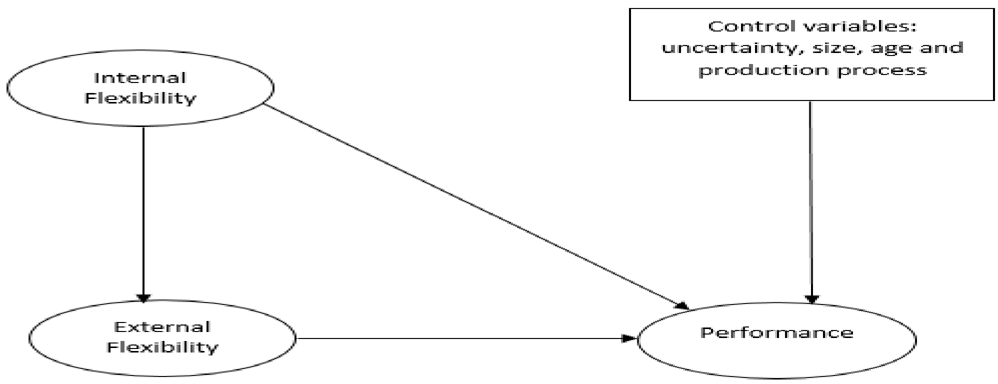


Source: Authors

5.6.3 Model 3: manufacturing flexibility: an integrative model (external mediation effect)

In this final model, the integration of both previous models in this dissertation was considered. Both multidimensional constructs are Type II reflective first-order and formative second-order (Jarvis et al., 2003). From the integrative framework in this dissertation in Figure 5, and considering the previous assessment of the first and second models in this study, the internal flexibility has a direct effect on the external flexibility, and external flexibility mediates the internal flexibility performance relationship (hypothesis 5). Please refer to Figure 12 for the visual presentation of the integrative model.

Figure 12. Integrative model



Source: Authors

5.6.3.1 First-order reflective evaluation of measurement models

For an assessment of the measurement models, Hair et al., (2014) systematic evaluation of PLS-SEM results was performed. Although both multidimensional constructs have been assessed before individually in this research study, for this integrative model a reassessment is recommended including all corresponding indicators to evaluate the structural model. The two step approach was used to calculate the latent variable scores to measure the constructs´ validity and reliability (Chin, 2010). Therefore, first, an evaluation of the reflective and formative first-order constructs was conducted according to the criteria explained previously. The results are summarized in Table 42.

Table 42. Results for reflective measurement models of the integrative model.

Latent Variable	Indicators	VIF	Weights	Loadings	Cronbach´s Alfa	Composite Reliability	AVE	Discriminant Validity?
Labour flexibility	B1_1	1.155	0.533***	0.772***	0.553	0.767	0.527	Yes
	B3_1	1.240	0.478***	0.781***				
	B5_1	1.126	0.352***	0.612***				
Material Flexibility	B2_2	1.106	0.210**	0.487***	0.666	0.797	0.504	Yes
	B3_2	1.246	0.382***	0.722***				
	B4_2	1.537	0.441***	0.822***				
	B5_2	1.497	0.340***	0.764***				
Machine Flexibility	B2_3	1.172	0.387***	0.688***	0.607	0.791	0.559	Yes
	B3_3	1.263	0.527***	0.820***				
	B5_3	1.215	0.414***	0.729***				
Quality Flexibility	B1_4	1.544	0.248***	0.659***	0.794	0.856	0.544	Yes
	B2_4	1.732	0.205***	0.698***				
	B3_4	1.962	0.235***	0.790***				
	B4_4	1.622	0.292***	0.746***				
	B5_4	1.643	0.370***	0.786***				
Routing Flexibility	G2_1	3.069	0.217***	0.771***	0.808	0.868	0.623	Yes
	G2_2	3.051	0.261***	0.776***				
	G4_2	1.624	0.464***	0.858***				
	G5_2	1.467	0.310***	0.747***				
Programme Flexibility	G3_1	1.671	0.403***	0.829***	0.783	0.873	0.696	Yes
	G4_1	1.505	0.454***	0.836***				
	G5_1	1.843	0.340***	0.836***				
Volume Flexibility	E1_1	1.332	0.352***	0.695***	0.677	0.802	0.505	Yes
	E3_1	1.412	0.433***	0.791***				
	E5_1	1.434	0.258**	0.662***				
	E6_1	1.425	0.353***	0.661***				
Mix Flexibility	E2_2	1.064	0.275***	0.488***	0.708	0.825	0.550	Yes
	E4_2	1.502	0.371***	0.790***				
	E5_2	1.818	0.306***	0.782***				
	E6_2	2.060	0.392***	0.852***				
New Product Flexibility	E1_4	1.407	0.359***	0.732***	0.719	0.826	0.543	Yes
	E3_4	1.536	0.361***	0.789***				
	E4_4	1.427	0.320***	0.733***				
	E6_4	1.366	0.315***	0.691***				
Delivery Flexibility	E1_5	1.564	0.341***	0.793***	0.737	0.835	0.560	Yes
	E2_5	1.334	0.316***	0.715***				
	E3_5	1.559	0.395***	0.818***				
	E4_5	1.264	0.274***	0.658***				
Performance	D1_2	1.071	0.324**	0.539***	N/A	N/A	N/A	N/A
	D1_6	1.036	0.196^t	0.344**				
	D1_8	1.190	0.599***	0.820***				
	D2_1	1.227	0.143	0.528***				
	D3_1	1.137	0.335**	0.573***				
Dynamic Environment	C1_2	1.139	0.463***	0.722***	0.518	0.797	0.666	Yes
	C1_5	1.139	0.739***	0.901***				
Batch	Dummy	1.000	1.000	1.000	1.000	N/A	1.000	N/A
Discrete	Dummy	1.000	1.000	1.000	1.000		1.000	N/A
Age	Age	1.000	1.000	1.000	1.000		1.000	N/A
Size	PC	1.000	1.000	1.000	1.000		1.000	N/A

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

Internal consistency reliability: Table 42 shows that all values are ranging from 0.767 to 0.873. Thus, high levels of internal consistency reliability were demonstrated among all latent variables in this model.

Indicator reliability: In the evaluation of reflective measurements, indicators in a construct can be used interchangeably and even to a certain extent be discarded (Henseler & Fassott, 2010). Therefore, we evaluate the loadings of the indicators, which refer to the absolute contribution of an indicator to the construct. The cut-off value for the loadings is 0.708. Table 42 shows all the individual indicators outer loadings, some of which were removed by following the above considerations, and were previously assessed individually in Sections 5.6.1.2 and 5.6.2.2.

Convergent validity: Table 42 shows that all AVE values are greater than the acceptable threshold of 0.5, verifying the convergent validity of the latent variables, and demonstrating good properties for the measures in this model (Bagozzi & Yi, 1988; Chin, 2010).

Discriminant validity: To probe that the constructs used in this model are unique and do not capture the same phenomena than any other construct within the model, the Fornell-Larcker criterion was used. Table 43 shows that the square roof of AVE are always larger that the correlations of each construct, so discriminant validity is not a problem in the data. Table 43 shows the correlation table to establish the discriminant validity according to this approach.

Table 43. Results of the reflective measurement model assessment.

Latent Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Age	**1.000**															
2.Batch Production	-0.086	**1.000**														
3. Delivery	0.033	0.045	**0.748**													
4. Discrete production	-0.002	-0.622***	-0.103^{t}	**1.000**												
5. Environment	-0.023	-0.004	0.192**	0.034	**0.816**											
6. Labour	-0.009	-0.100	0.375***	-0.050	0.259***	**0.726**										
7. Machine	-0.053	-0.061	0.387***	-0.036	0.288***	0.510***	**0.748**									
8. Material	-0.052	0.014	0.394***	-0.087	0.318***	0.613***	0.697***	**0.710**								
9. Mix	-0.025	-0.087	0.577***	-0.059	0.239***	0.546***	0.431***	0.498***	**0.742**							
10. New Product	-0.061	0.028	0.499***	-0.057	0.348***	0.404***	0.401***	0.471***	0.543***	**0.737**						
11. Performance	-0.013	-0.082	0.295***	0.042	0.319***	0.438***	0.310***	0.323***	0.301***	0.428***	**n/a**					
12. Quality	0.000	0.001	0.410***	-0.062	0.258***	0.444***	0.563***	0.599***	0.433***	0.409***	0.228***	**0.737**				
13. Routing	-0.038	-0.093	0.418***	-0.063	0.283***	0.459***	0.434***	0.547***	0.478***	0.459***	0.337***	0.429***	**0.798**			
14. Size	0.169**	-0.061	-0.128**	0.001	0.011	-0.036	-0.026	-0.083	-0.041	-0.015	0.013	-0.145**	-0.067	**1.000**		
15. Volume	0.037	-0.223***	0.471***	0.022	0.194***	0.493***	0.441****	0.479***	0.651***	0.384***	0.275***	0.351***	0.553***	0.011	**0.710**	
16. Programme	0.025	-0.119	0.431***	-0.099	0.281***	0.425***	0.429***	0.534***	0.544***	0.432***	0.381***	0.393***	0.784***	0.037	0.526***	**0.834**

N=266. Boldface values are the square root of the average variance extracted. They shows the variance shared between a construct and its measures.

t p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests), N/A=not applicable.

5.6.3.2 Second-order formative evaluation of measurement models

After assessing the content validity and reliability of the reflective and formative measures, the evaluation of the formative measurement models was then assessed prior to the evaluation of the structural model. Thus, the formative second-order constructs were assessed by considering the following elements according to Hair et al., (2014):

Collinearity among indicators: Table 44 shows the tolerance values for the multidimensional constructs, all indicators are above the 0.20 cutoff value. In addition it shows the corresponding assessment of collinearity for the formative second-order constructs. The values range from 1.530 to 2.775, suggesting that collinearity is not a problem in the data.

Table 44. Tolerance and variance inflation factor results of the integrative model.

Latent Variable	R^2	Tolerance ($1-R^2$)	VIF (1/Tolerance)
Internal Flexibility			
Labour	**0.411**	**0.589**	1.697
Material	**0.640**	**0.360**	2.775
Machine	**0.527**	**0.473**	2.116
Quality	**0.413**	**0.587**	1.704
Routing	**0.646**	**0.354**	2.828
Programme	**0.632**	**0.368**	2.714
External Flexibility			
Volume	**0.438**	**0.562**	1.778
Mix	**0.564**	**0.436**	2.294
New Product	**0.346**	**0.654**	1.530
Delivery	**0.361**	**0.639**	1.5652

Source: Authors

Significance and relevance of outer weights: The significance of the weights and loading was previously assessed for each of the two constructs in section 5.6.1.3 and 5.6.2.3 by conducting a bootstrapping routine in SmartPLS (Benitez-Amado & Walczuch, 2012; Chin, 1998; Hair et al., 2014). Table 45 confirms the relevance of the elements in the constructs, and shows a summary of the second-order indicators; in only one case –*material flexibility*-, the outer weight was not significant. However the outer loadings were above 0.50 and highly significant, so all indicators/dimensions were retained (Hair et al., 2014).

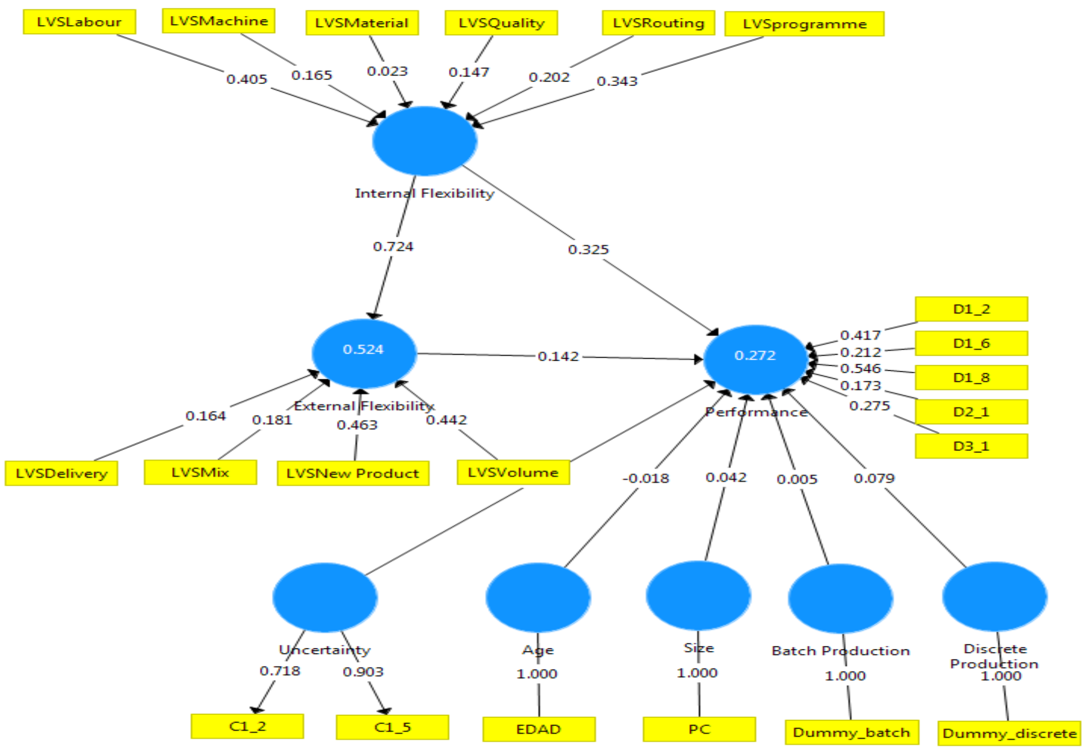
Table 45. Outer weights significance-testing results of the integrative model.

Latent Variable	Outer Weights	P Values	T Statistics	Outer Loadings	P Value	T Statistics
Internal Flexibility						
Labour	**0.405*** **	0.000	4.498	0.807***	0.000	15.453
Material	0.023	0.369	0.334	**0.768*** **	0.000	15.567
Machine	**0.165***	0.019	2.066	0.706***	0.000	12.278
Quality	**0.147***	0.030	1.887	0.655***	0.000	10.396
Routing	**0.202***	0.034	1.830	0.805***	0.000	13.848
Programme	**0.343*** **	0.001	3.027	0.815***	0.000	14.619
External Flexibility						
Volume	**0.442*** **	0.000	3.859	0.815***	0.000	14.879
Mix	**0.181***	0.050	1.649	0.815***	0.000	14.124
New Product	**0.463*** **	0.000	5.311	0.813***	0.000	15.665
Delivery	**0.164***	0.032	1.847	0.707***	0.000	10.481

Source: Authors ^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

5.6.3.3 Evaluation of the structural model

Figure 13. Manufacturing flexibility integrative path modeling estimation with control variables



Source: Authors

A bootstrap analysis with 5,000 subsamples was assessed to estimate the significance of the path coefficients (Chin, 1998). The path coefficients for the structural model are shown in Figure 13. Table 46 shows the path coefficients of the key constructs in the integrative model. These results provide **support to hypothesis 2**, where the path coefficient of the internal flexibility to performance is highly significant to a 0.000 level. In addition, there was **support for hypothesis 5**, where the path coefficient of internal flexibility to external flexibility is highly significant to a 0.001 level.

Table 46. Significance testing results of the structural model path coefficients of the integrative model.

Path	Path Coefficients	T Statistic	P value
Internal Flexibility → Performance	0.325***	3.594	0.000
External Flexibility → Performance	0.142*	1.671	0.047
Internal Flexibility → External Flexibility	0.724***	21.464	0.000
Uncertainty (control variable)→ Performance	0.162**	2.298	0.011
Batch Production (control variable)→ Performance	0.005	0.103	0.459
Discrete production (control variable) →	0.079^t	1.356	0.088
Age (control variable)→ Performance	-0.019	0.394	0.347
Size (control variable)→ Performance	0.042	0.042	0.161

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

The R^2 value of organisational performance is 0.272 with a p-value of 0.000, which shows a weak predictive quality and the R^2 of external flexibility is 0.523 with a p-value of 0.000 which shows a moderated predicative effect (Table 47).

Table 47. Results of R^2 and Q^2 Values of the integrative model.

Endogenous latent variable	R^2 Value	T Statistic	P value	Q^2 Value
External Flexibility	0.524***	10.679	0.000	0.321
Performance	0.272***	5.862	0.000	0.067

Source: Authors

Table 48 shows the Q^2 value in the model. The Q^2 values are greater than zero as recommended. These values show a satisfactory predictive power for the proposed model.

Table 48. Summary of results of the integrative model

Latent Variables	External Flexibility		Performance	
	Path Coefficients	f^2 Effect Size	Path Coefficients	f^2 Effect Size
External Flexibility			0.142*	0.021^t
Internal Flexibility	0.724***	1.103***	0.325***	0.064*
Uncertainty			0.162**	0.031
Batch Production			0.005	0.000
Discrete Production			0.079^t	0.005
Age			-0.019	0.000
Size			0.042	0.002

Source: Authors

As shown in Table 48, the f^2 value in the proposed model for external flexibility on performance was 0.021. Thus, the effect size of internal flexibility on performance is weak since is over to the 0.02 limit (Chin, 1998; Leal-Rodríguez et al., 2014). In addition, the effect size of internal flexibility on external flexibility is highly significant and large, well above the 0.35 level. These results provide **additional support for hypothesis 5** where internal flexibility has a significant and large effect on external flexibility. In addition, **hypothesis 4 is supported**, as external flexibility size effect on performance is significant but small. These results provide empirical support to the significant relationship between the internal flexibility and performance. More importantly, the highly significant and large effect of internal flexibility on external flexibility provides support to third premise of the strategic perspective of manufacturing flexibility.

5.6.3.4 Mediation analysis

One important consideration in this study is to assess the mediation effect of external flexibility on the relationship between internal flexibility and performance. For doing this, two different methods were used, Baron and Kenny´s (1986) four steps for evaluating mediation, and Preacher and Hayes´s (2008) indirect effects and bootstrapping significance.

In the first method, the first step refers to assess the direct effect, which should be significant if the mediator is not included in the model (step (a) in Table 49). Such significance was assessed while individually evaluating the internal flexibility model in section 5.6.1.4. The second and third steps refer to include the mediator variable in the model and assess the significance of the indirect effects. In other words, the path coefficients from internal flexibility to external flexibility, and from external flexibility to performance must be significant. This significance requirement was also met while evaluating the manufacturing flexibility model in section 5.6.2.4. And the fourth step refers to including a direct link between the initial and the outcome variable, where this path should be non-significant. According to Baron and Kenny (1986), if all conditions are met then there is a full mediation effect, but if the first three steps are met but not the fourth, then a partial mediation is indicated.

Table 49. Analysis for testing mediation proposed by Baron and Kenney (1986)

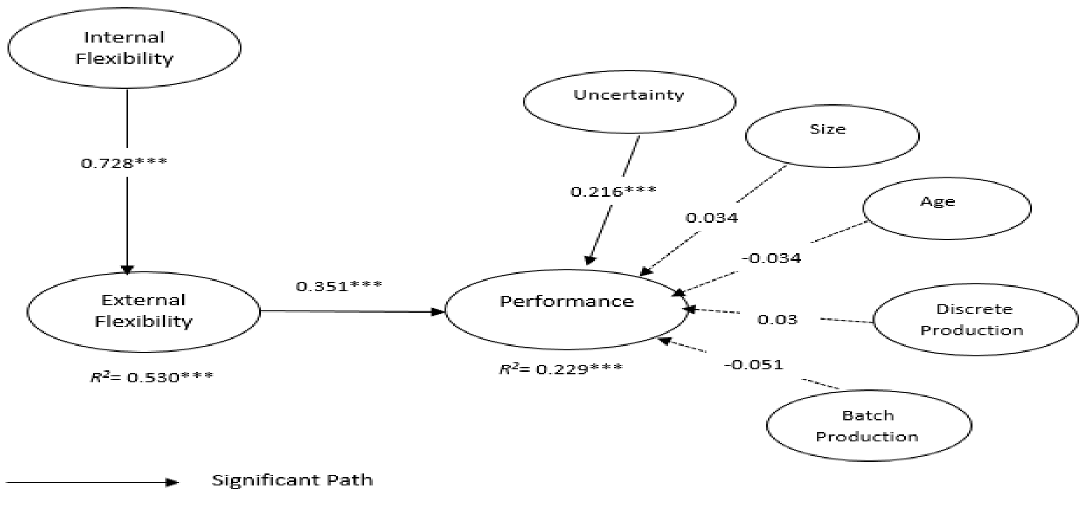
Paths	Coefficient
Step (a)	
(a.1) Internal Flexibility→Performance	0.451***
(a.2) R^2Internal Flexibility→Performance	0.28***
Step (b)	
(b.1) Internal Flexibility→External Flexibility	0.731***
(b.2) R^2Internal Flexibility→External Flexibility	0.535***
Step (c)	
(c.1) Internal Flexibility→External Flexibility	0.728***
(c.2) R^2Internal Flexibility→External Flexibility	0.530***
(c.3)External Flexibility →Performance	0.351***
(c.4) R^2 External Flexibility →Performance	0.229***
Step (d)	
(d.1) Internal Flexibility→Performance	0.325***
(d.2) Internal Flexibility→External Flexibility	0.724***
(d.3) R^2Internal Flexibility→External Flexibility	0.524***
(d.4) External Flexibility→Performance	0.142*
(d.5) R^2 External Flexibility→Performance	0.272***
f^2 = (R^2 partial mediation – R^2 full mediation)/(1 – R^2 partial mediation)	0.059
F (3, 266)	15.4737
p value for the pseudo F statistic (3,266)	0.000

^{t} p<0.10; * p<0.05; ** p<0.01; *** p<0.001 (one tailed tests).

According to the results in Table 49, the first three steps are fulfilled, since all paths are significant. However, in the fourth step a significant path is also present indicating a partial mediation effect. In addition, the full mediation model was compared to the partial mediation model (Benitez-Amado & Walczuch, 2012; Rai et al., 2006). The results of the path analysis for the full mediation model are shown in Figure 14, and the results for the mediated model are shown in Figure 15. The R^2 for organisational performance in the partially mediated model was 0.272, while 0.229 in the fully mediated model. The f^2 statistic is based on the difference in R^2 between the two models, and then used to obtain the pseudo F statistic (Rai et al., 2006). The results show the f^2 was 0.059 and the pseudo F (3, 266) statistic was 15.4737, which was significant with a p-value of 0.000. These results show that the additional variance explained from the path internal flexibility to performance does significantly add to the variance explained in the dependent variable. These results provide **partial support to hypothesis 5**, where the external flexibility partially mediates the link between the internal flexibility and performance.

The second method to measure and corroborate the partial mediation effect is the one defined by Preacher and Hayes (2008), calculating the indirect effect of the mediator and its level of significance. From Table 49, the effect of internal flexibility on external flexibility is known (d.2), as well as of external flexibility on performance (d.4); therefore, the indirect effect is the product of these two path coefficients 0.724 * 0.142 = 0.1028.

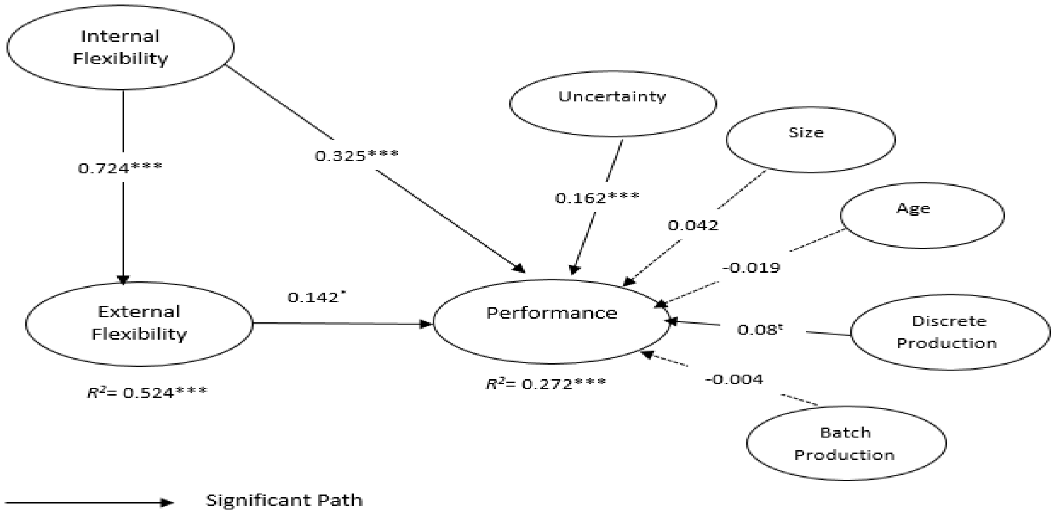
Figure 14. Results of the path analysis for the full mediation research model



Source: Authors

In order to assess the strength of the mediation effect of external flexibility on the relationship of internal flexibility and performance the *Variance Accounted Factor (VAF)* was assessed. The VAF determines the extent to which the variance of the dependent variable is directly explained by the independent variable and how much of the target construct variance is explained by the indirect relationship via the mediator variable (Hair et al., 2014).

Figure 15. Results of the path analysis for the partial mediation research model



Source: Authors

Table 49 shows the direct effect of internal flexibility on performance is 0.325 (d.1, whereas, the indirect effect via external flexibility is 0.1048). Thus, the total effect had a value of 0.325 + 0.1028 = 0.4278. The VAF equaled the indirect effect divided by the total effect 0.1028 / 0.4278 = 0.2403. As a result, it can be concluded that 24.03 percent of the effect of internal flexibility on performance is explained via the mediator external flexibility. Since the VAF is larger than 20 percent but smaller than 80 percent, this situation is characterized as a partial mediation, which confirms the results of the first method using Baron and Kenney´s (1986) approach. Hence, providing **partial support to hypothesis 5**. Table 50 shows the results of the hypotheses in this research study.

Table 50. Results of the hypotheses

Hypothesis	Relationship	Results
H1	Internal flexibility is a second order construct composed of six individual flexibility types, namely labour, material, machine, quality, routing and programme.	Supported
H2	External flexibility is a second order construct composed of five individual flexibility types, namely volume, mix, new product, modification and delivery.	Partiallly Supported
H3	Internal flexibility has a positive effect on performance.	Supported
H4	External flexibility has a positive effect on performance	Supported
H5	External flexibility mediates the relationship between internal flexibility and performance	Partiallly Supported

Source: Authors

CONCLUSIONS

In the current competitive environment, the capacity of firms to respond to the demands of the market has become critical to guaranteeing firm survival. The recognition of this reality, both in the academic as well as the professional area, is at the origin of this doctoral thesis. The objective of the thesis is to analyse the impact of the operational responsiveness of organisations, manifested through manufacturing flexibility, on firm performance in a broad sense.

In order to attain this objective, during the evolution of this doctoral thesis a series of steps were taken which promise ample opportunities for the development of the operations field, in general, and that of manufacturing flexibility, in particular. The objective of this last chapter is, thus, to state the principal conclusions of the work carried out, as well as the implications for research, upper management and organisational strategy.

In the first place, and in order to deeply understand the line of research on the relationship between *the operational responsiveness* of an organisation and *performance*, a systematic literature review of the manufacturing flexibility field was carried out employing bibliometric techniques (Chapter 1). In more specific terms, both activity indicators as well as first and second generation relation indicators were used. The utilisation of these tools constituted a methodological innovation which reduced the level of subjectivity as opposed to more traditional review processes. It also provided valuable methods and indicators which make it possible to describe the current structure of the field and to know, in turn, which are the most current lines of research, thus contributing to the development of the field. This review constitutes the first relevant contribution of this thesis to the previous literature in that the review papers on the structure and evolution of the field identified were scarce and lacked a systematic review process.

Analysing the content of the various research clusters resulting from the bibliometric analysis revealed the existence of a field of research in development and in need of more research into areas identified as emergent. In more concrete terms, the analysis of the works classified within the cluster of emergent topics revealed the need to study the relationship between manufacturing flexibility and performance from a strategic and global perspective, employing fully accepted theoretical frameworks and considering how the possible connections between the various flexibility types could affect this relationship.

Having identified both the need to analyse the flexibility – performance relationship from a strategic perspective and the key literature involved, the careful literature review was undertaken. This review provided evidence of the existence of a significant conceptual problem which required clarification prior to continuing with the research. It was found that even though there is consensus in the academic literature in terms of defining manufacturing flexibility as a complex and multidimensional concept, more than 50 distinct terms existed to allude to the various flexibility types which make up this construct. Additionally, these various terms had been used interchangeably, bringing about widespread confusion and ambiguity in terminology which resulted in a poor definition of the construct.

Given this situation, in a second step this doctoral thesis undertook a process of conceptual systematisation concerning the diversity of names and definitions of flexibility types which have been proposed in the academic literature (Chapter 2). This systematisation process constitutes a first attempt at developing a standardised taxonomy of terms and definitions of the flexibility types that make up the manufacturing flexibility construct. This represents a second important contribution of this thesis to the previous literature.

The systematisation process described in Chapter 2 made it possible to clarify the terminology associated with the various aspects that make up the construct as well as to identify the existence of two distinct theoretical perspectives which have coexisted over time (hierarchical perspective and strategic perspective). The main difference between these two approaches revolves around the criterion utilised to classify the various flexibility types. While the hierarchical perspective focuses on an internal view of the organisation, the strategic perspective bases the classification on the possibility (or lack of) to perceive the effects of flexibility by the external customer.

The analysis of the differences and similarities between both theoretical perspectives made it possible to conclude that the level of consensus between the two is greater than initially expected, and even that these two perspectives could end up joining together in the future into one framework. Notwithstanding this, and considering the suggestion that came out of the literature review carried out in Chapter 1 related to emergent topics in the field, in the thesis it was decided to adopt the strategic perspective as the theoretical framework of reference. The literature analysis employing this perspective made it possible to conclude that the manufacturing flexibility construct is a multidimensional concept made up of 11 individual flexibility types - *delivery, labour, volume, machine, material, programme, mix, modification, new product, routing* and *quality*-.

A second problem directly related with the abovementioned conceptual ambiguity which has traditionally existed for the manufacturing flexibility construct is that relating to its operationalisation. This operationalisation is limited to the existence of partial and incomplete scales in the empirical studies identified in the previous literature, which highlights a lack of consensus when it comes to identifying the number of elements necessary to measure each individual flexibility type. Due to this situation, in Chapter 3 it was decided to move forward with the development of generalisable, homogeneous and simplified scales of the construct which could be applied in a consistent way in future studies, and thus complementing the conceptual systematisation carried out in Chapter 2. This constitutes a third important contribution of this thesis to the previous literature.

The systematisation process performed to move forward with the design of scales to measure manufacturing flexibility resulted in the identification of 4 possible elements to measure the scope of each individual flexibility type through multi-item scales: 1) *range-number*, which measures the number of options available, 2) *range-*

heterogeneity, which measures the degree of difference between the various options, 3) *mobility,* which measures the impact in terms of cost or time, and 4) *uniformity,* which measures the impact in terms of quality and efficiency. The operational discussion based on four criteria deals with the broadest and most disaggregated measurement proposal possible from among the three proposals which have received the most attention in the academic literature. A review of the different scales used in the literature made it possible to identify those items which best define each element, as well as to establish a clear pattern by which to develop proprietary scales in those cases in which there was not sufficient previous literature available. All this led to a proposal which establishes solidly based measurement scales for the 11 individual flexibility types which make up the construct.

The results obtained during the testing of the models provided empirical support for the partial validation of the scales proposed in Chapter 3. The results supported the proposal to measure the scope of each flexibility type through three elements – *range, uniformity* and *mobility* – initially suggested by Upton (1995) instead of the later disaggregation into four elements initially proposed by Koste and Malhotra (1999) – *range number, range heterogeneity, mobility* and *uniformity*. The only two flexibility types in which this three element scale is not validated are the flexibility types *programme* and *delivery*. Both have been operationalised on a small number of occasions – two (Jayakumar, 1984; Arias-Aranda et al., 2011) and three (Slack, 1988; Fantazy et al., 2009; Chen et al., 2009) respectively – and the items employed were not only small in number but also heterogeneous, which could have had an influence over the results obtained. Nevertheless, the validation of the *programme* scales provides partial support for the previous scales found in the literature (Jayakumar, 1984 and Arias-Aranda et al., 2011). In more specific terms, the element *mobility* is confirmed for the measurement of the scope of this flexibility type, even though the element *uniformity* is substituted by the element range employed in previous studies. In the case of the flexibility type *delivery*, the element which disappears from the validation is *uniformity*. This result precisely confirms the scale developed in the previous study of Fantazy et al., (2009).

As an alternative to resolve the ambiguity relating to the conceptualisation and operationalisation of the manufacturing flexibility construct had been proposed, and for the purpose of fulfilling the main objective of the thesis, the next step was the development of a proposed model to explain the relationships between the various flexibility types identified and their effects on firm performance (Chapter 4). The proposal and later empirical validation of this model constitutes the last important contribution of this doctoral thesis to the previous literature. In the first place, this can be stated because the proposal is based on a solid theoretical framework and a systematic and complete conceptualisation and operationalisation of the construct, which constitutes an important difference with respect to the majority of the previous empirical studies. In the second place, this is so because this contribution to the validation of the theoretical framework employs parsimonious methodologies which permit the creation of multi-dimensional constructs, as well as the analysis of the relationships that exist between both flexibility levels. This last aspect has hardly been addressed in the literature to date.

The model proposed is based on the theoretical premises of the strategic perspective (Urtasun-Alonso et al., 2014; Jain et al., 2013; Bernardes & Hanna, 2009; Buzacott & Mandelbaum, 2008; Oke, 2005), which are:

1) The existence of two flexibility levels; an external one (perceived by the consumer) and an internal one (perceived with difficulty by the consumer).
2) Both levels have a direct impact on the performance of the organization,
3) There is a relationship between both levels such that the internal level is a determining factor on the development of the external level.

The integrated model proposed in this thesis is composed of 5 hypotheses and has been validated in two stages (Chapter 5). The first stage involves empirically validating the first two theoretical premises. In order to treat each one of the flexibility levels independently it is necessary to turn to the creation of multidimensional or second order constructs which are the result of the combination of the individual flexibility types classified within each level. The validation of the model was carried out through the use of two partial models (one at the internal level and the other at the external level). The first model validates the consideration of internal flexibility as a second order construct (Hypothesis 1) as well as its direct impact on performance (Hypothesis 3). Analogously, the second model validates the consideration of external flexibility as a second order construct (Hypothesis 2) as well as its direct impact on performance (Hypothesis 4). In the second stage, an effort is made to validate the third premise (Hypothesis 5), once again through the use of second order constructs. To do so, an analysis is carried out as to whether the internal flexibility level is a determining factor on the development of the external level, as well as its impact on performance through an integrated model. From an empirical point of view, while in the literature one could identify various works which could be considered antecedents or exponents of the treatment of flexibility as a multi-dimensional construct, an analysis of these works shows that the theory was not transferred successfully to practice (De Treville et al., 2007). Therefore, more complete and sophisticated analyses were required to test the premises of this theoretical framework.

For the validation and empirical testing of these models, the results of a survey which collected information from a sample of 266 Spanish firms from sectors SIC 34 to 38 were employed. With reference to the methodology chosen, Partial Least Squares Structural Equation Modelling (PLS-SEM) is beginning to be frequently used in this field (Kim et al, 2013; Malhotra & Mackelprang, 2012) given the multidimensional character of the manufacturing flexibility concept. In more specific terms, there are two main reasons to use PLS in this study. In the first place, this is because it is an approach which can be used to specify the relationships between constructs, as well as to measure them (Wold, 1989) without requiring an assumption about the distribution of the data (Haenlein & Kaplan, 2004). In the second place, PLS is less restrictive with respect to sample size with unbiased estimates (Falk & Miller, 1992) at the same time that it permits the validation of formative constructs. The constructs proposed in this model can be identified as Type II in agreement with Jarvis et al., (2003), reflective at first order level and formative at second order level. The use of these types of multidimensional constructs provides parsimonious models, with a certain facility to understand and analyse complex constructs such as manufacturing flexibility.

Having described the proposed models and the methodology used to test them, the thesis continues by presenting a discussion on the results and implications of the empirical validation of each of the hypotheses formulated:

The validation of hypotheses 1 and 2 constitutes a first attempt to provide empirical support for the first premise of the strategic theoretical approach. More specifically:

Hypothesis 1 proposed, on the basis of a clear theoretical foundation, that internal flexibility could be operationalised as a second order construct made up of 6 individual flexibility types – *labour, machine, material, quality, programme* and *routing*-. In agreement with the results obtained, these elements have demonstrated to be significant in the formulation of this second order construct, confirming the theory on the possibility to create an internal multi-dimensional construct. This also extends the initial results obtained by Zhang et al., (2003) who empirically validated an internal multi-dimensional construct made up of 4 individual flexibility types – *labour, machine, material* and *routing*-.

Hypothesis 2 postulated that external flexibility could be operationalised as a second order construct made up of 5 individual flexibility types – *volume, new product, modification, mix* and *delivery*. The results obtained provided partial validity for this hypothesis since the flexibility type *modification* had to be eliminated from the construct because it presented discriminant validity problems with the flexibility types *new product* and *mix*. This result made it clear that the flexibility construct *modification* does not appear to draw on information from one unique phenomenon but rather measures aspects which had been present in other constructs of the model.

This empirically confirms some theoretical antecedents which had suggested that the distinction between the flexibility types *modification* and *new product* or *mix* is not that easy to make in practice (Dixon, 1992; Das, 2001). Some authors have established that in many cases the incorporation of new products consists in modifying the functionalities and characteristics of existing products (Dixon, 1992) and that, therefore, the introduction of small design variations could be considered manifestations of the skill the organisation possesses to introduce new products or a mix of products rapidly (Suarez et al., 1996; Das, 2001). Perhaps an approach to make a clear distinction between these flexibility types related with the product involves the establishment of a clear temporal horizon. In this way, one could analyse the frequency with which such changes are made, or even determine the level and effort that such changes represent (Malhotra & Mackelprang, 2012) such that the scales measure phenomena considered unique.

The results obtained, therefore, made it possible to empirically validate that external flexibility could be operationalised as a second order multi-dimensional construct made up of 4 individual flexibility types – *volume, new product, mix* and *delivery*-. This is a result which is in line with previous studies by Slack (1988) and Chang (2012) in relation with the nature and composition of the construct, on one hand, at the same time that it contributes to increase the empirical evidence that makes it possible to confirm the existence of two independent levels of flexibility, on the other.

In the second place, hypotheses 3 and 4 sought to provide empirical validity for the second premise of the strategic approach which suggested a direct and positive impact of each flexibility block on performance.

Hypothesis 3 postulates that internal flexibility generates a direct and significant impact on the performance of the organisation. The results obtained in the validation of the model confirm the acceptance of this hypothesis with a coefficient of 0.451, highly significant ($p<0.001$) and an R^2 of 0.28. This result indicates that the implementation of flexibility practices at the internal level, although not directly perceived by the customer, have a highly positive and significant effect on the performance of organisations. Until now, the impact that internal flexibility has on performance has not been analysed in a global manner. Rather, the empirical evidence available has been limited to testing the direct impact generated by some specific flexibility types (Chan et al., 2006; Parker & Wirth, 1999; Gupta & Somers, 1996 are examples of this). This study provides, therefore, empirical evidence for a relationship absent from the literature until now, showing that the implementation of internal flexibility practices globally considered contributes to an increase in the efficiency of the production process, improves the workflow, reduces costs, and consequently directly and positively affects performance.

Hypothesis 4 proposes that external flexibility has a direct and significant impact on the performance of the organisation. The results obtained from the analysis empirically validate this hypothesis with a coefficient of 0.380, highly significant ($p<0.000$) and an R^2 of 0.246. This result is in line with Zhang et al., (2003), Slack (1988) and Chang (2012) who also showed that the implementation of flexibility practices perceived externally (more specifically, to have the capacity to vary the quantity, delivery time, or products offered) aids in increasing consumer satisfaction due to responding rapidly and efficiently to customer demands. This generates a positive impact on the performance of the organisation and the competitiveness of the company.

The results obtained with respect to the direct and positive impact of each flexibility level on performance contribute to increase the empirical evidence available, which, until now has been mainly concentrated around an analysis of the impact generated by the external flexibility level. Additionally, these results make it possible to conclude, in the first place, that the global implementation of the internal and / or external construct generates a positive result which compensates for, in some way, the possible negative or non-significant effects previously identified in the literature for some specific flexibility practices – see the empirical evidence available for the flexibility type *machine* (Arias-Aranda, 2003; Chan et al., 2006) or *new product* (Das, 2001; Gupta & Somers, 1996) for example. That is to say, it appears that there could be a synergistic effect between the individual flexibility types that make up each construct that contribute to generate a positive impact on performance. An exploration of this aspect requires additional research in the future.

In the second place, based on the results obtained for each individual model, the internal flexibility construct (path 0.451 and R^2 of 0.28) generates a greater impact on performance than the external flexibility construct (path 0.380 and R^2 of 0.246). These results take on special relevance since they go in opposition to the theoretical arguments which have assumed that the external flexibility level is the one which contributes to a greater extent to generate a positive effect on performance since this level makes it possible to strategically position the firm in the market by incentivising product development strategies which are more easily perceived outside the firm, and which generate greater value for consumers (Chu et al., 2011; Alolayyan et al., 2011; Buzacott & Mandelbaum, 2008). Future research is required to analyse this in greater detail.

Finally, the validation of Hypothesis 5 seeks to give empirical support to the third premise of the strategic approach by contributing a global view of the effect that the implementation of flexibility practices has on the performance of the organisation. In more specific terms, Hypothesis 5 proposes that external flexibility constitutes a mediating variable in the relationship that exists between internal flexibility and performance, thus determining the importance of the connection between both flexibility levels.

The results obtained from the analysis provide empirical validity to the hypothesis, confirming the influence of both flexibility types on organisational performance deriving from a partial mediation, as well as special relevance of the internal level for the performance improvement of an organisation. The results obtained in the validation of the integrated model revealed a positive and significant relationship of internal flexibility on external flexibility (coefficient 0.724 – $p<0.000$) confirming that the former supports and permits the development of the latter. The result of the model (R^2 0.272), moreover, endorses the fact that the effect of the mediation is partial, confirming a direct effect of internal flexibility on performance with a coefficient of 0.325, highly significant in the integrated model. This signifies that only a part of the effect (in this case 24.03%) generated by internal flexibility can be explained, or appears to be mediated by external flexibility. In this way, confirmation is received once again that, contrary to that suggested by theory, the internal level of flexibility is the one which really contributes to improve organisational results to a greater degree, at the same time that it constitutes an antecedent for the development of the external level.

In conclusion, the results obtained amply justify the conceptual and operational systematisation of the construct. They also provide empirical support for the premises of the theoretical framework of the strategic perspective by uncovering some extremely relevant aspects which have been avoided until now such as the direct effect of internal flexibility on external flexibility and performance. Specifically, the proposal and testing of the model presented in this doctoral thesis constitutes a first attempt, until now absent from the literature, to validate the strategic theoretical approach on the basis of a conceptual and operational systematisation of the construct. The results obtained afford greater understanding of the operationalisation of the construct through three elements, as well as the relationship that exists between the various flexibility types, at the same time that they make it possible to identify those elements that affect to a greater degree achieving superior productivity in the organisation.

Implications

The results obtained in this doctoral thesis have relevant implications for future research, as well as for upper management and organisational strategy.

In the first place, this doctoral thesis has important implications for those future researchers who wish to continue dealing with this topic since research themes worth exploring been identified, based on objective tools. Also, the conceptual and operational systematisation of the manufacturing flexibility construct could constitute a frame of reference for future studies making possible the comparison of results obtained and fomenting discussion.

In more specific terms, this doctoral thesis has made it possible to make progress on the proposal and validation of a clear taxonomy, consistent with the previous literature, which could unify the conceptual and operational treatment of flexibility through the use of flexibility types that are individual in character. The thesis has enabled the identification of the individual flexibility types which make up the construct, thus reducing the terminological ambiguity that exists in the field. Likewise, its operationalisation has been proposed and validated through three elements – range, uniformity and mobility – in all cases except for two. These two are the flexibility types *programme* and *delivery*, which appear to elude the pattern identified, thus requiring further research in the future.

On the other hand, the present study has empirically validated one of the two theoretical frameworks identified based on a complete conceptual and operational systematisation of the construct. In more specific terms, a deep analysis of the literature for the proposal and validation of the strategic theoretical approach made it possible to obtain a global view of the effect of the implementation of flexible practices on the performance of the organisation. The validation of the three premises suggested by this theoretical approach makes it possible to confirm the holistic development of manufacturing flexibility as well as the existing relationships between both flexibility levels and their effect on performance.

The analysis carried out confirms that the implementation of flexible practices in organisations turns out to be a key tool to increase the capacity of organisations to survive in global and competitive settings such as today's. This is due to the fact that these practices have a positive effect on the productivity of an organisation. However, researchers have traditionally emphasised the analysis of the impact of flexible responses that are external in nature instead of internal ones. They justified this fact by arguing that these are the flexible practices which can be perceived by consumers outside of the organisation (for example, adapting the quantity of product required, the date of delivery, and the capacity to increase the range of products) which make it possible to increase the perceived value of the firm, positioning it strategically in the current competitive environment. However, the results obtained in the present doctoral thesis suggest that in order to attain the type of strategic flexibility perceived by the consumer it is necessary that firms have the capacity to manage, in a flexible manner, various resources on a functional and organisational level (Martinez Sanchez et al., 2007; Dreyer & Gronhaug, 2004). Additionally, it is really the flexible management of these resources that are internal to the organisation to which more attention should be paid, and which opens a new line of research for future studies. This research is needed because the internal flexibility level has a significant, positive and direct impact on performance to a greater degree than flexibility practices that are external in character. And, it is needed because the internal flexibility level affects in a highly significant manner the development of the external flexibility level, consequently increasing the positive impact on performance.

In light of these results, this study not only opens a new line of research in the field by detecting the relevance of internal flexibility practices but also provides important implications for managers and for the definition of organisational strategy. Managers must plan, organise, coordinate and manage manufacturing flexibility both in external as well as internal terms since it is the latter (internal capacity to re-programme manufacturing orders, materials, work, etc.) that which provides a greater effect on performance. It is internal flexibility which makes it possible to plan for demand, coordinate distribution activities and produce rapid external responses without penalties in costs or significant delays.

Limitations

The results require qualification given that this study is not exempt from limitations. The first limitation is that it is a cross-section study and the information on the latent variables is based on subjective perceptions. Although subjective measures have demonstrated to be valid evaluations when objective data is not available, it is recommended to obtain complementary objective data and contrast it with the subjective measures to check the results.

Secondly, a sample of firms limited to manufacturing sectors SIC 34 – 38 was used to validate the scales and to check the models. While the size of the sample is reasonable and in line with previous works on manufacturing flexibility, one could consider increasing the sample size to improve the validity of the research. Furthermore, the results depend on the context, and as such the possibility to extend the analysis to other sectors or types of firms should be considered.

Finally, it should be taken into account that the proposal for scales related to products did not allow the establishment of a clear distinction between the three types of flexibility that allude to this concept. Thus, it would be necessary to continue working on the form of distinguishing clearly between the flexibilities of *modification, new product* and *mix*.

Future lines of research

This study established the validity of the utilisation of two multi-dimensional constructs to empirically validate the strategic approach of manufacturing flexibility in organisations and its impact on organisational performance.

Organisations, as complex systems, present a wide range of variables which affect operations. Consequently, it could be interesting to evaluate other elements which could generate a competitive advantage, and evaluate the corresponding relationships with manufacturing flexibility at the internal and external levels (for example, the implementation of advanced manufacturing systems, organisational culture or the installation of information systems).

As discussed previously, this study was carried out with a large sample of Spanish firms from SIC sectors 34 – 38. In view of this, the evaluation of different samples and other types of firms is believed necessary. It would also be interesting to replicate this study with multi-group analysis to examine more deeply if the results differ between different sectors or firm types. This study considered control variables such as the dynamic environment, age, type of production process and size, but other variables such as strategy or firm ownership structure, including family relationships in upper management, should be evaluated.

Other considerations which might be of interest for future research are:

1) Check the formative constructs proposed in this study in other firm samples in other contexts, as well as replicate the validation of the model in other sectors for the purpose of confirming the results obtained in this doctoral thesis.
2) Continue to make progress on the operationalisation of the construct, especially in the cases of the flexibility types *programme* and *delivery*, as well as to propose new scales for the flexibility type *modification* which make it possible to establish a clear difference with the scales for the flexibility types *new product* or *mix*.
3) Empirically validate the hierarchical theoretical approach by engaging in a discussion of the results obtained in this study for the purpose of making progress on the integration of both approaches in one unique framework.
4) Explore the existing relationships between the flexibility types which make up each level of analysis for the purpose of determining whether complementary or substitutable relationships exist between them, and evaluating their impact on performance.

5) Address in a more detailed manner the different approaches to the environment that determine different degrees of dynamism in order to examine under what conditions some flexibility types obtain better results.
6) Continue advancing in the study of the integration of manufacturing flexibility with supply chain flexibility, and analyse how manufacturing flexibility practices align upstream and downstream in the supply chain of an organisation.

In conclusion, this work offers the bases on which to carry out future research into the impact of the operational responsiveness of an organisation, measured as manufacturing flexibility, on performance.

CONCLUSIONES

En el actual entorno competitivo, la capacidad de respuesta de las empresas a las exigencias del mercado se ha convertido en una herramienta clave para garantizar su supervivencia. El reconocimiento de esta realidad tanto en el ámbito académico como profesional está en el origen de la presente tesis doctoral, cuyo objetivo es analizar el impacto que la capacidad de respuesta del área de operaciones de las organizaciones, manifestada a través de la flexibilidad de manufactura, genera sobre la performance empresarial en un sentido amplio.

Para cumplir con el objetivo planteado, durante el desarrollo de esta tesis doctoral se han abordado una serie de pasos que exhiben una amplia área de oportunidad para el desarrollo del campo de operaciones en general y el de flexibilidad de manufactura en particular. El objetivo de este último capítulo es, por tanto, exponer las principales conclusiones del trabajo realizado, así como las implicaciones del mismo para la investigación, la alta dirección y la estrategia de las organizaciones.

En primer lugar, y a fin de conocer en profundidad la línea de investigación que desarrolla el tema sobre la relación existente entre *la capacidad de respuesta del área de operaciones* de una organización y su impacto en la *performance,* se realizó una revisión sistemática de la literatura académica del campo de flexibilidad de manufactura, utilizando técnicas bibliométricas (Capítulo 1). De una forma más específica se utilizaron tanto indicadores de actividad como indicadores de relación (de primera y segunda generación). Su aplicación, además de constituir una innovación metodológica que redujo el grado de componente subjetivo frente a los procesos más tradicionales de revisión, aportó valiosos métodos e indicadores que permitieron describir la estructura del campo en la actualidad y conocer así cuáles eran las líneas más actuales de investigación susceptibles de ser investigadas, contribuyendo de esta forma al desarrollo del campo. Esta revisión constituyó una primera aportación relevante de esta tesis a la literatura previa, por cuanto los trabajos de revisión identificados acerca de la estructura y evolución del campo eran escasos y carecían de un proceso sistemático de revisión.

El análisis de contenido de los diferentes clusters de investigación resultantes del análisis bibliométrico realizado reveló la existencia de un campo de investigación en desarrollo y requerido de más investigación en torno a unas áreas identificadas como emergentes. Más concretamente, el análisis de los trabajos clasificados dentro del cluster de temáticas emergentes reveló la necesidad de abordar el estudio de la relación entre flexibilidad operacional y performance desde una perspectiva estratégica y global, empleando marcos teóricos plenamente aceptados y considerando cómo las posibles relaciones existentes entre los diferentes tipos de flexibilidad podían afectar a esta relación.

Identificada la necesidad de análisis de la relación flexibilidad-performance desde una óptica estratégica y la literatura clave para realizarlo, se procedió a la revisión en profundidad de la misma. Esto evidenció la existencia de una importante problemática de naturaleza conceptual que necesitaba ser clarificada antes de continuar avanzando en la investigación. De una forma más específica se detectó que, si bien existe un consenso en la literatura académica a la hora de definir la flexibilidad de manufactura como un concepto complejo y multidimensional, existían más de 50 términos distintos para aludir a los diferentes tipos de flexibilidad que componen dicho constructo. Adicionalmente, estos diferentes términos habían sido utilizados de forma intercambiable, provocando una amplia confusión y ambigüedad terminológica que redundaba finalmente en una mala definición del constructo.

Dada esta situación, en un segundo paso la presente tesis doctoral abordó un proceso de sistematización conceptual en torno a la variedad de nombres y definiciones de flexibilidad que se habían propuesto en la literatura académica (Capítulo 2). El mismo constituye un primer intento para desarrollar una taxonomía estandarizada de términos y definiciones de los tipos de flexibilidad que componen el constructo flexibilidad de manufactura, configurándose de esta forma como una segunda aportación relevante que realiza esta tesis a la literatura previa.

El proceso de sistematización abordado en el capítulo 2 permitió clarificar la terminología asociada a los diferentes aspectos que integran el constructo, así como identificar la existencia de dos perspectivas teóricas diferentes que habían coexistido en el tiempo para el desarrollo de su conceptualización (perspectiva jerárquica y perspectiva estratégica). De una forma más específica la principal diferencia entre ambas corrientes se halla en torno al criterio utilizado para la clasificación de los diferentes tipos de flexibilidad. Así, mientras la perspectiva jerárquica se centra en una óptica interna a la organización, la perspectiva estratégica basa la clasificación en términos de la posibilidad o no de percepción de los efectos de la flexibilidad por parte del cliente externo.

El análisis de las diferencias y similitudes entre ambas corrientes teóricas permitió concluir que el grado de consenso entre las mismas es mayor a lo inicialmente esperado, e incluso que ambas perspectivas podrían llegar a integrarse en el futuro en un único marco. No obstante lo anterior, y considerando la sugerencia que surge a partir de la revisión de literatura realizada en el Capítulo 1 en lo relativo a temáticas emergentes en el campo, en la tesis se decidió adoptar la perspectiva estratégica como marco teórico de referencia. El análisis de la literatura realizado bajo esta perspectiva permitió concluir que el constructo de flexibilidad de manufactura es un concepto multidimensional integrado por 11 tipos o dimensiones individuales de flexibilidad -*delivery, labour, volume, machine, material, programme, mix, modification, new product, routing* and *quality*-.

Una segunda problemática directamente relacionada con la mencionada ambigüedad conceptual que tradicionalmente ha existido en torno al constructo flexibilidad de manufactura es la relativa a su operativización. La misma se concreta en la existencia de escalas parciales e incompletas de medición en los estudios empíricos identificados en la literatura previa, lo que pone de relieve una falta de consenso a la hora de identificar el número de elementos necesarios para medir cada tipo de flexibilidad individual. Ante esta situación, en el Capítulo 3 se decidió avanzar en el desarrollo de escalas generalizables, homogéneas y simplificadas del constructo que pudieran ser aplicadas de forma consistente en futuros estudios, complementando de esta forma la sistematización conceptual realizada en el Capítulo 2, lo que constituye una tercera aportación relevante que realiza esta tesis a la literatura previa.

El proceso de sistematización realizado para avanzar en el diseño de escalas de medición de la flexibilidad de manufactura se concretó en la identificación de 4 posibles elementos para medir el alcance de cada tipo de flexibilidad individual a través de escalas multi-item: 1) rango número, que mide el número de opciones disponibles, 2) rango heterogeneidad, que mide el grado de diferencia entre las diferentes opciones, 3) movilidad, que mide el impacto en términos de coste y rapidez o facilidad y 4) uniformidad, que mide el impacto en términos de calidad y eficiencia. La discusión operativa en base a cuatro criterios atiende a la propuesta de medición más amplia y desagregada posible de entre las tres propuestas que mayor atención habían recibido en la literatura académica. La revisión de las diferentes escalas utilizadas en la literatura permitió identificar aquellos ítems que mejor definían cada elemento, así como establecer un patrón claro para desarrollar escalas propias en los casos en los que no se disponía de suficiente literatura previa. Todo ello condujo a una propuesta que establece escalas de medición sólidamente fundamentadas para los 11 tipos de flexibilidad individuales que componen el constructo.

Los resultados obtenidos durante la contrastación de los modelos proporcionaron soporte empírico para la validación parcial de las escalas propuestas en el Capítulo 3. Más concretamente, los resultados mostraron soporte para la propuesta de medición del alcance de cada tipo de flexibilidad a través de tres elementos –rango, uniformidad y movilidad- sugerida inicialmente por Upton (1995) en lugar de su posterior desagregación en cuatro elementos inicialmente propuesta por Koste and Malhotra (1999) –rango número, rango heterogeneidad, movilidad y uniformidad-. Los dos únicos tipos de flexibilidad en los que no se valida una escala con los tres elementos mencionados son las flexibilidades de programa y entrega. Ambos han sido operativizadas en un escaso número de ocasiones -dos (Jayakumar, 1984; Arias-Aranda et al., 2011) y tres (Slack, 1988; Fantazy et al., 2009; Chen et al., 2009) respectivamente- y los ítems empleados no sólo eran escasos sino también heterogéneos, lo que ha podido influir en los resultados obtenidos. No obstante, la validación de las escalas de programa proporciona soporte parcial a las escalas previas existentes en la literatura (Jayakumar, 1984 y Arias-Aranda et al., 2011). De una forma más específica se confirma el elemento movilidad para la medición del alcance de este tipo de flexibilidad, si bien el elemento uniformidad se ve sustituido por el elemento rango empleado en estudios previos. En el caso de la flexibilidad de entrega, el elemento que desaparece de la validación es la uniformidad, resultado que confirma exactamente la escala desarrollada por el estudio previo de Fantazy et al., (2009).

Una vez planteada una alternativa para resolver la ambigüedad en cuanto a la conceptualización y operativización del constructo flexibilidad de manufactura, y a fin de dar cumplimiento al objetivo principal de la tesis, se procedió al desarrollo de una propuesta de modelo explicativo de las relaciones entre los diferentes tipos de flexibilidad identificados y sus efectos sobre la performance empresarial (Capítulo 4). La propuesta y posterior validación empírica de este modelo constituye la última aportación relevante de esta tesis doctoral a la literatura previa. En primer lugar porque la misma se apoya en un marco teórico sólido y una conceptualización y operativización sistematizada y completa del constructo, lo que constituye una importante diferencia con respecto a la mayoría de los estudios empíricos previos. En segundo lugar, porque se contribuye a la validación del marco teórico mediante el empleo de metodologías parsimoniosas que permiten la creación de constructos multidimensionales, así como el análisis de las relaciones existentes entre ambos tipos de flexibilidad, aspecto este último que no había sido prácticamente abordado en la literatura hasta la fecha.

De una forma más específica, el modelo propuesto se fundamenta en las premisas teóricas procedentes de la perspectiva estratégica (Urtasun-Alonso et al., 2014; Jain et al., 2013; Bernardes & Hanna, 2009; Buzacott & Mandelbaum, 2008; Oke, 2005), las cuales son:

1) La existencia de dos niveles de flexibilidad, uno externo (percibido por el consumidor) y otro interno (difícilmente perceptible por el consumidor).
2) Ambos niveles ejercen un impacto directo sobre la performance de la organización y,

3) Se establece una relación entre ambos niveles de tal forma que el nivel interno es un factor determinante para el desarrollo del nivel externo.

El modelo integrador propuesto en esta tesis está compuesto por 5 hipótesis y ha sido validado en dos etapas (Capítulo 5). La primera etapa trata de dar validez empírica a las dos primeras premisas teóricas. En este sentido, para poder tratar cada uno de los niveles de flexibilidad de forma independiente es preciso recurrir a la creación de constructos multidimensionales o de segundo orden que son el resultado de la combinación de los tipos individuales de flexibilidad que se clasifican dentro de cada nivel. Su validación se realizó a través de dos modelos parciales (uno a nivel interno y otro a nivel externo). En este sentido, el primer modelo valida la consideración de la flexibilidad interna como un constructo de segundo orden (hipótesis 1) así como su relación directa con la performance (hipótesis 3). Análogamente el segundo modelo valida la consideración de la flexibilidad externa como un constructo de segundo orden (hipótesis 2) y su efecto directo sobre la performance (hipótesis 4). En la segunda etapa, para tratar de validar la tercera premisa (hipótesis 5), de nuevo a través del uso de constructos de segundo orden, se analiza si el nivel interno de flexibilidad es un factor determinante para el desarrollo del nivel externo, así como su impacto en la performance a través de un modelo integrador. Desde un punto de vista empírico, aunque en la literatura se habían identificado varios trabajos que podían ser considerarse antecedentes, o exponentes, del tratamiento de la flexibilidad como constructo multidimensional, un análisis de los mismos mostraba que la teoría no había sido transferida de forma exitosa a la práctica (De Treville et al., 2007) y que, por tanto, se requerían análisis más completos y sofisticados que permitieran contrastar las premisas contenidas en este marco teórico.

Para la validación y contrastación empírica de estos modelos se emplearon los resultados de una encuesta que recogió información de una muestra de 266 empresas españolas de los sectores SIC 34 a 38. Por lo que se refiere a la metodología elegida ecuaciones estructurales de mínimos cuadrados parciales (PLS-SEM) está empezando a utilizarse con frecuencia en este campo (Kim et al., 2013; Malhotra & Mackelprang, 2012) dado el carácter multidimensional del concepto flexibilidad de manufactura. De una forma más específica hay dos razones principales para utilizar PLS en este estudio. En primer lugar porque se trata de un enfoque que se puede utilizar para especificar tanto las relaciones entre los constructos, así como una medición de los mismos (Wold, 1982) sin exigir una suposición acerca de la distribución de los datos (Haenlein & Kaplan, 2004). En segundo lugar, PLS es menos restrictivo con respecto al tamaño muestral con estimaciones insesgadas (Falk & Miller, 1992) a la vez que permite llevar a cabo la validación de constructos formativos. En este sentido, los constructos propuestos en este modelo se identifican como de Tipo II de acuerdo a Jarvis et al., (2003), reflectivos de primer orden y formativos de segundo orden. El empleo de este tipo de constructos multidimensionales proporciona modelos parsimoniosos, con cierta facilidad para entender y replantear su estudio subsecuente cuando se aborda el análisis de constructos tan complejos como el analizado.

Una vez descrita la propuesta de modelos y la metodología utilizada para su contrastación se presenta a continuación una discusión sobre los resultados e implicaciones de la validación empírica de cada una de las hipótesis formuladas:

En primer lugar, la validación de las hipótesis 1 y 2 constituyen un primer intento para proporcionar soporte empírico a la primera premisa del marco teórico estratégico. Más específicamente:

La hipótesis 1 proponía, sobre la base de una clara fundamentación teórica, que la flexibilidad interna podía ser operativizada como un constructo de segundo orden integrado por 6 tipos individuales de flexibilidad -laboral, máquina, materiales, calidad, programa y rutas-. De acuerdo a los resultados obtenidos, estos elementos han demostrado ser significativos en la formulación de este constructo de segundo orden confirmando la teoría acerca de la posibilidad de crear un constructo multidimensional interno y extendiendo de esta forma los resultados iniciales obtenidos por Zhang et al., (2003) quienes validaron empíricamente un constructo interno integrado por 4 tipos individuales de flexibilidad -laboral, máquina, materiales y rutas-.

La hipótesis 2, por su parte, postulaba que la flexibilidad externa podía ser operativizada como un constructo de segundo orden integrado por 5 tipos individuales de flexibilidad –volumen, nuevo producto, modificación, mix y entrega-.Los resultados obtenidos han proporcionado validez parcial a esta hipótesis puesto que la flexibilidad de modificación tuvo que ser eliminada del constructo al presentar problemas de validez discriminante con las flexibilidades de nuevo producto y mix. Este resultado ha puesto de manifiesto que el constructo flexibilidad de modificación no parece recoger información de un fenómeno único sino que mide aspectos que estaban presentes en otros constructos del modelo confirmando empíricamente algunos antecedentes teóricos que habían sugerido que la distinción entre la flexibilidad de modificación y la flexibilidad de nuevo producto o mix no es tan fácil de realizar en la práctica (Dixon, 1992; Das, 2001). Algunos autores han puesto de manifiesto que en muchos casos la incorporación de nuevos productos consiste en modificar las funcionalidades y características de los productos existentes (Dixon, 1992) y que, por tanto, la introducción de pequeñas variaciones en el diseño podían considerarse manifestaciones de la habilidad que posee la organización para introducir nuevos productos o mix de productos de forma rápida (Suarez et al., 1996; Das, 2001). En este sentido, quizá un posible planteamiento para realizar una distinción clara entre estos tipos de flexibilidad relacionados con el producto pasa por el establecimiento de un claro horizonte temporal, analizar la frecuencia con la que se realizan tales cambios o incluso determinar el grado y esfuerzo que dichos cambios supondrían en cada caso (Malhotra & Mackelprang, 2012) a fin de que las escalas de medición midan fenómenos considerados únicos.

Los resultados obtenidos, por tanto, han permitido validar empíricamente que la flexibilidad externa puede ser operativizada como un constructo de segundo orden integrado por 4 tipos de flexibilidad individual –volumen, nuevo producto, mix y flexibilidad de entrega-, un resultado que se encuentra en línea con los estudios previos de Slack (1988) y Chang (2012) en relación con la naturaleza y composición del constructo, por un lado, a la vez que contribuye a ampliar la evidencia empírica que permite confirmar la existencia de dos niveles independientes de flexibilidad, por otro.

En segundo lugar, las hipótesis 3 y 4 pretendían proporcionar validez empírica a la segunda de las premisas del marco estratégico que sugería un impacto directo y positivo de cada bloque de flexibilidad sobre la performance.

Por un lado, la hipótesis 3 postulaba que la flexibilidad interna generaba un impacto directo y significativo sobre la performance de la organización. Los resultados obtenidos en la validación del modelo confirman la aceptación de esta hipótesis con un coeficiente de 0.451 altamente significativo ($p<0.001$) y un R^2 de 0.28. Este resultado indica que la implantación de prácticas de flexibilidad a nivel interno, aunque no son percibidas directamente por el consumidor, ejerce un resultado positivo altamente significativo sobre la performance de las organizaciones. Hasta la fecha, el impacto que ejerce la flexibilidad interna sobre la performance no había sido analizado de forma global, limitándose la evidencia empírica disponible a testar el impacto directo generado por algunos tipos de flexibilidad específicos (Chan et al., 2006; Parker & Wirth, 1999 o Gupta & Somers, 1996 son ejemplo de ello). Este estudio proporciona, por tanto, evidencia empírica a una relación hasta ahora ausente en la literatura, testando que la implantación de prácticas flexibles internas globalmente consideradas contribuye al incremento de la eficiencia del proceso productivo, mejorando el flujo de trabajo, reduciendo costes, y consecuentemente afectando directa y positivamente a la performance.

Por otro lado, la hipótesis 4 proponía que la flexibilidad externa ejercía un impacto directo y significativo sobre la performance de la organización. Los resultados obtenidos tras el análisis validan empíricamente esta hipótesis con un coeficiente de 0.380 altamente significativo ($p<0.000$) y un R^2 de 0.246. Este resultado está en línea con Zhang et al., (2003), Slack (1988) o Chang (2012) quienes también testaron que la implantación de prácticas flexibles percibidas externamente, más concretamente tener la capacidad de variar la cantidad, el plazo de entrega, o los productos ofrecidos por la empresa ayuda a incrementar la satisfacción del consumidor al responder de forma rápida y eficiente a sus demandas, generando así un impacto positivo en la performance de la organización y la competitividad de la empresa.

Los resultados obtenidos con respecto al impacto directo y positivo de cada nivel de flexibilidad sobre la performance contribuyen a ampliar la evidencia empírica disponible hasta la fecha que mayoritariamente se concentraba en torno al análisis del impacto generado por el nivel externo de flexibilidad. Adicionalmente, estos resultados permiten concluir, en primer lugar, que la implantación global del constructo interno y/o externo genera un resultado positivo que compensa de alguna forma los posibles efectos negativos o no significativos previamente identificadas en la literatura para algunas prácticas de flexibilidad en concreto –véase la evidencia empírica disponible para la flexibilidad de máquina (Arias-Aranda, 2003; Chan et al., 2006), o nuevo producto (Das, 2001; Gupta & Somers, 1996) por ejemplo-. Es decir, parece que pudiera existir un efecto sinérgico entre los tipos de flexibilidad individual que componen cada constructo que contribuyen a generar un impacto positivo sobre la performance. La exploración de este aspecto requerirá de una mayor investigación en el futuro.

En segundo lugar, a la luz de los resultados obtenidos por cada modelo individual el constructo de flexibilidad interno (path 0.451 y R^2 de 0.28) genera un impacto superior sobre la performance que el constructo de flexibilidad externo (path 0.380 y R^2 de 0.246). Estos resultados adquieren especial relevancia puesto que van en contraposición a los argumentos teóricos que han supuesto que el nivel externo de flexibilidad es el que contribuye en mayor medida a generar un efecto positivo sobre la performance pues permite posicionar estratégicamente a la empresa en el mercado al incentivar estrategias de desarrollo de productos que son más fácilmente perceptibles en el exterior y generan mayor valor frente a los consumidores (Chu et al., 2011; Alolayyan et al., 2011; Buzacott & Mandelbaum, 2008), y deberán ser analizados en mayor detalle en futuras investigaciones.

Finalmente, la validación de la hipótesis 5 pretende dar soporte empírico a la tercera de las premisas de la corriente estratégica aportando una visión global del efecto que genera la implantación de prácticas flexibles en el rendimiento de la organización. De una forma más específica la hipótesis 5 propone que la flexibilidad externa constituye una variable mediadora en la relación existente entre la flexibilidad interna y la performance determinando así la importancia de la relación entre ambos niveles de flexibilidad.

Los resultados obtenidos tras el análisis proporcionan validez empírica a la hipótesis confirmando la influencia de ambos tipos de flexibilidad sobre el rendimiento organizacional derivado de una mediación parcial, así como la especial relevancia del nivel interno para la mejora del rendimiento de una organización. De una forma más específica, los resultados obtenidos en la validación del modelo integrador pusieron de manifiesto una relación positiva y significativa de la flexibilidad interna sobre la flexibilidad externa (coeficiente de 0.724 –$p<0.000$-) confirmando que la primera da soporte y permite el desarrollo de la segunda. El resultado del modelo (R^2 0.272) además suscribe que el efecto de la mediación es parcial, confirmándose un efecto directo de la flexibilidad interna sobre la performance con un coeficiente de 0.325 altamente significativo en el modelo integrador. Esto significa que sólo una parte del efecto (en este caso 24.03 %) que genera la flexibilidad interna se explica o aparece mediado por la flexibilidad externa. De esta forma se confirma de nuevo que, contrariamente a lo sugerido desde la teoría, es realmente el nivel interno de flexibilidad el que contribuye a mejorar en mayor medida el resultado organizacional, a la vez que constituye un antecedente para el desarrollo del nivel externo.

En conclusión, los resultados obtenidos justifican ampliamente la sistematización conceptual y operativa del constructo, así como proporcionan soporte empírico a las premisas del marco teórico de la perspectiva estratégica, descubriendo algunos aspectos de gran relevancia que habían sido obviados hasta la fecha como el efecto directo de la flexibilidad interna sobre la externa y la performance. De una forma más específica, la propuesta y contrastación del modelo presentado en esta tesis doctoral constituye un primer intento, hasta ahora ausente en la literatura, para aportar validez al marco teórico estratégico sobre la base de una sistematización conceptual y operativa del constructo. Los resultados obtenidos brindan una mayor comprensión de la operativización del mismo a través de tres elementos, así como de la relación existente entre los diferentes tipos de flexibilidad, a la vez que permite señalar aquellos elementos que afectan en mayor medida a conseguir un mejor rendimiento en la organización.

Implicaciones

Los resultados obtenidos en esta tesis doctoral ofrecen implicaciones relevantes para los futuros investigadores, así como para la dirección y la estrategia de las organizaciones.

En primer lugar, la presente tesis doctoral tiene importantes implicaciones para los futuros investigadores que quieran seguir abordando esta temática puesto que, no sólo se han identificado en base a herramientas objetivas las temáticas de investigación susceptibles de ser desarrolladas, sino que la sistematización conceptual y operativa del constructo flexibilidad de manufactura puede constituir un marco de referencia para futuros estudios posibilitando la comparabilidad de los resultados obtenidos y fomentando su discusión.

De una forma más específica, el desarrollo de esta tesis doctoral ha permitido avanzar en la propuesta y validación de una taxonomía clara de forma consistente a la literatura previa que puede unificar el tratamiento conceptual y operativo de la flexibilidad a través del uso de tipos de flexibilidad de carácter individual. En este sentido, el desarrollo de la presente tesis doctoral ha permitido identificar los tipos individuales de flexibilidad que conforman el constructo reduciendo la ambigüedad terminológica existente en el campo. De igual forma se ha propuesto y validado su operativización a través de tres elementos –rango, uniformidad y movilidad- en todos los casos salvo en dos excepciones –flexibilidad de programa y entrega- las cuales parecen escapar a la pauta identificada, requiriendo una mayor investigación en el futuro.

Por otro lado, el presente estudio ha proporcionado validez empírica a uno de los dos marcos teóricos identificados sobre la base de una sistematización conceptual y operativa completa del constructo. De una forma más específica, el análisis en profundidad de la literatura para la propuesta y validación del marco teórico estratégico ha permitido obtener una visión global del efecto generado por la implantación de las prácticas flexibles en la performance de la organización. La validación de las tres premisas sugeridas por este marco teórico permite confirmar el desarrollo holístico de la flexibilidad de manufactura así como las relaciones existentes entre ambos niveles de flexibilidad y su efecto en la performance.

En este sentido el análisis efectuado confirma que la implantación de prácticas flexibles en las organizaciones resulta una herramienta clave para incrementar la capacidad de supervivencia de las organizaciones en entornos globales y competitivos como el actual puesto que afecta de forma positiva al rendimiento de la organización. Sin embargo, tradicionalmente los investigadores han enfatizado el análisis del impacto generado por las respuestas flexibles de carácter externo en lugar de las internas. Justificaban este hecho argumentando que son las prácticas flexibles que pueden ser percibidas en el exterior por los consumidores, (por ejemplo la adaptación a la cantidad de producto requerido, a la fecha de entrega y la capacidad de ampliar la gama de productos) lo que permite incrementar el valor percibido de la empresa posicionándola estratégicamente en el actual entorno competitivo. Sin embargo, los resultados obtenidos en el desarrollo de la presente tesis doctoral sugieren que alcanzar el tipo de flexibilidad estratégica percibida por el consumidor requiere que las empresas sean capaces de gestionar de manera flexible los diferentes recursos a nivel funcional y organizativo (Martinez Sanchez et al., 2007; Dreyer & Gronhaug, 2004) y es realmente la gestión flexible de estos recursos internos a la organización a la que se debe prestar mayor atención abriendo una nueva vía de investigación para futuros estudios. En primer lugar porque el nivel interno de flexibilidad genera un impacto significativo, positivo y directo sobre la performance en un sentido amplio mayor que las prácticas flexibles de carácter externo. Y en segundo lugar porque afecta de forma altamente significativa a que el nivel de flexibilidad externo pueda desarrollarse incrementando consecuentemente el impacto positivo generado sobre la performance.

A la luz de estos resultados, este estudio no sólo abre una nueva vía de investigación en el campo al detectarse la relevancia del bloque interno de flexibilidad sino que también proporciona importantes implicaciones para los directivos y la definición de la estrategia de las organizaciones. En este sentido los gerentes deben planificar, organizar, coordinar y gestionar la flexibilidad de manufactura tanto en términos externos como internos, puesto que es este último nivel interno de flexibilidad -capacidad interna de reprogramar las órdenes de fabricación, los materiales, la redistribución del trabajo etc- el que proporciona un mayor efecto sobre la performance, posibilitando la capacidad de planificar la demanda, coordinar las actividades de distribución y provocar respuestas externas rápidas sin penalizaciones de costes y retrasos de tiempo significativos.

Limitaciones

Los resultados anteriores deben matizarse teniendo en cuenta que este trabajo no está exento de limitaciones. La primera limitación es que se trata de un estudio cross-section y la información de las variables latentes se basa en percepciones subjetivas. Aunque las medidas subjetivas han demostrado ser una evaluación válida cuando los datos objetivos no están disponibles, se recomienda conseguir datos objetivos complementarios y contrastarse con las medidas subjetivas para comprobar los resultados.

Por otro lado, para la validación de las escalas y la contrastación de los modelos se ha empleado una muestra de empresas delimitadas en sectores de manufactura SIC 34-38. En este sentido, aunque el tamaño de la muestra es razonable y acorde a los trabajos previos sobre flexibilidad de manufactura, podría considerarse ampliar el tamaño de la muestra para mejorar la validez de la investigación desarrollada. Por otra parte, los resultados dependen del contexto y, debe considerarse la posibilidad de extender el análisis a otros sectores o tipos de empresas.

Finalmente, debe tenerse en cuenta que la propuesta de escalas relacionadas con los productos no ha permitido establecer una distinción clara entre los tres tipos de flexibilidad que aluden a este concepto. Por lo que sería necesario continuar avanzando en la forma de distinguir de forma clara entre la flexibilidad de modificación, nuevo producto y mix.

Futuras líneas de investigación

En este estudio se ha establecido la validez de la utilización de dos constructos multidimensionales para validar empíricamente el marco estratégico de flexibilidad de manufactura dentro de las organizaciones y su vinculación con el desempeño organizacional.

Las organizaciones, como sistemas complejos, presentan una amplia gama de variables que afectan a sus operaciones, por lo que puede ser interesante evaluar otros elementos que puedan generar una ventaja competitiva, y evaluar sus correspondientes relaciones con la flexibilidad de manufactura a nivel interno y externo (por ejemplo la implantación de sistemas avanzados de manufactura, la cultura organizativa o la implantación de sistemas de información).

Como se ha discutido antes, este estudio se realizó con una muestra importante de empresas españolas de los sectores SIC 34-38; por lo cual se cree necesario la evaluación de muestras diferentes y de otros tipos de empresas. También sería interesante replicar este estudio con análisis multi-grupo para profundizar en una posible tipología de flexibilidad de manufactura. Este estudio ha considerado variables de control como el entorno dinámico, la edad, el tipo de proceso productivo y el tamaño, pero otras variables como la estrategia o la estructura de propiedad de las empresas, incluyendo las características familiares en la alta administración, deberían ser evaluadas. Otras consideraciones que pueden ser de interés para investigaciones futuras son:

1. Contrastar los constructos formativos que se proponen en este estudio con otras muestras de empresas en otros contextos, así como replicar la validación del modelo en otros sectores a fin de confirmar los resultados obtenidos en el desarrollo de esta tesis doctoral.
2. Continuar avanzando en la operativización del constructo, especialmente en los casos de flexibilidad de programa y de entrega, así como proponer escalas nuevas para la flexibilidad de modificación que permitan establecer

una diferencia clara con las escalas de las flexibilidades de nuevo producto o mix.

3. Validar de manera empírica el marco teórico jerárquico, realizando una discusión acerca de los resultados obtenidos en este estudio a fin de poder avanzar en la integración de ambas corrientes en un único marco.
4. Explorar las relaciones existentes entre los tipos de flexibilidad que integran cada nivel de análisis a fin de determinar si existen relaciones de complementariedad o sustituibilidad entre ellas, evaluando el impacto sobre la performance.
5. Abordar de una manera más detallada las diferentes aproximaciones al entorno determinando diversos niveles de dinamismo a fin de analizar bajo qué condiciones son más efectivas unos tipos de flexibilidad que otros.
6. Continuar avanzando en el estudio de la integración de la flexibilidad de manufactura con la flexibilidad de las cadenas de suministro y analizar cómo las prácticas flexibles utilizadas en el resto de eslabones de la cadena de suministro impactan en el desarrollo de la flexibilidad de manufactura de la organización.

En definitiva, el trabajo ofrece las bases sobre las que desarrollar futuras investigaciones sobre el impacto que la capacidad de respuesta flexible de una organización genera en la performance.

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Zhang, Q., Vonderembse, M.A. & Cao, M. (2009). Product concept and prototype flexibility in manufacturing: Implications for customer satisfaction. *European Journal of Operational Research* 194 (1): 143-154.

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APPENDIX

APPENDIX I

Articles by cluster

	Cluster	Reference	Times cited
1	Technology	Jordan, W.C., and Graves, S.C. 1995. Principles on the benefits of manufacturing process flexibility. *Management Science* 41 (4): 577-594.	217
2	Technology	Suarez, F.F., Cusumano, M.A., and Fine C.H. 1995. An empirical-study of flexibility in manufacturing. *Sloan Management Review* 37 (1): 25-32.	67
3	Technology	Lei, D., Hitt, M.A., and Goldhar, JD. 1996. Advanced manufacturing technology: Organisational design and strategic flexibility. *Organisation Studies* 17 (3): 501-523.	62
4	Technology	Parker, R.P., and Wirth, A. 1999. Manufacturing flexibility: Measures and relationships. *European Journal Of Operational Research* 118 (3): 429-449.	36
5	Technology	Boyer, K.K., and Leong, G.K.1996. Manufacturing flexibility at the plant level. Omega-*International Journal Of Management Science* 24 (5): 495-510.	34
6	Technology	Gaimon, C., and Singhal, V. 1992. Flexibility and the choice of manufacturing facilities under short product life-cycles. European Journal of Operational Research 60(2): 211-223.	28
7	Technology	Pyoun, YS, and Choi, BK. 1994. Quantifying the flexibility value in automated manufacturing systems. *Journal Of Manufacturing Systems* 13 (2): 108-118.	16
8	Technology	Pereira, J., and Paulre, B. 2001. Flexibility in manufacturing systems: A relational and a dynamic approach. *European Journal Of Operational Research* 130 (1): 70-82.	15
9	Technology	Alexopoulos, K, Mourtzis, D., Papakostas, N., and Chryssolouris, G. 2007. DESYMA: assessing flexibility for the lifecycle of manufacturing systems. *International Journal of Production Research* 45 (7): 1683-1694.	14
10	Technology	Kaluwa, B.M., and Reid, G.C. 1995. Profitability and price flexibility in manufacturing for a developing-country. *Journal Of Industrial Economics* 8(4): 265-276.	14
11	Technology	Philippart, E., and Edwards, G. 1999. The provisions on closer co-operation in the Treaty of Amsterdam: The politics of flexibility in the European Union. *Journal Of Common Market Studies* 37(1): 87-108.	10
12	Technology	Muriel, A., Somasundararn, A., and Zhang, Y.M. 2006. Impact of partial manufacturing flexibility on production variability. *MandSOM-Manufacturing and Service Operations Management* 8 (2): 192-205.	9
13	Technology	Shipley, D.D. 1983. Pricing flexibility in british manufacturing-industry. *Managerial And Decision Economics* 4 (4): 224-233.	8
14	Technology	Beach, R., Muhlemann, A.P., Price, D.H.R., Paterson, A., and Sharp, J.A. 1998. Information systems as a key facilitator of manufacturing flexibility: a documented application. *Production Planning and Control* 9 (1): 96-105.	4
15	Technology	Pal, S.P., and Saleh, S. 1993. Tactical flexibility of manufacturing technologies. *IEEE Transactions On Engineering Management* 40 (4): 373-380.	4
16	Technology	Francas, D., Lohndorf, N., and Minner, S. 2011. Machine and labor flexibility in manufacturing networks. *International Journal of Production Economics* 131 (1): 165-174.	2
17	Technology	Asif, M., Fisscher, O.A.M., de Bruijn, E.J., and Pagell, M. 2010. Integration of management systems: A methodology for operational excellence and strategic flexibility. *Operations Management Research* 3 (3-4): 129-137.	2
18	Technology	Zhang, Q.Y., Vonderembse, M.A., and Cao, M. 2009. Product concept and prototype flexibility in manufacturing: Implications for customer satisfaction. *European Journal Of Operational Research* 194 (1): 143-154.	2
19	Technology	Wilhelm, W.E., and Zhu, X.Y. 2009. Enabling flexibility on a dual head placement machine by optimizing platform-tray-feeder picking operations.	2

		Flexible Services And Manufacturing Journal 21 (1-2): 1-30.	
20	Technology	Skarlo, T. 1999. 'The flexible landscape': a model for explaining operational mix and volume flexibility. *Production Planning and Control* 10 (8): 735-744.	1
21	Technology	Acaccia, G.M., Michelini, R.C., Molfino, R.M., and Piaggio, M. 1993. The govern-for-flexibility of manufacturing facilities - an explanatory example. *Computer Integrated Manufacturing Systems* 6 (3):149-160.	1
22	Technology	Gola, A., and Swic, A. 2011. Computer-aided machine tool selection for focused flexibility manufacturing systems using economical criteria. *Actual Problems Of Economics* 124: 383-389.	0
23	Technology	Aurich, J.C., and Barbian, P. 2004. Production projects - Designing and operating lifecycle-oriented and flexibility-optimized production systems as a project. *International Journal of Production Research* 42 (17): 3589-3601.	0
24	Technology	Buxey, G. 1992. CAD-CAM in Australia - flexibility quality and manufacturing strategy. *Computer Integrated Manufacturing Systems* 5 (4): 300-310.	0
25	Technology	Frantzen, D.J. 1985. Cost shifting and price flexibility in the small open-economy - a disaggregated study for belgian manufacturing. *Applied Economics* 17 (1): 173-189.	0
26	Technology	Karasek, FW. 1978. Automation and crt display provide operating ease and flexibility in HPLC analysis. *Industrial Research and Development* 20 (7): 94-98.	0
27	Perspective	Narasimhan, R., and Das, A. 1999. An empirical investigation of the contribution of strategic sourcing to manufacturing flexibilities and performance. *Decision Sciences* 30 (3): 683-718.	90
28	Perspective	Zhang, Q.Y., Vonderembse, M.A., and Lim, J.S. 2003. Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction. *Journal Of Operations Management* 21 (2): 173-191.	74
29	Perspective	Upton, D.M. 1997. Process range in manufacturing: An empirical study of flexibility. *Management Science* 43(8): 1079-1092.	67
30	Perspective	Swink, M., Narasimhan, R., and Kim, S.W. 2005. Manufacturing practices and strategy integration: Effects on cost efficiency, flexibility, and market-based performance. *Decision Sciences* 36(3): 427-457.	51
31	Perspective	Liker, J.K., Collins, PD., and Hull, F.M. 1999. Flexibility and standardization: Test of a contingency model of product design-manufacturing integration. *Journal Of Product Innovation Management* 16 (3): 248-267.	43
32	Perspective	Koste, L.L., Malhotra, M.K, and Sharma, S. 2004. Measuring dimensions of manufacturing flexibility. *Journal Of Operations Management* 22 (2): 171-196.	42
33	Perspective	Narasimhan, R ., Talluri, S., and Das, A. 2004. Exploring flexibility and execution competencies of manufacturing firms. *Journal Of Operations Management* 22 (1): 91-106.	37
34	Perspective	Sawhney, R. 2006. Interplay between uncertainty and flexibility across the value-chain: Towards a transformation model of manufacturing flexibility. *Journal Of Operations Management* 24 (5): 476-493.	33
35	Perspective	Benson, J., Debroux, P., Yuasa, M., and Zhu, Y. 2000. Flexibility and labour management: Chinese manufacturing enterprises in the 1990s. *International Journal Of Human Resource Management* 11 (2): 183-196.	28
36	Perspective	Bordoloi, S.K., Cooper, W.W., and Matsuo, H. 1999. Flexibility, adaptability, and efficiency in manufacturing systems. *Production And Operations Management* 8 (2): 133-150.	24
37	Perspective	Kathuria, R., and Partovi, F.Y. 1999. Work force management practices for manufacturing flexibility. *Journal of Operations Management* 18 (1): 21-39.	24

38	Perspective	Llorens, F.J., Molina, L.M., and Verdu, A.J. 2005. Flexibility of manufacturing systems, strategic change and performance. *International Journal Of Production Economics* 98 (3): 273-289.	18
39	Perspective	Correa, H., and Slack, N. 1996. Framework to analyse flexibility and unplanned change in manufacturing systems. *Computer Integrated Manufacturing Systems* 9(1): 57-64.	18
40	Perspective	Avittathur, B., and Swamidass, P. 2007. Matching plant flexibility and supplier flexibility: Lessons from small suppliers of US manufacturing plants in India. *Journal Of Operations Management* 25 (3): 717-735.	18
41	Perspective	Bernardes, E. S., and Hanna, M.D. 2009. A theoretical review of flexibility, agility and responsiveness in the operations management literature Toward a conceptual definition of customer responsiveness. *International Journal Of Operations and Production Management* 29 (1-2): 30-53.	17
42	Perspective	Caputo, M. 1996. Uncertainty, flexibility and buffers in the management of the firm operating system. *Production Planning and Control* 7 (5): 518-528.	17
43	Perspective	Das, A. 2001. Towards theory building in manufacturing flexibility. *International Journal of Production Research* 39(18): 4153-4177.	14
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45	Perspective	Narasimhan, R., and Das, A. 2000. An empirical examination of sourcing's role in developing manufacturing flexibilities. *International Journal Of Production Research* 38 (4): 875-893.	13
46	Perspective	Kher, HV, and Malhotra, MK. 1994. Acquiring and operationalizing worker flexibility in dual resource constrained job shops with worker transfer delays and learning losses. OMEGA-*International Journal Of Management Science* 22 (5): 521-533.	13
47	Perspective	Smith, A.D., and Zeithaml, C. 1996. Garbage cans and advancing hypercompetition: The creation and exploitation of new capabilities and strategic flexibility in two regional bell operating companies. *Organisation Science* 7(4): 388-399.	13
48	Perspective	Aprile, D., Garavelli, A.C., and Giannoccaro, I. 2005. Operations planning and flexibility in a supply chain. *Production Planning and Control*. 16 (1): 21-31.	13
49	Perspective	Young, R.C,Francis, JD., and Young, C.H. 1994. Flexibility in small manufacturing firms and regional industrial formations. *Regional Studies* 28 (1): 27-38.	12
50	Perspective	Chang, S.C., Lin, N.P., and Sheu, C. 2002. Aligning manufacturing flexibility with environmental uncertainty: evidence from high-technology component manufacturers in Taiwan. *International Journal Of Production Research* 40 (18): 4765-4780	12
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52	Perspective	Hutchison, J., and Das, S.R. 2007. Examining a firm's decisions with a contingency framework for manufacturing flexibility. *International Journal Of Operations and Production Management* 27 (2): 159-180.	8
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55	Perspective	Huang, H.J., andCullen, J.B. 2001. Labour flexibility and related HRM practices: A study of large Taiwanese manufacturers. *Canadian Journal Of Administrative Sciences-Revue Canadienne Des Sciences De L Administration* 18 (1) : 33-39.	4

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206	Performance	Oke, A. 2003. Drivers of volume flexibility requirements in manufacturing plants. *International Journal of Operations and Production Management*, *23*(12): 1497-1513.	8
207	Performance	Price, D. H. R., Beach, R., Muhlemann, A. P., Sharp, J. A., and Paterson, A. 1998. A system to support the enhancement of strategic flexibility in manufacturing enterprises. *European Journal of Operational Research*, *109*(2): 362-376.	8
208	Performance	Chan, F. T. S., Bhagwat, R., and Wadhwa, S. 2006. Increase in flexibility: productive or counterproductive? A study on the physical and operating characteristics of a flexible manufacturing system. *International Journal of Production Research*, *44*(7): 1431-1445.	8
209	Performance	Dooner, M. 1991. Conceptual modelling of manufacturing flexibility. *International Journal of Computer Integrated Manufacturing*, *4*(3): 135-144.	7
210	Performance	Chod, J., Rudi, N., and Van Mieghem, J. A. 2010. Operational flexibility and financial hedging: Complements or substitutes?. *Management Science*, *56*(6): 1030-1045.	7

211	Performance	Reimann, M., and Schiltknecht, P. 2009. Studying the interdependence of contractual and operational flexibilities in the market of specialty chemicals. *European Journal of Operational Research*, *198*(3): 760-772.	6
212	Performance	Malhotra, M. K., and Sharma, S. 2008. Measurement equivalence using generalizability theory: an examination of manufacturing flexibility dimensions. *Decision Sciences*, *39*(4): 643-669.	6
213	Performance	Gerwin, D. 2005. An agenda for research on the flexibility of manufacturing processes. *International Journal of Operations & Production Management*, *25*(12): 1171-1182.	5
214	Performance	Buzacott, J. A., and Mandelbaum, M. 2008. Flexibility in manufacturing and services: achievements, insights and challenges. *Flexible services and manufacturing journal*, *20*(1-2): 13-58.	5
215	Performance	Lieberman, S. M., and Bertko, J. M. 2011. Building Regulatory And Operational Flexibility Into Accountable Care Organisations And 'Shared Savings'. *Health Affairs*, *30*(1): 23-31.	5
216	Performance	Van Hop, N., and Ruengsak, K. 2005. Fuzzy estimation for manufacturing flexibility. *International Journal of Production Research*, *43*(17): 3605-3617.	5
217	Performance	Chuu, S. J. 2005. Fuzzy multi-attribute decision-making for evaluating manufacturing flexibility. *Production Planning and Control*, *16*(3): 323-335.	5
218	Performance	Roll, Y., Karni, R., and Arzi, Y. 1992. Measurement of processing flexibility in flexible manufacturing cells. *Journal of Manufacturing Systems*, *11*(4): 258-268.	5
219	Performance	Schütz, P., and Tomasgard, A. 2011. The impact of flexibility on operational supply chain planning. *International Journal of Production Economics*, *134*(2): 300-311.	3
220	Performance	Yang, C. L., Lin, C. H., and Sheu, C. 2007. Developing manufacturing flexibility through supply chain activities: evidence from the motherboard industry. *Total Quality Management*, *18*(9): 957-972.	3
221	Performance	Iravani, S. M., Kolfal, B., and Van Oyen, M. P. 2011. Capability flexibility: A decision support methodology for parallel service and manufacturing systems with flexible servers. *IIE Transactions*, *43*(5): 363-382.	3
222	Performance	Kahyaoglu, Y., and Kayaligil, S. 2002. Conceptualizing manufacturing flexibility: an operational approach and a comparative evaluation. *International Journal of Production Research*, *40*(10): 2187-2206.	3
223	Performance	Zukin, M., and Young, R. E. 2001. Applying fuzzy logic and constraint networks to a problem of manufacturing flexibility. *International Journal of Production Research*, *39*(14): 3253-3273.	3
224	Performance	Calvo, R., Domingo, R., and Sebastián, M. A. 2007. Operational flexibility quantification in a make-to-order assembly system. *International Journal of Flexible Manufacturing Systems*, *19*(3): 247-263.	2
225	Performance	Rogers, P. P., Ojha, D., and White, R. E. 2011. Conceptualising complementarities in manufacturing flexibility: a comprehensive view. *International Journal of Production Research*, *49*(12): 3767-3793.	2
226	Performance	Dodgson, M. 1987. Small firms, advanced manufacturing technology and flexibility. *Journal of General Management*, *12*(3): 58-75.	2
227	Performance	Guo, H., Tao, F., Zhang, L., Laili, Y. J., and Liu, D. K. 2012. Research on measurement method of resource service composition flexibility in service-oriented manufacturing system. International Journal of Computer Integrated Manufacturing, 25(2): 113-135.	2
228	Performance	Daniel, S. J., Reitsperger, W. D., and Morse, K. 2009. A longitudinal study of Japanese manufacturing strategies for quality, JIT and flexibility. *Asian Business and Management*, *8*(3): 325-356.	2
229	Performance	Yu, D. Z., Tang, S. Y., and Niederhoff, J. 2011. On the benefits of operational flexibility in a distribution network with transshipment. *Omega*, *39*(3): 350-361.	1

230	Performance	Malhotra, M. K., and Mackelprang, A. W. 2012. Are internal manufacturing and external supply chain flexibilities complementary capabilities?. *Journal of Operations Management*, *30*(3): 180-200.	1
231	Performance	Tamayo-Torres, J., Ruiz-Moreno, A., and Lloréns-Montes, F. J. 2011. The influence of manufacturing flexibility on the interplay between exploration and exploitation: the effects of organisational learning and the environment. *International Journal of Production Research*, *49*(20): 6175-6198.	1
232	Performance	Laki, M. 1983. Growth and Flexibility: The Case of a Transformer-Manufacturing Cooperative. Eastern European Economics, 21(3/4): 170-187.	1
233	Performance	Waller, M. A., and Christy, D. P. 1992. Competitive incentives for manufacturing flexibility. *International journal of production economics*, *28*(1): 35-45.	1
234	Performance	He, P., Chen, Z., and Xu, X.Y. 2011. On flexibility investment in manufacturing system: a multi-objective decision making method. *Expert systems with applications* 38(9): 11813-11819.	1
235	Performance	Ishfaq, R. 2012. Resilience through flexibility in transportation operations. *International Journal of Logistics Research and Applications*, *15*(4): 215-229.	0
236	Performance	Kalchschmidt, M., Nieto, Y., and Reiner, G. 2010. The impact of forecasting on operational performance: Mediation effects through flexibility enablers. *Operations Management Research*, *3*(3-4): 129-137.	0
237	Performance	Wadhwa, R. S. 2012. Flexibility in manufacturing automation: A living lab case study of Norwegian metalcasting SMEs. *Journal of Manufacturing Systems*.	0
238	Performance	Xu, X. G., Han, W. M., and Ye, T. F. 2011. Flexibility of service-oriented manufacturing: A. *African Journal of Business Management*, *5*(35): 13534-13540.	0
239	Performance	Arias-Aranda, D., Bustinza, O. F., and Barrales-Molina, V. 2011. Operations flexibility and outsourcing benefits: an empirical study in service firms. *The Service Industries Journal*, *31*(11): 1849-1870.	0
240	Performance	Goss, B. M., and Knudsen, D. C. 1994. Flexibility in offshore assembly operations: electronics assembly in the Commonwealth Caribbean. *The Developing Economies*, *32*(2): 210-227.	0
241	Performance	Alolayyan, M. N., Ali, K. A. M., and Idris, F. 2011. The influence of total quality management (TQM) on operational flexibility in Jordanian hospitals: Medical workers' perspectives. *Asian Journal on Quality*, *12*(2): 204-222.	0
242	Performance	Brush, B. C., and Crane, S. 1989. Market power and cyclical wage flexibility in united-states manufacturing-industries. *Review of business and economic research*, *24*(2): 59-74.	0
243	Performance	de Weerd-Nederhof, P. C., Visscher, K., Altena, J., and Fisscher, O. A. 2008. Operational effectiveness and strategic flexibility: scales for performance assessment of new product development systems. *International journal of technology management*, *44*(3): 354-372.	0
244	Performance	Takagi, N., and Tokinaga, S. 2002. Prediction of Chaotic Time-series by Using the Multistage Fuzzy Inference Systems and its Applications to the Analysis of Operational Flexibility. *Journal of the Operations Research Society of Japan-Keiei Kagaku*, *45*(3): 243-259.	0
245	Performance	Chang, A. Y. 2012. Prioritising the types of manufacturing flexibility in an uncertain environment. *International Journal of Production Research*, *50*(8): 2133-2149.	0

APPENDIX II

Terms used by works which conceptualise the construct

Papers which discuss or review manufacturing flexibility concept			(Slack 1983)	(Browne et al., 1984)	(Slack 1987)	(Gerwin 1987)	(Slack 1988)	(Taymaz 1989)	(Gupta & Goyal 1989)*	(Sethi & Sethi 1990)	(Dooner 1991)	(Ramasesh & Jayakumar 1991)	(Chen, Calantone, & Chung 1992)	(Gerwin 1993)	(Upton 1994) **	(Suarez, Cusumano, & Fine 1996)	(Parker & Wirth 1999)*	(Narasimhan & Das 1999)	(Koste & Malhotra 1999)*	(D'Souza & Williams 2000)	(Braglia & Petroni 2000)	(Beach et al., 2000)**	(Vokurka & O'Leary-Kelly 2000)**	(Olhager & West 2002)	(Arias-Aranda 2003)	(Zhang, Vonderembse, & Lim 2003)	(De Toni & Tonchia 2005)**	(Oke 2005)	(Gerwin 2005)	(Sawhney 2006)	(Cao & Zhang 2008)	(Bernardes & Hanna 2009)**	(Arias-Aranda, Bustinza, & Barrales-Molina 2011)	(Rogers, Ojha, & White 2011)	(Xu, Han, & Ye 2011)**	(Chang 2012)	(Jain et al., 2013) **	(Seebacher & Winkler 2013)**	**TOTAL = 36**
Terms used to define the forms of flexibility (variety of flexibility names which appeared in the literature).	Synonymous terms	TYPE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	35 (97,2%)
		DIMENSION				x		x		x		x		x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x		x	x		x	x	x	25 (69,4%)
		COMPONENT																		x																			1 (2,8%)
Terms used to define the scope of each flexibility type (metrics for measuring each flexibility type).	Synonymous terms	DIMENSION	x		x		x		x		x		x				x	x														x			x			x	10 (27,8%)
		ELEMENT													x				x	x		x	x	x		x											x	x	9 (25%)
		ASPECT				x								x															x										3 (8,3%)
		PARAMETER																														x							1 (2,8%)
		COMPONENT	x		x		x																																3 (8,3%)

Source: Authors *Papers which also discuss measures (3 papers). ** Review paper

Terms used by works which measure the construct

Papers which discuss manufacturing flexibility measures			(Brill & Mandelbaum 1989)	(Mandelbaum & Brill 1989)	(Gupta & Goyal 1989)	(Gupta & Somers 1992)	(Gupta 1993)	(Das & Nagendra 1993)	(Olhager 1993)	(Sarker, Krishnamurthy, & Srinivasa	(Gupta & Buzacott 1996)	(Upton 1997)	(Shewchuk & Moodie 1998)	(Shewchuk 1999)	(Batteman 1999)	(Parker & Wirth 1999)	(Koste & Malhotra 1999)	(Kahyaoglu & Kayaligil 2002)	(Jack & Raturi 2002)	(Koste, Malhotra, & Sharma 2004)	(Van Hop 2004)	(Wahab 2005)	(da Silveira 2006)	(Wahab, Wu, & Lee 2008)	(Ling-yee & Ogunmokun 2008)	(Malhotra & Sharma 2008)	(Hallgren & Olhager 2009)	(Tamayo-Torres, Ruiz-Moreno, &	(Wadhwa 2012)	(Malhotra & Mackelprang 2012)	(Patel, Terjesen, & Li 2012)	**TOTAL = 29**
Terms used to define the forms of flexibility (variety of flexibility names which appeared in the literature).	Synonymous terms	TYPE	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		x	x	x	26 (89,7%)
		DIMENSION							x				x	x			x		x	x					x	x		x		x	x	11 (37,9%)
		KIND								x																						1 (3,4%)
		COMPONENT				x																										1 (3,4%)
Terms used to define the scope of each flexibility type (metrics for measuring each flexibility type).	Synonymous terms	DIMENSION			x							x			x	x	x				x	x	x	x								9 (31%)
		ELEMENT										x	x	x				x	x	x						x		x	x	x	x	11 (37,9%)
		PARAMETER								x	x																					2 (6,9%)
		COMPONENT																		x						x						2 (6,9%)

Source: Authors

APPENDIX III

Table 1 Items Labour Flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility	Hybrid
Zhang et al., (2003); Cao & Zhang (2008); Oke (2013)	**-Workers can operate various types of machines**	*A typical worker can use many different tools effectively*	***-Workers can perform a broad range of manufacturing tasks effecient in the organisation*** *-Workers can perform many types of operations effectively*	***Workers can be transferred easily between organisational units***	
Koste et al., (2004); Malhotra & Sharma (2008)	-Workers can perform a large number of tasks -Workers are responsible for more than one task -A large number of job classifications exist in the workforce **-Workers are cross-trained to perform many different tasks** -Workers possess many different skills	-The tasks which workers perform are very similar to one another -Workers perform a diverse set of tasks -Workers can perform various types of tasks **-Workers can perform tasks which differ greatly from one another**	-**Workers are equally efficient at all tasks** -Workers achieve similar performance levels for all tasks -Worker choice does not affect the processing cost (in dollars) of a task -Workers are equally reliable for all tasks -**Workers are equally effective, in terms of productivity, for all tasks**	-**A short time delay occurs when workers are moved between different tasks** -**It is easy to move workers between different tasks** -A small cost is incurred (in dollars) when workers are moved between different tasks **-A small cost is incurred (in terms of lost productivity) when workers are moved between different tasks** **-Workers can move easily between different tasks**	
Patel et al., (2012)	**Workers are cross-trained to perform many different tasks**	**Workers can perform tasks which differ greatly from one another**	**Workers are equally effective, in terms of quality for all tasks**	**A small cost is incurred (in terms of lost productivity) when workers are moved between different tasks**	
Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)	***-Employees are cross–trained to perform a variety of activities.*** *-Workers operate various types of machines.*			*Workers are cross-trained in multiple cells/teams*	
Arias-Aranda (2003); Arias Aranda et al., (2011)					*-The number of different operations an employee can perform without incurring in high changing costs is very high* *-The number of different operations an employee can perform without spending a lot of time when changing is very high*
Kim et al., (2013)					*We frequently utilize job rotation for workers* *A large proportion of our labour is non-union* *Much of our workforce is organised as teams*

Source: Authors

Table 2 Items Machine flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Zhang et al., (2003); Cao & Zhang (2008)	***-A typical machine can perform many types of operations*** *-A typical machine can effectively use many different tools*	*Machines often become obsolete when new operations are required*		***-Machine set-up can be done quickly*** ***-Machine set-ups are easy*** *-Machine tools can be changed quickly*
Arias- Aranda (2003)	***Number of different operations***			*Cost of switching from one operation to another*
Koste et al., (2004); Malhotra & Sharma (2008)	-A typical machine can perform a large percentage of the total number of operations performed in the plant -A large number of operations can be performed by more than one machine -A typical machine can use many different tools **-The number of different operations that a typical machine can perform is high**	-Machines can perform operations which are not very similar to one another -Machines can perform various types of operations -Existing machines cannot be used to perform new operations -Machines can perform a variety of operations **-Machines can perform operations which differ greatly from one another**	-All machines achieve similar performance across all operations **-Machines are equally effective, in terms of productivity, for all operations** -Machines are equally efficient for all processing operations **-Machines are equally effective, in terms of quality, for all operations** **-Machines are equally reliable for all operations** -The processing cost (in dollars) of an operation is not affected by machine choice	**-Machine changeovers between operations are easy** **-Machine set-ups between operations are quick** -A lot of available capacity is used in changing between machine operations -Machine tools can be changed quickly
Tamayo-Torres et al., (2014)	*-Typical machines can use many different tools.*	***-Machines can perform operations, which are not very similar to one another.*** *-Machines can perform a high variety of operations.*	***-Machines produce equal quality for all operations.*** ***-Machines are equally reliable for all operations***	
Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)	***Our typical machine performs many types of operations.***			***Machine set–ups are easy.*** ***Machines/tooling can be set–up quickly.***
Patel et al., (2012)	**The number of different operations that a typical machine can perform is high**	**Machines can perform operations which differ greatly from one another**	**Machines are equally effective, in terms of productivity for all operations**	**Machine set-ups between operations are quick**
Kim et al., (2013)	***Number of operations a typical machine in our plant can perform***			***Machine set ups between operations are relatively quick*** *Changes in machining processes can be handled by existing machines*

Source: Authors

Table 3 Items Material flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility	Hybrid
Zhang et al., (2003); Cao & Zhang (2008)	*A typical material handling system can link different processing centers*	*-A typical material handling system can handle different part types* *-Material handling system can move different part types through manufacturing facilities*		*Material handling changeovers between parts are quick* ***Material handling tools can be changed or replaced quickly***	
Koste et al., (2004); Malhotra & Sharma (2008)	-Material can be routed along many paths **-There are many different material handling paths between processing centers** -Many processing centers are linked by the material handling system -There are a large number of material handling paths -There are a limited number of material handling paths between processing centers	The material handling system can transport materials of different shapes The material handling paths used by the system are very different from one another The material handling system uses a large proportion of general purpose pallets The material handling system uses a large proportion of general purpose fixtures **The material handling system can transport materials of different sizes** **The material handling system can transport a wide variety of materials**	**The choice of material handling path does not affect the efficiency of material transfer** The choice of material handling path does not affect the material transfer time **The quality of materials is not affected by the material handling path used** All material handling paths exhibit similar performance	Changing a material handling path is easy **Changing a material handling path is inexpensive** **Changing a material handling path is quick** **Material handling paths can be easily added** The choice of material handling path does not affect the material transfer cost Material handling paths can be easily removed	
Tamayo-Torres et al., (2014)		***The material handling system can transport materials of different sizes.*** ***The materials handling system can transport a wide variety of materials.***	*The choice of material handling path does not affect the material transfer time.* ***The choice of material handling path does not affect the efficiency of material transfer.***	***Changing a material handling path is inexpensive.*** ***Changing a material handling path is quick.*** *The choice of material handling path does not affect the material transfer cost.*	
Patel et al., (2012)	**There are many different material handling paths between processing centers**	**The material handling system can transport materials of different sizes**	**The choice of material handling path does not affect the efficiency of material transfer**	**Changing a material handling path is quick**	
Gupta & Somers (1996); D´Souza & Williams (2000)					*The material system is designed to link every machine which every other machine on the shop floor* *The material system can move every part for proper positioning & processing through the manufacturing facility*

Source: Authors

Table 4 Items Routing flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Gupta & Somers (1996)				*Decrease in throughput because of a machine breakdown is extremely low.* *Cost of the production lost as a result of expediting a preemptive order is extremely low.*
Arias Aranda (2003)	*Average number of ways in which a service can be delivered.*			*Cost of production lost due to rescheduling an urgent job.*
Zhang et al., (2003); Cao & Zhang (2008)	***A typical part operation can be routed to different machines*** *The operating sequence through which the parts flow can be changed* *The system has alternative routes in case machines break down*	***A typical part can use many different routes***		***Machine visitation sequence can be changed or replaced quickly*** ***Route changeovers are easy***
Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)	***A typical part can be routed to alternate machines.*** *The system has alternative routes in case machines break down*	***A route can process products/parts which differ greatly to one another***		
Tamayo-Torres et al., (2014)	***A route can process a variety of products/parts***	***A typical part can use many different routes.***	*Alternate routes do not decrease quality of products/parts*	***Route changes can be made quickly*** ***Alternate routes do not increase costs***

Source: Authors

Table 5 Items Programme Flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Jayakumar (1984), Arias-Aranda et al., (2011)	*Number of systems with unattended operations*			*Expected percentage uptime during second & third shift*

Source: Authors

Table 6 Items Volume Flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
D´Souza & Williams (2000); Mendes & Machado (2015)	***The range of output volumes at which the firm can run profitably***			*Time required to increase or decrease output.* ***Cost of increasing or decreasing volume of output.***
Jayakumar (1984); Arias-Aranda (2003; 2011)	*Ratio of average volume fluctuation to total capacity.* *Smallest volumes for profitable operation of the system*			*Stability of manufacturing costs over widely varying levels production volume.*
Gupta & Somers (1996)	***The range of output volumes at which the firm can run profitably***		***The ability to operate a system profitably at different production volumes.***	
Narasimhan & Das (1999;2004) Das (2001) Slack (1988)	*Difficulty in increasing system capacity*			*Time required to vary production by 20%*
Jack & Raturi (2002)	*Our production processes & equipment give us the capability to produce high volume levels* ***We can significantly increase (or decrease) our output levels***		***When we increase (or decrease) our volume levels we do not experience more than proportionally higher product quality problems***	***When we increase (or decrease) our volume levels we do not experience more than proportionally higher (or lower) production costs***
Zhang et al., (2003); Cao & Zhang (2008)	***We can economically run various batch sizes***	***We can vary aggregate output from one period to the next***	***We can operate efficiently at different levels of output*** ***We can operate profitably at different production volumes***	***We can quickly change the quantities for our products produced*** ***We can easily change the production volume of a manufacturing process***
Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)		***We vary total output from one period to the next.***		***We easily change the output volume of a manufacturing process.*** ***We quickly change the quantities of our products produced.***
Urtasun-Alonso et al., (2014)				***We can relatively easily adapt to constant changes in the quantities to produce*** ***The cost to increase or decrease the quantity of output is low.***

Source: Authors

Table 7 Items Mix flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Das (2001)				***Cost of changing between different products in the product mix*** ***Time required to change between different products in the product mix***
Zhang et al., (2003); Cao & Zhang (2008); Oke (2013)		*We can produce a wide variety of products in our plants* *We can build different products in the same plants at the same time* *We can produce different product types without major changeover* *We can vary product combinations from one period to the next*	*We can produce, **simultaneously** or periodically, multiple products in a steady-state operating mode*	*We can changeover quickly from one product to another*
Koste et al., (2004) Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)	The average number of products produced in the plant is large **A large number of product lines are produced in the plant** A limited number of products are produced in the plant Existing product lines are very broad	The variety of products produced in the plant is extensive **The processing requirements for the products produced in the plant vary greatly from one product to another** The products produced in the plant are very different from one another Products are only slightly different from one another A diverse set of products is produced in the plant The material requirements for the products produced in the plant vary greatly from one product to another	**Productivity levels are not affected by changes in product mix** **The efficiency of the production process is not affected by changes in product mix** **Product quality is not affected by changes in product mix** The performance of the system is not affected by changes in product mix	The cost (in dollars) of including a product in the product mix is small **The product mix produced by the plant can be changed easily** **The time required to change to a different product mix is short** The manufacturing system can quickly changeover to a different product mix **The cost of changing to a different product mix is small**
Patel et al., (2012)	**A large number of product lines are produced in the plant**	**The processing requirements for the products produced in the plant vary greatly from one product to another**	**The efficiency of the production process is not affected by changes in product mix**	**The product mix produced by the plant can be changed easily**
Rogers et al., (2011); Ojha et al., (2013); Ojha et al., (2015)		*We build different products in the same plant at the same time.* *We produce different product types without major changeovers.*		***We easily change from one product to another.***
Urtasun-Alonso et al., (2014)	***A high number of product references are manufactured in the plant***	*The products manufactured in the plant are very different from each other*		***The mix of products manufactured in the plant can be easily changed***
Mendes & Machado (2015)				*Time & costs involved in performing a number of different operations* ***Time required to switch from one part mix to another***

Source: Authors

Table 8 Items Modification Flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Malhotra & Mackelprang (2012); Koste et al., (2004) Malhotra & Sharma (2008)	A large number of products are modified to the customer's specifications There are a limited number of modified products produced each year **The features of existing products are often modified** Engineering change orders are often used to modify products **There are a large number of modified products produced each year** **Existing product lines are frequently modified**	The product modifications made are fairly similar to one another Modified products are very similar to existing products Modified products are very different from existing products	**Productivity levels are not affected when a modified product is introduced into the manufacturing system** **Manufacturing system performance is not affected by the production of modified products** **The quality of existing products is not affected when a modified product is introduced into manufacturing system**	**Modified products can be made quickly** **The average cost of introducing modified products into full-scale production is low** Product modifications are performed quickly **The time to produce modified products is small** Product modifications are easy to make
Das (2001)	*Extent of new/extra parts required in minor design changes* *Number of new/extra operations required in minor design changes*		*Complexity of new/extra operations in minor design changes*	*Time required to accommodate minor design changes* ***Cost of accommodating minor design changes***
Narasimhan & Das (1999;2004)				*Time required to accommodate minor design changes* ***Cost of accommodating minor design changes***
Tamayo-Torres et al., (2014)	***There are a large number of product modifications every year*** ***Existing products lines are frequently modified.*** ***The features of existing products are often modified***			***Modified products can be made quickly***

Source: Authors

Table 9 Items New Product Flexibility

References	Range number	Rangeheterogeneity	Uniformity	Mobility
Das (2001); Narasimhan & Das (1999); Narasimhan & Das (2004)				***Time required to introduce new products*** ***Cost of introducing new products***
Koste et al., (2004); Malhotra & Sharma (2008); Malhotra & Mackelprang (2012)	**The number of new products introduced into production each year is high** limited number of new products are introduced each year A large number of new product prototypes are produced in the system each year A large proportion of our products have been introduced within the past year A large number of new products are introduced each year	New products are very similar to existing products New products are incremental improvements of existing products New product variety is extensive New products are often extensions of existing product lines New products are often improvements of existing products New products are very innovative **New products are very different from existing products** New products are refinements of existing products	Manufacturing system performance is not affected when a new product is introduced into the production system **The quality of existing products is not affected when a new product is introduced into the production system** **Productivity levels are not affected when a new product is introduced into the production system**	The managerial effort required to introduce a new product into full scale production is low **The cost (in dollars) required to design & develop new products is extremely high** The start-up cost (in dollars) of introducing new products into full-scale production is low The number of months from the earliest stage of design to production of a saleable product is low **The time required to develop & introduce new products is extremely low**
Swink et al., (2005); Nair (2005)	***Number of new products introduced each year***			***Lead time to introduce new products***
Patel et al., (2012)	**The number of new products introduced into production each year is high**	**New products are very different from existing products**	**The quality of existing products is not affected when a new product is introduced into the production system**	**The time required to develop & introduce new products is extremely low**
Kim et al., (2013)				***It takes a short time for us to introduce new products*** ***It is no costly for us to introduce new products*** *It is not costly for us to introduce design changes*
Urtasun-Alonso et al., (2014)	***Each year, a high number of new products are introduced***	***The new products are very different from the existing ones.***		
Mendes & Machado (2015)	***Number of new product introduced***			***Time required to introduce new products*** ***Cost of introducing new products***

Source: Authors

Table 10 Items Delivery Flexibility

References	Range number	Range heterogeneity	Uniformity	Mobility
Slack (1988)	*-the extent to which delivery dates can be brought forward*			***-the time taken to reorganize the manufacturing system so as to replan for the new delivery date***
Fantazy et al., (2009)	*Managing the varying number of delivery modes available per product* *Managing small delivery order quantity from the customer can be satisfied*	*delivering urgent request with different & faster modes of transportation* *Handling one or more delivery order of a customer from more than one warehouses, distribution channels or factories*		***The time & the cost implications of changing the delivery due dates*** *The cost of mixing different products into a delivery load*
Chen et al., (2009)			*Your company's defective rate of products still stable when customers shorten the delivery deadlines*	*Your company can still prompt delivery of products when customers shorten the delivery deadlines*

Source: Authors

APPENDIX IV

ENCUESTA PRÁCTICAS FLEXIBLES

Y

RENDIMIENTO

UNIVERSIDAD DE CANTABRIA

SECCIÓN A: DATOS GENERALES

A) En este establecimiento, ¿se realizan procesos industriales (es decir, se fabrican directamente productos) o sólo se desarrollan tareas administrativas, comerciales, de dirección o de planificación, etc?

☐Se realizan procesos de fabricación - CONTINUAR ☐Sólo tareas administrativas o de gestión - FIN

B) ¿Pertenece la empresa a un grupo? ☐Si ☐ No

C) Nª trabajadores en la planta: ☐ 0-49 ☐50-249 ☐ más de 250

D) ¿Realiza actividad internacional? ☐Si ☐ No

E) Indique su puesto actual dentro de la empresa:_________________________

F) ¿Cuál de las siguientes categorías define mejor el flujo de trabajo de su proceso productivo dominante?

☐Funcional (por secciones) ☐ Celular ☐En línea ☐ Otros (indique cuál)

SECCIÓN B: RECURSOS PRODUCTIVOS

Señale su valoración respecto al grado de aplicación en su planta de los siguientes conceptos (1 = nada aplicado y 7= totalmente aplicado)							
Dentro de su planta CONSIDERA QUE…							
Los trabajadores están formados para realizar un amplio número de tareas	1	2	3	4	5	6	7
Existen diferentes rutas de manipulación de materiales entre los centros de procesamiento	1	2	3	4	5	6	7
El número de operaciones que puede realizar una máquina es alto	1	2	3	4	5	6	7
El sistema de producción puede operar con un amplio rango de tolerancias para las especificaciones de los	1	2	3	4	5	6	7
En su planta DIFIEREN SIGNIFICATIVAMENTE ENTRE SÍ…							
….las tareas que pueden realizar los trabajadores.	1	2	3	4	5	6	7
…los materiales que puede transportar el sistema de manipulación de materiales	1	2	3	4	5	6	7
…las operaciones que pueden realizar las máquinas	1	2	3	4	5	6	7
…los rangos de tolerancia de las especificaciones de los productos	1	2	3	4	5	6	7
En general diría que en su planta PUEDEN REALIZARSE FÁCIL Y RÁPIDAMENTE…							
… cambios en las tareas de los trabajadores	1	2	3	4	5	6	7
…cambios en las rutas de manipulación de materiales	1	2	3	4	5	6	7
…cambios en las operaciones de preparación de las máquinas	1	2	3	4	5	6	7
…variaciones en los rangos de tolerancia de las especificaciones de los productos	1	2	3	4	5	6	7
En general diría que en su planta NO SE INCURRE EN ALTOS COSTES cuando….							
… los trabajadores cambian de una tarea a otra	1	2	3	4	5	6	7
… se altera la ruta de manipulación de materiales	1	2	3	4	5	6	7
… se modifican las operaciones de preparación de las máquinas	1	2	3	4	5	6	7
… se altera el rango de tolerancia de las especificaciones de los productos	1	2	3	4	5	6	7
En general, diría que LA PRODUCTIVIDAD/EFICIENCIA de la planta no se ve afectada por cambios en ….							
….las tareas de los trabajadores	1	2	3	4	5	6	7
…las rutas de manipulación de materiales	1	2	3	4	5	6	7
…las operaciones de preparación de las máquinas	1	2	3	4	5	6	7
… los rangos de tolerancia de las especificaciones de los productos	1	2	3	4	5	6	7

SECCIÓN C: ENTORNO

Señale su grado de acuerdo con las siguientes afirmaciones. (1 = totalmente falso y 7 = totalmente cierto)							
Los cambios del entorno en nuestro mercado local son intensos	1	2	3	4	5	6	7
La obsolescencia de productos y servicios es muy rápida en el sector.	1	2	3	4	5	6	7
Es difícil predecir las acciones de nuestros competidores.	1	2	3	4	5	6	7
Es difícil predecir las demandas y gustos de nuestros consumidores.	1	2	3	4	5	6	7
Los cambios tecnológicos de producción/servicio ocurren de forma rápida y significativa.	1	2	3	4	5	6	7

SECCIÓN D: RESULTADOS EMPRESARIALES

Indicar la evolución que ha tenido la planta en los últimos 3 años con respecto a sus principales competidores: 1=más baja que la media de la industria; 4=media; 7=superior a la media							
Crecimiento de ventas	1	2	3	4	5	6	7
Cuota de mercado	1	2	3	4	5	6	7
Rentabilidad	1	2	3	4	5	6	7

Coste de manufactura	1	2	3	4	5	6	7
Rotación de inventarios	1	2	3	4	5	6	7
Tiempo desde la recepción de materiales hasta el envío del producto	1	2	3	4	5	6	7
Conformidad con las especificaciones de calidad	1	2	3	4	5	6	7
Velocidad en innovación de los productos	1	2	3	4	5	6	7
Indicar la evolución que ha tenido la planta en los últimos 3 años con respecto a sus principales competidores: 1=más baja que la media de la industria; 4=media; 7=superior a la media							
Nuestra empresa….							
…satisface los requerimientos y expectativas de nuestros clientes	1	2	3	4	5	6	7
…cumple con los estándares exigidos por los clientes	1	2	3	4	5	6	7
Nuestros consumidores….							
…son fieles a nuestros productos	1	2	3	4	5	6	7
…están satisfechos con el ratio precio/calidad de nuestros productos	1	2	3	4	5	6	7
… opinan que los productos de nuestra empresa tienen buena reputación	1	2	3	4	5	6	7

SECCIÓN E: PRODUCTOS Y LÍNEAS DE PRODUCTO **Señale su valoración respecto al grado de aplicación en su planta de los siguientes conceptos... (1 = nada aplicado y 7= totalmente aplicado)**

En general nuestra planta….							
….puede operar a diferentes VOLÚMENES DE PRODUCCIÓN	1	2	3	4	5	6	7
…produce un amplio NÚMERO DE LÍNEAS DE PRODUCTOS	1	2	3	4	5	6	7
…realiza un amplio NÚMERO DE MODIFICACIONES DE PRODUCTO cada año	1	2	3	4	5	6	7
…introduce un amplio NÚMERO DE PRODUCTOS NUEVOS cada año	1	2	3	4	5	6	7
…dispone de un amplio NÚMERO DE OPCIONES DE PLAZOS DE ENTREGA del producto	1	2	3	4	5	6	7
En nuestra planta se considera que DIFIEREN SIGNIFICATIVAMENTE ENTRE SÍ….							
…los volúmenes de producción de un periodo a otro	1	2	3	4	5	6	7
…los requisitos de procesamiento de las líneas de productos	1	2	3	4	5	6	7
…las modificaciones efectuadas sobre los productos actuales	1	2	3	4	5	6	7
…los productos introducidos con respecto a los productos actuales	1	2	3	4	5	6	7
…los plazos de entrega a disposición del cliente	1	2	3	4	5	6	7
En general considera que PUEDEN REALIZARSE FÁCIL Y RÁPIDAMENTE…							
.. cambios en los VOLÚMENES de producción	1	2	3	4	5	6	7
…cambios en el MIX de productos	1	2	3	4	5	6	7
…MODIFICACIONES de los productos	1	2	3	4	5	6	7
…INTRODUCCIONES DE NUEVOS PRODUCTOS	1	2	3	4	5	6	7
…cambios en los PLAZOS DE ENTREGA	1	2	3	4	5	6	7
En general diría que NO SE INCURREN EN ALTOS COSTES cuando…							
…se altera el VOLUMEN de producción	1	2	3	4	5	6	7
…se altera el MIX de productos	1	2	3	4	5	6	7
…se realizan MODIFICACIONES DE PRODUCTOS	1	2	3	4	5	6	7
…se desarrollan e introducen NUEVOS PRODUCTOS	1	2	3	4	5	6	7
…se varían los PLAZOS DE ENTREGA	1	2	3	4	5	6	7
En general, diría que LA CALIDAD DE LOS PRODUCTOS NO SE VE AFECTADA cuando….							
…se altera el VOLUMEN de producción	1	2	3	4	5	6	7
…se altera el MIX de productos	1	2	3	4	5	6	7
…se introduce un PRODUCTO MODIFICADO	1	2	3	4	5	6	7
…se introduce UN NUEVO PRODUCTO	1	2	3	4	5	6	7
En general, diría que LA EFICIENCIA DEL PROCESO PRODUCTIVO NO SE VE AFECTADA cuando …							
…se altera el VOLUMEN de producción	1	2	3	4	5	6	7
…se altera el MIX de productos	1	2	3	4	5	6	7
...se introduce un PRODUCTO MODIFICADO	1	2	3	4	5	6	7
…se incorpora un NUEVO PRODUCTO	1	2	3	4	5	6	7
El ratio de entregas erróneas se mantiene estable cuando los clientes modifican los plazos de entrega	1	2	3	4	5	6	7

SECCIÓN G:

Señale su valoración respecto al grado de aplicación en su planta de los siguientes conceptos... (1 = nada aplicado y 7= totalmente aplicado)							
La programación del sistema de manufactura permite al mismo procesar, sin ser atendido durante un periodo largo de tiempo….							
…un alto número de productos o partes	1	2	3	4	5	6	7
…productos o partes significativamente diferentes entre sí.	1	2	3	4	5	6	7
El flujo de fabricación permite procesar…							
…una amplia variedad de productos o partes	1	2	3	4	5	6	7
…productos/ partes que difieren significativamente entre sí	1	2	3	4	5	6	7
La eficiencia del sistema de producción no se ve afectada por…							
…cambios en la programación prevista	1	2	3	4	5	6	7
… cambios en el flujo de fabricación	1	2	3	4	5	6	7
Se considera que puede realizarse fácil y rápidamente cambios en….							
… la programación del sistema de manufactura	1	2	3	4	5	6	7
… el flujo de fabricación	1	2	3	4	5	6	7
En general no se incurren en altos costes cuando variamos…							
… la programación del sistema de manufactura	1	2	3	4	5	6	7
…el flujo de fabricación	1	2	3	4	5	6	7