Pontifícia Universidade Católica
do Rio de Janeiro

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Design-Manufacturing Integration impact on Manufacturing Operational Performance

Dissertação de Mestrado

Thesis presented to the Programa de Pós-Graduação em Engenharia de Produção of the Departamento de Engenharia Industrial, PUC-Rio as partial fulfillment of the requirements for the degree of Mestre em Engenharia de Produção.

Advisor: Prof. Luiz Felipe Roris Rodriguez Scavarda do Carmo

Co-Advisor: Prof. Antônio Márcio Tavares Thomé

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Abstract

Fernández, Paula Suclla; Carmo, Luiz Felipe Roris Rodriguez Scavarda do (Advisor), Thomé, Antônio Márcio Tavares (Co-Advisor). **Design-Manufacturing Integration Impact on Manufacturing Operational Performance.** Rio de Janeiro, 2015. 76p. M.Sc. Dissertação – Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro

Design-Manufacturing Integration (DMI) is a new and growing research field in Operations Management. The primary goal of the Dissertation is to identify and measure the DMI impact on manufacturing operational performance. The research findings point to a paucity of rigorous empirical research on the impact of DMI on manufacturing operational performance under the lens of moderating effects of market uncertainty and market complexity. Data from 725 metal products and machinery manufacturers (ISIC 3.1, code 28-35) in 21 countries from the fifth round of the International Manufacturing Strategy Survey was used for hypotheses tests. Scales were validated with confirmatory factor analysis and analyzed with hierarchical stepwise multiple regressions. DMI positively impact on the three dimensions of manufacturing operational performance (quality, flexibility, and delivery). Manufacturing complexity moderates flexibility and delivery but not quality. Market uncertainty did not appear as a moderator for the relationship between DMI and manufacturing operational performance. Practitioners should pursue DMI implementations, under higher levels of manufacturing complexity. Further research should focus on market uncertainty, and strengthen the construct of uncertainty with technological uncertainty.

Keywords

New product development; manufacturing operational performance; contingency theory; structural equation modeling; stepwise multiple regression.

Resumo

Fernández, Paula Suclla; Carmo, Luiz Felipe Roris Rodrigues Scavarda do (Orientador), Thomé, Antônio Márcio Tavares (Coorientador). **Impacto da Integração de projeto e manufatura no Desempenho Operacional de Manufatura.** Rio de Janeiro, 2015. 76p. M.Sc. Dissertação – Departamento de Engenharia Industrial, Pontifícia Universidade Católica do Rio de Janeiro

Esta dissertação aborda o tema de Integração de Projeto e Manufatura, designado pelo acrônimo inglês de DMI (“Design-Manufacuring Integration”). Trata-se de um novo e crescente campo de pesquisa dentro da Gerência de Operações. DMI é definido como um conjunto de práticas de integração, coordenação e colaboração, que unificam diferentes áreas funcionais da organização (e.g., vendas, marketing, desenvolvimento de novos produtos, manufatura e compras) com a finalidade de criar valor e impacto no desempenho das empresas. Nas últimas décadas, as organizações estão enfrentando uma feroz concorrência e competem simultaneamente em qualidade, eficiência, flexibilidade e entrega de produtos cada vez mais complexos, com ciclos de vida mais curtos e demandas flutuantes. Por conseguinte, requerimentos de sistemas de planejamento e controle em empresas de manufatura são cada vez mais complexos. Esse contexto levanta a seguinte questão de pesquisa: "Em diferentes contextos do ambiente em que se desenvolve a organização, as práticas de integração produzem o mesmo impacto sobre o desempenho? ” Resultados da pesquisa apontam para uma escassez de pesquisas empíricas rigorosas sobre o impacto do DMI no desempenho operacional da manufatura, sob a lente de efeitos moderadores da incerteza do mercado e da complexidade do mercado. Incerteza é entendida como a falta de habilidade de predizer ou prever devido à aleatoriedade do ambiente externo, que não pode ser alterado pelas ações das empresas individuais ou gerentes; e complexidade é entendido como sendo o estado ou qualidade de ser intricado ou complicado. O objetivo principal da Dissertação é identificar e medir o impacto do DMI sobre o desempenho operacional da manufatura, sob o efeito moderador da Complexidade da manufatura e da Incerteza do mercado. Os dados de 725 produtos da indústria de metal e fabricantes de máquinas (ISIC 3.1, código 28-35) foram obtidos em 21 países a partir da quinta rodada do International Manufacturing Strategy Survey e foram usados para testes das hipóteses. As escalas foram validadas por meio da análise fatorial confirmatória e analisadas com regressão múltipla hierárquica passo a passo. DMI impacta positivamente em três dimensões do desempenho operacional da manufatura (qualidade, flexibilidade e entregas). Complexidade da manufatura modera a flexibilidade e entrega, mas não a qualidade. A incerteza do mercado não apareceu como um moderador para a relação entre a DMI e desempenho operacional da manufatura. Profissionais devem perseguir implementações do DMI, em níveis mais elevados de complexidade de manufatura. Mais pesquisas devem se concentrar na incerteza do mercado, e fortalecer o construto de incerteza com a incerteza tecnológica.

Palavras Chave

Projeto de novos produtos; Desempenho operacional de Manufatura; Teoria de contingencia; Modelos de Equações Estruturais; Regressão Múltipla.

Summary

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1.
Introduction

Design-Manufacturing Integration (DMI) is a new and growing research field in Operations Management, repeatedly considered relevant to Manufacturing operational performance (Souder et al., 1998; Dekkers et al., 2013). DMI is a process based on interaction and collaboration in which different functional areas of the organization work together in a cooperative manner to arrive at acceptable outcomes (Pagell, 2004). Companies are facing fierce competition and are competing simultaneously in quality, cost-efficiency, flexibility and consistent delivery of more complex products, with shorter life-cycles and fluctuating demand (Liker et al. 1999). Consequently, requests for planning and control systems in manufacturing firms are increasingly more complex (Thomé et al. 2014b). This context raises the following research question: "does some practices of integration have the same impact on performance under different environments?" In this context, not much has been said about the effects of market uncertainty and manufacturing complexity on this integration-performance relationship. It is an assumption of this dissertation that uncertainty moderates this relationship. Design-manufacturing integration is considered highly important to manufacturing operational performance when market uncertainty and manufacturing complexity are high and less important when those environments are less uncertain. This expectation would be consistent with the postulates of contingency theory (Donaldson, 2001).

This Master Thesis intends to contribute to filling this gap with the research goal of measuring the impact of DMI practices on manufacturing operational performance and test the moderating effect of manufacturing complexity and market uncertainty. It is grounded in what Sousa and Voss (2008) termed operations management practice contingency research (OM-PCR) or the application of a contingency approach to the study of OM best practices. It is based on a dataset of 725 companies from 21 countries, gathered in 2009-2010 as part of the fifth round of the International Manufacturing Strategy Survey (IMSS-V). The IMSS is a research network of operations management schools and assembly manufacturing firms. It was carried out in 1992, 1996, 2001, 2005, 2009 and 2013-2014 first by the London Business School and Chalmers University of Technology and today the research is coordinated by Politecnico di Milano (Italy). Figure 1.1 shows the evolution of the number of countries considered in each round and Table 1.1 shows the types of companies selected in the assembly industry.

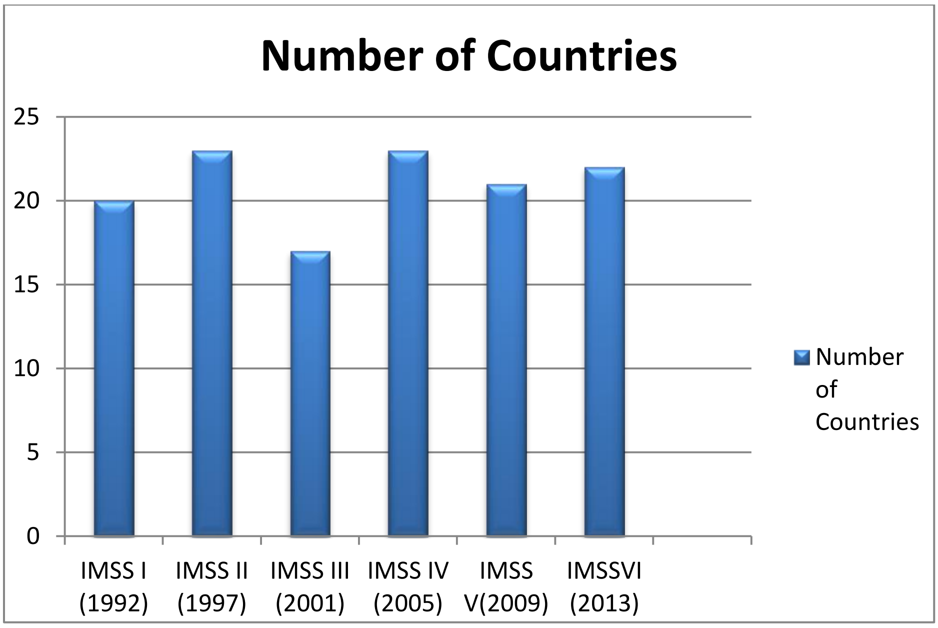

Figure 1.1 Numbers of Countries (*IMSS, 2015*)

Table 1.1 Types of Companies in the IMSS *(*IMSS, 2015)

ISIC code	**Industry Description**
25	Manufacture of fabricated metal products, except machinery and equipment
26	Manufacture of computer, electronic and optical products
27	Manufacture of electrical equipment
28	Manufacture of machinery and equipment not elsewhere classified
29	Manufacture of motor vehicle, trailers and semi-trailers
30	Manufacture of other transport equipment

The IMSS project was chosen because it gives us the possibility of understand the nature and quality of manufacturing's responses under different national and industrial contexts through the investigation about strategies and practices in industrialized nations throughout the world.

This Master Thesis investigates the direct relationships between the use of DMI practices and the different dimensions of manufacturing operational performance of quality, flexibility, and delivery. The moderating effect of market uncertainty and manufacturing complexity are also put to the empirical test, with the backdrop of contingency theory research. The statistical analysis of the data was based on Da Silveira and Sousa, (2010); Thomé et al. (2014a, 2014b) and He et al. (2014). They applied dispersion and distribution measures to the IMMS survey, also performed the analyses of the data through confirmatory factor analysis and stepwise multiple linear regressions.

The Thesis seeks to offer several significant contributions. First, it seems to be the first study to measure DMI as a second-order construct with three latent variables: i) Products; ii) People and iii) Tools. Second, the individual impact of DMI on different dimensions of operational performance is empirically tested, rather than using a unique dimension of manufacturing performance or a general measure of business performance. Third, it is the first attempt to apply two complex types of contingency to DMI explicitly and be empirically tested: (i) Market uncertainty; and (ii) Manufacturing complexity. For practitioners, the study intends to shed light about under what environmental context DMI contributes the most to manufacturing performance.

The structure of the Thesis is as follows. After this introduction, the theoretical foundations of the empirical research and basic concepts are defined in Chapter two. The empirical investigation of DMI impact on manufacturing operational performance, and the test of moderating effects of contingency theory are described in Chapter three, where the methodology, theoretical models, and results are presented and discussed. Findings are further debated in Chapter four. Finally, conclusions are offered in Chapter five.

2.
Theoretical foundations: definitions and basic concepts

This chapter covers the definitions and basic concepts of Design-Manufacturing Integration. First, a definitional synthesis of DMI comprising a set of management practices deemed necessary for the planning process to succeed is proposed, as well as its impact on Manufacturing Operational Performance. Second, the fundamental concepts of Contingency theory are analyzed with an emphasis on moderating effects. Third basics concepts of Market Uncertainty and Manufacturing Complexity are presented. Therefore, the chapter starts with an overview on DMI; then it defines DMI as a second-order construct, discusses DMI and the impact on performance. Next the chapter offers an OM perspective for contingency theory. Finally, contingency applications are presented for market uncertainty and manufacturing complexity. The theoretical foundation was guided by a systematic literature review in the Science Direct database. This database contains main journals of new product development (NPD), such as Journal of Product Innovation Management and Technovation (Table 2.1), among others. A total of 64 articles was obtained for full-text review. Thirty-one additional articles were retrieved by backward searching on the references made in the articles selected from Science Direct, following the “six-step approach” of Thomé et al. (2012a, 2014a). In total 95 articles were gathered, and full-text reviewed.

Table 2.1 Classification of Journals.

Journal	Articles retrieved	%	% cumulate
Journal of Product Innovation Management	10	16%	16%
Technovation	10	16%	31%
Journal of Operations Management	8	13%	44%
Industrial Marketing Management	9	14%	58%
Journal of Business Research	5	8%	66%
International Journal of Production Economics	4	6%	72%
Journal of Engineering and Technology Management	4	6%	78%
International Journal of Research in Marketing	3	5%	83%
Journal of Business Venturing	1	2%	84%
The Journal of High Technology Management Research	2	3%	88%
Long Range Planning	1	2%	89%
Technological Forecasting and Social Change	1	2%	91%
European Journal of Purchasing & Supply Management	1	2%	92%
International Journal of Project Management	1	2%	94%
Knowledge-Based Systems	1	2%	95%
Procedia - Social and Behavioral Sciences	1	2%	97%
Research Policy	1	2%	98%
Australasian Marketing Journal (AMJ)	1	2%	100%

2.1
Overview on DMI

An emerging topic of relevance in operations management has been the issue of integrative decision-making, and the interaction between two or more functional areas in an organization. Several studies in the literature have been focused on practices to improve integrative decision making (Calantone et al. 2002; Boyle et al., 2006; Swink and Song, 2007; Thomé et al., 2012a, 2014a). Following Pagell's (2004) definition of integration, DMI is a process based on interaction and collaboration in which different functional areas of the organization work together in a cooperative manner to arrive at acceptable outcomes for their organization. Consistent with Dekkers et al. (2013) the terms "design and manufacturing integration (DMI)" and NPD will be treated interchangeably within this master thesis.

Kahn and Mentzer (1998) state that DMI is a process of interdepartmental interaction, and collaboration that links departments into an interconnected organization. Interactions are used to establish contacts, further led by a collaborative process. According to Lawrence and Lorsch (1967) formal devices had emerged to achieve coordination among departments (e.g., NPD, cross-functional coordinating teams and task forces).

DMI is the coordination of strategies and functional activities between design and manufacturing to reach mutually acceptable outcomes for their organization (Thomas, 2013). This approach, based on the collaboration and communication among functional areas of product development is consistent with other studies of cross-functional integration in NPD. (Swink, 1999; Pagell, 2004; Chen et al., 2010). According to Drögue et al. (2004), internal integration cannot be fully achieved by the use of boundary-spanning practices alone. Instead requires management tools with technology tools such as Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM).

Boyle et al. (2006) captures DMI using two principal practices: (i) cross functional integration and (ii) concurrent engineering. In addition, Boyle et al., (2006) suggest several methods to implement DMI classified into: process focused (e.g., top management support, design for manufacture, project specification, project planning); people focused (e.g. job rotation, joint design reviews, concurrent process) and tools (e.g., shared databases, simulation tools). Other studies relate DMI to Concurrent Engineering (CE) practices, defined as the inclusion of manufacturing factors early in the product design phase (Abdalla, 1999). These factors include product functionality, manufacturing, assembly, testing, maintenance, reliability, cost, and quality. Koufteros et al. (2005) defines concurrent engineering as the early involvement of a cross-functional team in a process to plan product design, process design, and manufacturing activities simultaneously.

Consistent with NPD Concurrency, DMI is a systematic approach involving integrated design of products and their related manufacturing and support processes. DMI captures two types of concurrency: i) process concurrency (i.e. encompassing upstream and downstream decisions) and ii) product concurrency (i.e. representing the precursor considerations of the new product) (Jayaram and Malhotra, 2010),

The essence of DMI is not only the concurrence of the activities but also the cooperative effort from all parties involved, which leads to improving profitability and competitiveness. Being an approach for improving performance (e.g., delivery, quality and flexibility; see Section 2.2.), which occurs partly through overlap (i.e. partially or completely parallel execution) and interaction (exchange of information) of certain activities in the NPD process (Gerwin and Barrowman, 2002). DMI is also important because it is at the design stage that such aspects as product quality and cost are specified first.

DMI importance to manufacturing performance is well established (see Section 2.2. DMI and the Impact on Performance), and several approaches to achieve such integration have been suggested. Table 2.1 summarizes main studies related to the operationalization of DMI constructs used in the literature. These commonly researched constructs do not have a single, accepted definition or operationalization. However, it should be clear from Table 2.2 that the various definitions and operationalization do share some common themes and tend to overlap in content.

Table 2.2 Definitions of integrative construct

Reference	**Focus of Study**	**Definition**
Kahn and McDonough (1997)	New Product Development	Integration as a multidimensional process including communication components, interaction, and collaboration.
Song et al. (1997)	New Product Development	Series of steps or activities including idea generation, product development and product commercialization linked through cross-functional cooperation.
Kahn and Mentzer (1998)	Marketing and other departments	Interaction and collaboration where collaboration is more important than interaction.
Souder et al. (1998)	New Product Development and R&D	Collaboration between R&D and marketing personnel purchasing new product goals
Abdalla (1999)	Global Manufacture	Consideration of the factors involved in manufacturing during the design phase.
Stank et al. (1999)	Marketing and Logistics	Interaction, communication and collaboration between departments
Swink (1999)	Product Development and Technological Innovation	Coordination of the scheduling of the various disciplines and organizational functions
Calantone et al. (2002)	Marketing and Manufacturing	Cross-functional Integration
O'Leary –Kelly and Flores (2002)	Marketing and Manufacturing	The extent to which separate parties work together in a cooperative manner to achieve mutually acceptable outcomes.
Parente et al. (2002)	Sales and Production Relationship	Cross-functional integration
Gimenez and Ventura (2003)	Supply Chain	Internal integration as collaboration among internal processes before implementing Supply Chain Management (SCM).
Sánchez and Perez (2003a)	New Product Development	Cooperation, Concurrent Engineering, Multifunctional teams, Design For Manufacturability (DFM)
Drögue et al. (2004)	Supply Chain	Internal integration as practices encompassing design requirements and process capabilities (e.g. concurrent engineering, DFM*, CAD and CAM)

Reference	Focus of Study	Definition
Pagell (2004)	Supply Chain	Internal integration as interaction and collaboration between different areas of the organization
Koufteros et al. (2005)	Supply Chain	Internal integration as concurrent engineering- early involvement of cross-functional team, promoting external integration.
Boyle et al. (2006)	Integrated Product Development Diffusion	The early and active involvement of design, manufacturing, and marketing. Achieving cross-functional integration and concurrent execution of various activities.
Swink et al. (2007)	Strategic Integration on Manufacturing Plants	Co-developing products and processes are sharing information.
Nakano (2009)	Supply Chain	Internal Integration through sharing resources (i.e. standardized information and customized information) and collaboration (e.g. schedule established)
Daugherty et al. (2009)	Marketing and Logistics	Bring all departments together into a cohesive organization through coordination and collaboration.
Chen et al. (2010)	New Product Development	Interactive and collaborative interdepartmental integration
Jayaram and Malhotra (2010)	New Product Development Concurrency	Systematic approach involving integrated design of products and their related manufacturing and support processes
Thomas (2013)	Supplier Integration	Coordination of strategies and functional activities between design and manufacturing to reach mutually acceptable outcomes

Note (*)
DFM: Design for Manufacturing

Based on prior definitions and empirical tests (Section 3) DMI is defined as a second-order construct comprising three latent constructs: (i) Products; (ii) People and (iii) Tools. As such, the DMI construct is composed of several practices enabling better integration and coordination (Table 2.3).

Table 2.3 DMI second order construct

Latent Construct/ Practice	Practice Definition
Products	
Design Integration	Plant design/organization design, especially between product development (Boujut and Laureillard, 2002)
Technological Integration	Integration between product development and manufacturing through e.g. CAD – CAM, (International Manufacturing Strategy Survey)
Design for Manufacturing	The practice of designing products with manufacturing in mind. (O'Driscoll, 2002)
People Focused	
Job-Rotation	People are rotating in different departments e.g. design people working in manufacturing. (Boyle et al., 2006)
Co-location	Bringing personnel together from different departments into the same physical location (Kahn and McDonough, 1997)
Tools	
Failure Mode and Effect Analysis (FMEA)	FMEA is an integrated approach for product design and process control (Teng and Ho, 1996).
Quality Function Deployment (QFD)	A method designed to identify and interpret needs and wants and transform them into technical requirements (Nijssen and Frambach, 2000)

2.2.
DMI and the impact on Performance

The literature offers several studies on integration focused on operational improvements in specific areas, such as forecast, inventory, management and balance of the mix and the volume of products, and capacity resources. In all cases, the performance of the company was measured differently. Among the 95 papers reviewed, just twenty papers analyzed the impact of DMI practices on the performance of the firm; finding mix results (see Table 2.3.).

Several studies found empirical evidence of a direct effect of internal cross-functional integration on performance (Stank et al., 1999; Swink et al., 2007; Daugherty et al., 2009; Nakano, 2009).

According to Stank et al. (1999), DMI is directly related to firm's competitiveness and profitability through improvements in cycle time. Swink et al., (2007) found that product-process integration is associated with better quality, delivery, and flexibility, with a more significant impact on flexibility. Companies achieving higher levels of internal integration enjoy the higher absolute performance (e.g., achieving cost, stock-out, and lead time reductions) than those with lower levels of internal integration (Gimenez and Ventura, 2003). According to Nakano, (2009), internal collaboration has a significant effect on logistics and production performance (i.e. cost, product quality, delivery speed, and new product introduction time). For consumer products, manufacturers with a high intensity of integration achieve superior product quality, delivery reliability, process flexibility and cost leadership (Rosenzweig et al., 2003).

Internal integration was also reported to improve performance in the areas of customer service, better management of inventory, higher forecast accuracy and greater customer and employee satisfaction. (Kahn and Mentzer, 1998; Stank et al., 1999). Equally, internal integration is conducive to external integration as there is a timely exchange of critical information amongst supply chain partners. In addition, internal integration was shown to impact information technology (IT) capability (Daugherty et al., 2009).

Kahn and Mentzer (1998) found a significant impact of collaboration on performance outcome, but interaction (e.g. meetings, document exchange) had no significant positive relationship with performance. The authors recommended that interdepartmental integration should emphasize a collaboration component, to achieve better performance.

Some studies did not find a direct relationship between internal integration and performance. Giménez and Ventura (2005) examined the integration between logistic-production and logistic–marketing, presenting two different stages: i) high level of collaborating relationship, where neither logistic-production nor logistic-marketing present a direct effect on performance; and ii) low level of collaborating relationship, where the integration between logistic-production has a positive effect on firm's performance. Similarly, Koufteros et al. (2005) did not find direct effects between internal integration and competitive capabilities but found an indirect effect on product innovation and quality. Chen et al., (2010) did not find a positive relationship between interdepartmental integration and new product competitive advantage.

Other studies found that the effect of DMI on performance was contingent upon a number of factors such as business strategy and demand uncertainty (Souder et al., 1998; Calantone et al., 2002; O'Leary and Flores, 2002). Souder et al., (1998) affirmed the importance of R&D and marketing integration on performance. In addition, the contingency theory prediction that high degrees of integration are important in high uncertainty environment was tested, meeting with mixed results. Parente et al. (2002) found that integration activities between sales and production enhance the customer's perception of satisfaction. This positive effect on performance was contingent upon the type of production (i.e. order-type as engineering-to-order). Swink (1999) found that collaborative integration improve time to market and financial performance. Also, integration mitigates the negative effects exerted by the complexity of projects. In Table 2.4 we made a synthesis of the impacts of DMI on performance.

Table 2.4. Performance Measurement

Authors/ Year	**Name**	**Determinant**	**Impact on Performance**	**Results**
Kahn and McDonough (1997)	An empirical study of the relationships among co-location, integration, performance, and satisfaction	Interdepartmental integration	Product performance	Collaboration appears to promote performance and satisfaction factors
Kahn and Mentzer (1998)	Marketing's Integration with other Departments	Interaction and Collaboration	Marketing, company, product development and product management performance	Collaboration has a positive impact on performance while interactions do not.
Souder et al. (1998)	Environmental Uncertainty, Organizational Integration, and New Product Development Effectiveness: a Test of Contingency Theory	R&D and Marketing Integration	Cycle time, Prototype development proficiency, Design change frequency.	The positive impact of R&D and Marketing integration on performance with mixed results of environmental contingency.
Stank et al. (1999)	Marketing/Logistics Integration and Firm Performance	Interfunctional Integration: Marketing/Logistics	Logistics performance: Cycle time	DMI is directly related to firm's competitiveness and profitability through improvements in cycle time.
Swink (1999)	Threats to New Product Manufacturability and the effects of development team integration processes	Collaborative work. Manufacturing involvement.	New Product Performance	Improve time, market and financial performance. Also integration alleviates the negative impacts of project complexity and design outsourcing, exerting a moderator effect.
Swink (2000)	Technological innovativeness as a moderator of New Product Design	Design Integration	Development Time, Design Quality, Financial	DI is not always associated with high levels

Authors/ Year	Name	Determinant	Impact on Performance	Results
	Integration and Top Management support		Performance	of performance. Is most valuable in contexts of high uncertainty and the benefits do not span over all aspects of NPD effectiveness
Parente et a.l (2002)	An exploratory study of the Sales-Production relationship and customer satisfaction	Sales- Production cross-functional coordination, connectedness	Customer satisfaction: Product availability, on-time delivery.	The higher the interdepartmental connectedness, the higher the customer satisfaction. This relationship is affected by product type.
Gimenez and Ventura (2003)	Supply Chain Management as a Competitive Advantage in the Spanish Grocery Sector	Internal Integration and External Integration	Cost and Logistics Performance.	Companies achieving the higher levels of internal integration enjoy, the higher absolute performance (e.g. achieving cost, stock-out, and lead time reductions) than those with lower levels.
Rosenzweig et al. (2003)	The influence of an integration strategy on competitive capabilities and business performance: an exploratory study of consumer products manufacturers	Supply Chain Internal and external Integration	Quality, delivery reliability, process flexibility, and cost leadership.	Consumer products manufacturers with high integration intensity achieve superior product quality, delivery reliability, process flexibility, and cost leadership.
Sánchez and Pérez	Cooperation and the Ability to	Cross-functional design	Cost and Time	Design-Manufacturing

Authors/ Year	Name	Determinant	Impact on Performance	Results
(2003a)	Minimize the Time and Cost of New Product Development within the Spanish Automotive Supplier Industry			Interface and Cross-Functional Design were related positively to the NPD time and cost minimization abilities in a sub-sample of high cooperation companies.
Sánchez and Pérez (2003, b)	Flexibility in new product development: a survey of practices and its relationship with the products technological complexity	Cooperation activities. (Cross-functional design integration and Design – manufacturing integration)	Cost and Time	Cross-functional design and design-manufacturing interface both positively explained the cost introduction advantage of the surveyed companies in product development and cooperation explained positively the new product introduction time.
Drögue et al. (2004)	The effects of internal versus external integration practices on time-based performance and overall firm performance	Internal (i.e. CAD, CAM, and DFM) and external Design Process Integration	Time to market, Product Cycle time and Responsiveness.	Internal Design process integration has a direct positive impact on performance.
Gimenez and Ventura (2005)	Logistics-Production, Logistics-Marketing and external integration. Their impact on performance.	Logistic-production and Logistic–marketing	Logistics Performance	Neither logistic-production nor logistic-marketing has a direct effect on performance
Koufteros et al. (2005)	Internal and External Integration for Product Development: The Contingency Effects of Uncertainty, Equivocality, and Platform Strategy	Internal and External Integration	Product Innovation and Quality	Found no direct effects of internal integration and competitive capabilities but found an indirect effect on product innovation and

Authors/ Year	Name	Determinant	Impact on Performance	Results
				quality
Swink and Song (2007)	Effects of marketing-manufacturing integration (MMI) on new product development and competitive advantage	Marketing-Manufacturing Integration	Quality Return on Investment (ROI)	Findings support the theory that integration leads to greater product design quality. MMI is strongly associated with greater product competitive advantage, which in turn is a strong driver of ROI
Swink et al. (2007)	Managing beyond the factory walls: Effect of four types of strategic integration on manufacturing plant Performance	Product-Process technology integration	Cost Efficiency, Quality, Delivery, Process flexibility and New Product flexibility	Product-process integration is associated with better quality, delivery, and flexibility, with a stronger effect on flexibility
Matsui et al.(2007)	A comparative analysis of new product development by Italian and Japanese manufacturing companies: A case study	Concurrent Approach	Financial profit goals and revenue goals	Cross-functional linkages among marketing, manufacturing and design personnel are beneficial for new product performance, with a direct impact on timing and financial successful.
García et al. (2008)	New product Internal performance and market performance: Evidence from Spanish firms regarding the role of trust, inter-functional integration, and innovation type.	Inter-functional integration. Trust	Market success (met time)	The three dimensions of internal performance are positively and significantly associated with market performance.

Authors/ Year	Name	Determinant	Impact on Performance	Results
Chen et al. (2010)	The performance impact of Post Merger and Acquisition M&A: an interdepartmental integration: An empirical analysis	Post M&A Interdepartmental Integration (interaction and collaboration)	NPD performance	Interdepartmental integration is positively correlated with product vision. Interdepartmental integration was not significantly correlated with new product competitive advantage.

The direct impact of DMI on Manufacturing Performance has been shown to be important and well-studied, as highlighted in Table 2.2. However, what is not yet completely understood from past research is if the impact of DMI on Manufacturing Performance will be the same for different environmental characteristics. In other words, the relationship DMI- Manufacturing Performance is moderated by environmental factors.

2.3.
Contingency theory from an OM perspective

This review of basic concepts relating to contingency theory and its implementation in the field of OM will be restricted to basic concepts necessary to situate the empirical research formulated and discussed in Chapter 3.

Several practices in literature have attained a strong dogmatic posture and have often been promoted as universally applicable to organizations and organizational activities. These practices along the time have developed and improved emerging doubts about their universal validity and problems in implementing these best practices. Against this background, researchers in OM practices have begun to change their interest to understand the contextual conditions under those practices are effective instead of justifying their value. Sousa and Voss (2008) were among the first to call for a systematic investigation of contingent effects in the field of OM. They named this approach Operations Management Practice Contingency Research (OM – PCR).

According to Donaldson (2001), contingency is defined as any variable that moderates the effect of an organizational characteristic in organizational performance. According to Kahn and McDonough (1997), a moderating variable is a variable which systematically modifies either the form or a criterion variable (i.e. the effect of one variable (X) on a second variable (Y) is affected by a third variable (Z)) (See Figure 2.1). In addition structural contingency presents three types of contingencies: i) environment; ii) size and iii) strategy. Changes in any of these contingencies tend to produce a change in the corresponding structural aspect (Kahn and McDonough, 1997).

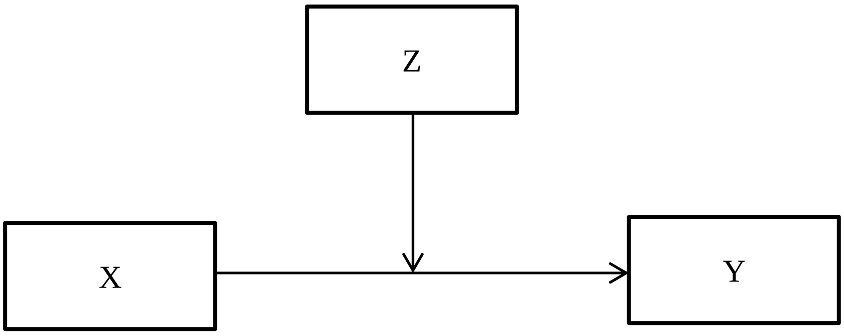

Figura 2.1. Contingency theory: moderator variable

Structural contingency is a dynamic theory, as organizations are changing over the time. These changes lead the organization out of fit with the old structure and with lower performance. Organizations face the necessity of adapting their structures to fit the new environment in order to restore their performance (Donaldson, 2001).

According to Donaldson (2001), the theory of structural contingency state that there are two main contingencies, task, and size; where task contingency is composed of task uncertainty and task interdependencies. He also proposed two contingency theories of organizational structure:

i) organic theory, where task contingency is the main contingency; and

ii) Bureaucracy theory, where size is their main contingency. In both cases, task interdependence plays a minor role.

In addition, contingency theory can be subdivided into three main areas:

i) Uncertainty, diversity and complexity (i.e. the harmonization of organizational structures and the environment);

ii) The effect of technology on performance; and

iii) The study of the relationships between company size and structure.

Viewed with the lenses of contingency theory, we will study whether the effect of DMI on manufacturing performance is modified by Manufacturing Complexity and Market Uncertainty. That is if the relationship between DMI-Manufacturing Performance is moderated by a third variable; tested in Chapter 3.

2.4. Contingency Applications

This section presents applications of contingency theory, developing concepts of Market uncertainty and Manufacturing complexity as moderator variables, followed by a literature review of their impact on the relationship DMI-Manufacturing operational performance.

2.4.1. Market Uncertainty

Uncertainty is the lack of ability to predict or foresee. As Calantone et al. (2002) emphasize, uncertainty is the unpredictability of products, competitors, and consumers. Folta and O'brien (2004) define uncertainty as the randomness of the external environment that cannot be altered by the actions of individual firms or managers. It is not simply a variation or quick change; variation or quick but entirely predictable change does not generate uncertainty. Uncertainty emerges when a decision maker cannot consistently predict future events based on information that she possesses (Anderson and Tushman, 2001). The environment in which a firm competes affects the mechanism it uses to adapt to NPD (Jeong et al., 2006). Uncertainty is hazardous for firms because it creates confusion about the objectives of NPD and how decisions should be made. It challenges the capability of the organization to understand thoroughly or accurately predict key aspects of the environment, more easily deviating from fulfilling their strategic goal. (Swink, 2000; Aronson et al., 2006; Ho and Tsai, 2011).

Several researchers (e.g. Sutcliffe and Zaheer, 1998) stated that uncertainty is a complex construct resulting from different sources that include customers, suppliers, competitors, technology and so forth. Sutcliffe and Zaheer (1998) classify uncertainty as: (i) primary (i.e. exogenous sources), (ii) competitive (i.e. moves or signal by economic actors) and (iii) supplier-related (i.e. actions of the exchange partner firm). Strategic decisions about firm scope are critically affected both by exogenous events and by the actions of a competitor, suppliers, and buyers.

Organizational theory suggests two types of uncertainty: (i) External uncertainty and (ii) Internal Uncertainty; both impacts organizational structure and performance. External uncertainty shapes the interaction among individuals, organizational structure, and performance. Several authors define technical and market uncertainties as main sources of external uncertainty. (Aronson et al., 2006; Jeong et al., 2006; Land et al., 2012). According to Song et al. (1997) market and technological uncertainty are external forces that affect companies and their methods of operations. These external forces are also called environmental turbulence because the environment in which a firm competes affects the mechanisms it uses to adopt NPD. The ambiguity and uncertainty of customers, technology, and competition challenge the organization's ability to function solely on a rational basis. (Ho and Tsai, 2011).

Technical uncertainty is related to the lack of knowledge about the exact means to accomplish a project. Some sources can cause technical uncertainty such as technological evolution, rates of technology change, among others. (Folta and O'Brien, 2004; Oriani and Sobrero, 2008)

For the purposes of this study, only Market Uncertainty will be treated. Market Uncertainty refers to the variability or volatility of markets, changes in the market structure, or in the degree of competition (Bstieler, 2005). Oriani and Sobrero, (2008) also called Market Uncertainty as Demand Uncertainty referring to the instability in the expected values of the demand for a product. According to Jeong et al. (2006) demand uncertainty is related to the concept of market turbulence; changing preferences of consumers is a source of demand uncertainty.

Souder et al. (1998) define market uncertainty as the lack of information, knowledge, and understanding of markets (e.g. uncertainties about product demands, a user needs, pricing, and distribution). It is also defined as the level of uncertainty that exists in the external environment, concerning determining the requirements that customers have about a product (MacCormack and Verganti, 2003). Market uncertainty can be measured in terms of variability, diversity and dynamics (e.g. changing consumers or changing preferences among consumers; supplier diversity) (Lu and Chyan, 2004). High market uncertainty results from a fast-changing market or an emerging, new market (Chen et al., 2010). A firm faces market uncertainty when it is unclear about the nature of a particular market and its ability to create a product that will succeed in that market. (Souder et al., 1998).

Prior studies focused on the moderating effects of manufacturing uncertainty in the relationships between Integration and Performance. However, mixed support for these notions has been reported in the literature. Therefore, a primary objective of this study is to test and attempt to reconcile these conflicting findings. The next section places the research in the field of market uncertainty as a moderator of the impact of DMI on manufacturing operational performance.

2.4.2 The Moderator effect of Market Uncertainty

When the market environment is predictable, well understood, and characterized by low rates of change, decisions and actions may be preprogrammed, and Design- Manufacturing Integration may be unnecessary. On the other hand, high degrees of DMI may be required to succeed under conditions of high market uncertainties, being an interpretation of the contingency theory adopted for this study. Through the 95 articles of the literature review mixed results supported this postulated moderator effects of market uncertainty on the relationship between Design-Manufacturing integration and Performance.

Calantone et al. (1997) found that the presence of environmental hostility magnified the positive influence of DMI activities on new product success. In this study, they recommended concurrent engineering for firms facing hostile environment conditions to simplify, speed up, and facilitate parallel processing of activities. The most successful firms will recognize, and will adapt to a hostile environment.

Other studies that do not use integration as a determinant of impact on performance, also studied the moderating effect of market uncertainty. Jeong et al. (2006) propose a direct impact of Organizational Support on Strategic orientation (i.e. market and technology orientations) and NPD Performance. Such relationship is moderated by market and technological uncertainty. The authors found that market turbulence enforces customer orientation, supporting the hypotheses of a moderating effect. High levels of environmental turbulence put pressure to adapt and becoming more efficient and effective. In addition Primo and Amundson, (2002) in their study of supply chain integration impact on NPD outcomes (i.e. Product quality, Product Development time, and cost) found a moderator role of uncertainty. This result is consistent with the contingency theory.

Calantone et al. (2002) proposed a model of antecedents (i.e. Marketing's Knowledge, communication, and integration) predicting Marketing-Manufacturing Integration and Quality under the lens of contingency theory. Results confirm the moderating effect of uncertainty on the link between communication/integration and Marketing Manufacturing Integration, but no moderating effect on Quality.

According to Calantone et al. (2002) the lack of moderating effect on quality may be due that marketing and manufacturing in companies with high rates of uncertainty are already so concerned on improving quality by necessity that increasing communication/integration has no further incremental or detrimental impact on quality.

In one hand, O'Leary-Kelly and Flores (2002) found partial support for the moderating effects of demand uncertainty on the relationship between the integration of manufacturing –planning process and firm performance. The level of integration was significantly associated with higher firm performance, for firms confronted with lower levels of demand uncertainty. However, higher levels of integration were not associated with higher firm performance for those firms facing higher levels of demand uncertainty.

In another hand, few studies relating DMI or different integration practices with performance do not find any moderating effect of uncertainty. Song et al. (1997) analyzes Market Uncertainty as external forces exerting an indirect effect on the relationship between cross-functional cooperation and performance, not finding any moderating effect between these variables.

Song et al. (1997) explained this lack of moderating effect as follows:

i) Internal mechanisms are at the operational level organizational design issues; while External forces (i.e. market uncertainty) typically impact the firm at the strategic decision-making level and superior echelons of organizations.

ii) Market uncertainty plays a role as the determinant of cross-functional cooperation and new product performance; that is the external environment may moderate the entire process rather than directly produce an effect.

Souder et al. (1998) studied the influence of R&D/Marketing Integration on Performance under the lens of contingency theory (i.e. environmental uncertainty). Finding similar results with Song et al. (1997), they find a low incidence of moderating effects. This lack of moderating effect could be because "the contingency theory of organizational design is delusory to reproducible testing in some product development environments, with the results varying according to where the projects lie on the uncertainty continuum" (Souder et al. 1998; p 530).

Koufteros et al. (2005) studied the influence of internal and external integration under the lens of contingency theory. They found the same results of the Impact of Integration on Performance under low and high uncertainty environments. In other words, they did not find a moderating effect. Such results were explained by the authors as the possibility of having failed in the operationalization of the construct of uncertainty, which was proposed as an unidimensional construct Table 2.5 summarizes the evidence of Moderating Effects of Market Uncertainty and Table 2.6 summarizes the evidence of the lack of Moderating Effect of Market Uncertainty.

Table 2.5 Evidence of Moderating Effects of Market Uncertainty

Authors	**Tittle**	**Determinant**	**Construct of Uncertainty**	**Impact on Performance**	**Moderating effects**
Calantone et al. (1997)	New Product Activities and Performance: The Moderating Role of Environmental Hostility	New product development activities (e.g. concurrent engineering, prototype)	Risk, few marketing opportunities and a lot of competition.	Speed to Market	The presence of environmental hostility magnified the positive influence of DMI activities on new product success.
Calantone et al. (2002)	Investigating the manufacturing-marketing interface in new product development: does context affect the strength of relationships?	Antecedents of Marketing-manufacturing integration (i.e. marketing's Knowledge, communication, and integration)	Environmental Uncertainty (e.g. demand uncertainty, competitors uncertainty)	Marketing-manufacturing integration and Quality	Uncertainty has a moderating effect on the relationship communication/integration and Marketing Manufacturing integration. No moderating effect on Quality.
Jeong et al. (2006)	Antecedents and consequences of the strategic orientations in New product Development: The case of Chinese manufacturers	Organizational Support	Market Uncertainty and Technological Uncertainty.	Strategic orientation (i.e. market or technological orientation). Successful New Product Development	Market turbulence enforces customer orientation, exerting a moderating effect.

Table 2.6 Evidence of the lack of Moderating Effect of Market Uncertainty.

Authors	**Tittle**	**Determinant**	**Construct of Uncertainty**	**Impact on Performance**	**Moderating effects**
Song et al. (1997)	Antecedents and Consequences of Cross-Functional Cooperation: A Comparison of R&D, Manufacturing, and Marketing Perspective	External Forces and internal facilitators	Demand Uncertainty	New Product performance in market	Did not find any moderating effect
Souder et al. (1998)	Environmental Uncertainty, Organizational Integration, and New Product Development Effectiveness: a Test of Contingency Theory	R&D / Marketing Integration	Market Uncertainty (i.e. uncertainties about product demands, user needs, pricing, and distribution) and Technological Uncertainty	Cycle time, Prototype development proficiency, Design change frequency	Low incidence of moderating effects
Koufteros et al. (2005)	Internal and External Integration for Product Development: The Contingency Effects of Uncertainty, Equivocality, and Platform Strategy	Internal and External Integration	External environment	Product Innovation and Quality	Did not find a moderating effect of uncertainty on Internal Integration – Performance relationships.

2.4.3.
Manufacturing Complexity

Complexity has been treated by several fields, including social sciences, biology, engineering, and management. (Adami, 2002; Bozarth et al., 2009; Guliciuc, 2014). Also, the term complexity was introduced in the organizational theory and extended to the supply chain management literature (e.g. Flynn and Flynn 1999; Choi et al., 2001). Manufacturing environments have augmented in complexity intensely as they have moved to manufacturing and competing in a global environment using advanced technology.

One simple definition of Complexity taken from Oxford Dictionary is: “The state or quality of being intricate or complicated”. Pursuant to Lawrence and Lorsch, (1967) definition of differentiation, complexity is the subdivision of a system into subsystems, being more of a division of labor. Oke et al. (2008) define Complexity as the number of interfaces that the design of the product requires. The degree of differentiation between the design expertise and the level of difficulty expected in the manufacture of the designed product compared to similar or substitute products. For Swink, (1999) complexity is inherent in the organizational size and technical range of the development project. As the number of organizational departments and technical specialists present or the project team increases, difficulties in coordination also increase.

The term “Complexity” and “Equivocality” can be used interchangeably since equivocality is defined as the presence of multiple and conflicting interpretations about a phenomenon that generates confusion and lack of understanding (Koufteros et al., 2005). Complexity is portrayed as being similar to uncertainty, but complexity presumes a messy, unclear field and an information stimulus that may have several interpretations while uncertainty is the lack of ability to predict or foresee.

Complexity has been measured with different variables like a product, technological and organizational variables creating a variety of definitions and applications depending on the perspective and theories (Vachon and Klassen, 2002). It can be encompassed in two major components. The first component is defined as the complexity internal to a firm, which is manufacturing complexity.

The second component involves complexity external to a firm, supply chain complexity. (Fynn and Flynn, 1999; Bozarth et al., 2009). For the purpose of this work, only manufacturing complexity is emphasized.

Bozarth et al. (2009) classify complexity in two types:

i) Detail complexity, measured by the number of parts or steps in manufacture.

ii) Dynamic complexity is the unpredictability to respond to a set of inputs generated by the interconnectedness of many parts.

Some examples of detail complexity are the number of active parts, number of products and shorter product life cycles while dynamic complexity can be represented by manufacturing schedule instability and volume batch production (i.e. one of a kind, small batch, large batch)among others.

According to Vachon and Klassen, (2002) complicatedness is an inherent characteristic of complexity. It concerns the level and type of interactions present in the system (e.g. number of tasks, number of products).

Labor diversity is also a source of manufacturing complexity since the manufacturing environment increases in complexity when the variety and volume of tasks increase as well as the sequence of movement of work between them. Consequently, employees face the need to restructure their activities. Other factors that contribute to labor diversity include employee layoffs and callbacks. (Flynn and Flynn, 1999). A bill of materials with a large number of levels is a driver for manufacturing complexity because tracking parts and coordinate information becomes more complicated than a shorter list.

Dalton and Lawrence (1970) measured product complexity by the number of steps or parts used in assembly, in a manner similar to the one proposed in this study of product complexity. Funk (1995) also measured product complexity by the number of steps or parts involved in product technology; and by the type of industries, ranging from low (process industries) to high complexity (metal fabrication and assembly).

Prior studies focused on the moderating effects of project complexity on the relationships between Integration and Performance, finding little information focused on the moderator effect of manufacturing complexity on DMI-Manufacturing Performance. However, mixed support for these notions has been reported in the literature. Therefore, a primary objective of this study is to test whether complexity interacts with DMI by positively moderating the impact of DMI on manufacturing operational performance, and reconciles these conflicting findings as reported in the literature. The next section places the research in the field of manufacturing complexity as a moderator variable.

2.4.4. The Moderator effect of Manufacturing Complexity

Many firms are facing an environment that is replete with change and complexity; these changes affect product performance, quality, length of product and life cycles, among others. Furthermore, as management best practices mature, a shift of interest has been driving from its impact on performance to the conditions under which it impacts will improve the performance (Sousa and Voss, 2008). Nevertheless among the 95 papers reviewed, several studies found empirical evidence of a direct impact of complexity on performance (Bozarth et al. 2009). Only a few articles refers to manufacturing complexity as a moderator of the impact of DMI on manufacturing operational performance (Crittenden, 1992; Koufteros et al., 2005). Other studies found that the effect of integration on performance was contingent upon manufacturing complexity (Thomé et al., 2014b).

Crittenden, (1992) who use a simulation approach, demonstrated that the relationship between the level of integration of manufacturing planning decisions and performance was moderated by production environmental conditions (e.g. complexity). Another analytical study by Kim et al.(1992) found that environmental complexity (i.e. degree of product variety) moderated the relationship between the level of integration and firm performance. Koufteros et al. (2005) who studied the influence of internal and external integration under the lens of contingency theory, found the same results of the moderating effect of manufacturing complexity.

Van Dierdonck and Miller (1980) examined the influence of environmental complexity on the need to integrate production planning decisions and performance, finding that complexity was not related to the relationship of integration and performance.

In summary, very little systematic (empirical or analytical) research has examined the impact of manufacturing complexity on the relationship between the DMI and manufacturing operational performance, which constitutes one of the key contributions of this thesis.

3.
Empirical research on the impact of DMI on manufacturing performance

In this chapter, quantitative techniques were applied to analyze the impact of DMI on manufacturing performance, through the use of the fifth round of the International Manufacturing Strategy Survey (IMSS-V). The direct impact of DMI on manufacturing performance is analyzed, as well as the moderating effect exerted by market uncertainty and manufacturing complexity on the DMI - Manufacturing Performance relationship. The measurement scales of the questionnaire were validated with confirmatory factor analysis in structural equation models. Two different models have been tested: i) the direct impact of DMI on manufacturing performance; ii) the moderating effect of market uncertainty and manufacturing complexity on the relationship between DMI and manufacturing performance. The two models have been tested with hierarchical stepwise multiple regressions, consistent with the definitions and theoretical background described in Chapter 2.

3.1.
Research Methodology

This section presents the techniques used for data analysis and the survey dataset. The validation of the data is based on two-step model-building according to Anderson and Gerbing (1988). Confirmatory factor analysis is used in structural equation modeling (SEM), with maximum likelihood estimates calculated in AMOS 19.0 (Yuanqiong He et al., 2014; Land et al., 2012; Verworn, 2009). Hypothesis testing was conducted through the statistical significance of standardized regression coefficients and F-change statistics computed with hierarchical stepwise multiple regression in SPSS19.0. The procedures used to validate the two models are detailed in this chapter in the section on measurement model.

The data was taken from the fifth round of the International Manufacturing Strategy Survey (IMSS-V). This is a worldwide research project using standard questionnaires which periodically collects information about practices and performance associated with manufacturing strategy on medium and large size manufacturing firms (over 50 employees). This survey has been carried out in 1992, 1996, 2001, 2005, 2009 and 2013-2014 by an international network of OM researchers. IMSS-V started in 2009, with 725 completed questionnaires returned, from 21 countries of Europe, Asia, and America. Different sectors of manufacturing and assembly are represented, with a larger proportion of manufacturer of metal products (ISIC 28) and machinery (ISIC 29). Semiconductor (ISIC 30), transportation (ISIC 35), advanced instruments (ISIC 33), and audio/video (ISIC 32) industries are least represented. About 50 % of the sample was batch manufacturers, 26% was one-off producers, and 23% was mass producers (for more details on the sample, see Laugen and Boer, 2011)

The questionnaire is divided into three sections: (a) Description, strategy and performance of the business unit; (b) Description, strategy and performance of manufacturing for the dominant activity and (c) Current manufacturing and supply chain practices, and past and planned action programs. Questionnaires were mailed or emailed to the Director of Operations/Manufacturing or equivalent in each company, with an attached letter explaining the purpose of the survey, the structure of the questionnaire and assurances of confidentiality. In countries where English was not a primary or common language, the surveys were translated by the research coordinator, typically a full-time university professor in the operations management field. On the whole, 4,457 questionnaires were sent, gathering 725 usable surveys (16.3% response rate). Analysis of non-respondent biases on key demographics such as company size and ISIC codes were not significant (Thomé et al., 2014a). The sample (Table 3.1) is spread over a large range of GDP per capita, and firm sizes (number of employees).

Table 3.1: Distribution of firm sizes and GDP per capita by country – IMSS-V

Country	Respondents	Size (No. of employees)	2009 GDP Per capita in US$ (*)
Belgium	36	294	43799
Brazil	37	687	8251
Canada	19	205	39656
China	59	1198	3749
Denmark	18	110	56330
Estonia	27	134	14375
Germany	38	754	40275
Hungary	71	314	12635
Ireland	6	206	50034
Italy	56	253	35237
Japan	28	4447	39456
Korea	41	52	17110
Mexico	17	639	7876
Netherlands	51	192	47998
Portugal	10	251	22016
Romania	31	231	7500
Spain	40	270	31891
Switzerland	31	370	63568
Taiwan	31	2042	32300
UK	30	136	35129
USA	48	629	45793
Total	**725**	**623**	**29379**

Note (*) World Bank (2012)
Source: Thomé et al. 2014a

3.2.
DMI and manufacturing operational performance

The measurement model development began with the selection of items to form each construct. Subsequently, the two-step approach to structural equation modeling of Anderson and Gerbing (1988) was applied to the dataset. The measurement model aims to verify and to validate unidimensionality, validity (i.e. convergent and discriminant validity) (Anderson and Gerbing, 1988) and reliability (concerns the extent to which an experiment, test, or any measuring procedure yields the same results on repeated trials) (Carmines and Zeller, 1979). Prior to the analysis, data were visually checked for errors and outliers and assessed for skewness and kurtosis. Neither major outliers nor departures from the assumptions of normality and homoscedasticity were detected.

3.2.1. Theoretical model and hypothesis

The theoretical framework depicted in Figure 3.1 represents the direct and contingent relationships examined in this study. This framework is consistent with the findings of research from a contingency perspective in the areas of strategic management and organizational theory. The model is proposed to test the moderating effect of Manufacturing Complexity and Market Complexity on the direct relationship between DMI and manufacturing operational performance (Figure 3.1). The following hypothesis will be tested based on the statistical significance of standardized regression coefficients and F-value.

Hypotheses:

H1: Higher levels of the use of design-manufacturing integration lead to higher levels of manufacturing operational performance

H2: The positive relationship between DMI and manufacturing operational performance will be stronger when manufacturing complexity is high

H3: The positive relationship between DMI and manufacturing operational performance will be stronger when market uncertainty is high

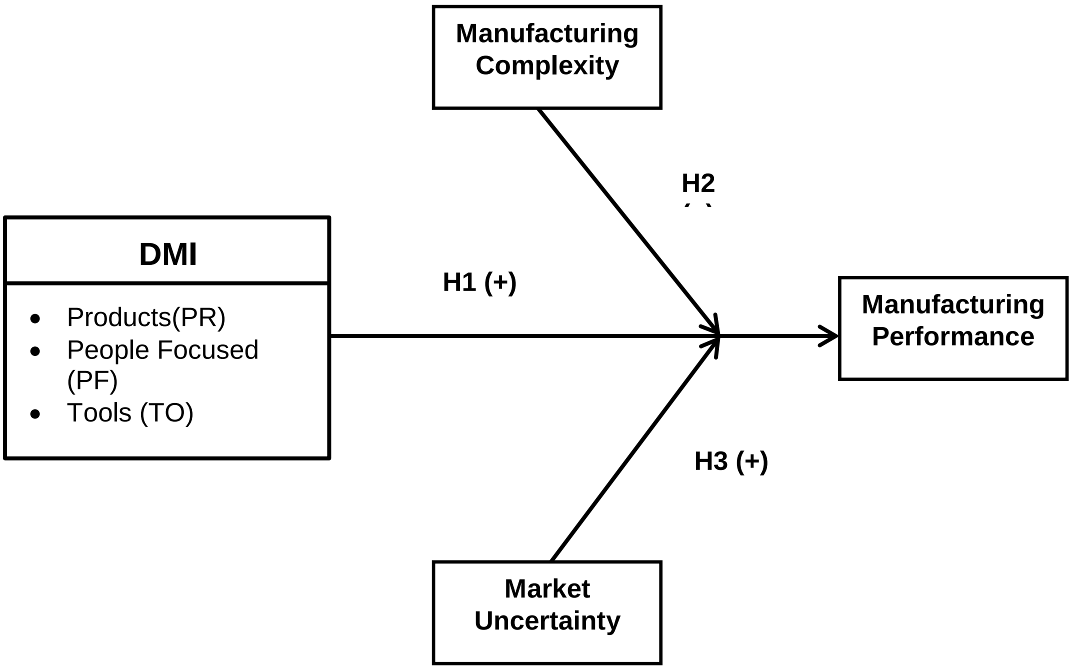

Figura 3.1. Theoretical model and hypotheses

3.2.2. Measures

The first selection of items to form the constructs was theoretically developed according to the following criteria:

i) theoretical consistency e.g. the concepts of the manifest variables that form a construct fits with existing definitions for similar constructs in the literature (Ping, 2004);

ii) the degree to which the inclusion of the item improved overall model fit;

iii) ensuring unidimensional constructs e.g. the item can load on one factor only in the confirmatory factor analysis;

iv) satisfying statistical standards based on the two-step approach (Anderson and Gerbing, 1998). It assesses reliability (i.e. composite reliability (CR) close to or above 0.6) and validity (i.e. convergent validity and discriminant validity; and

v) subsequently some items were eliminated

Consistent with our earlier conceptualization of Design-Manufacturing Integration, DMI is a second-order latent variable comprising the latent variables of Products (PR), People focused (PE) and Tools (TOO) (directly formed by manifest or observed variables). The measure of Market Uncertainty was framed around demand and supply fluctuations while manufacturing complexity encompasses the number of task and complexity of the bill of materials. The corresponding measurement items and descriptive statistics are given in Tables 3.2 and 3.3. The items in these tables cover the conceptual domain of the associated DMI practices, as discussed in Chapter 2.

The measures of manufacturing operational performance were cost, quality, delivery and flexibility (Akyuz and Erkan 2010; Hill 1994). These measures had been widely used in previous research (Schmenner and Swink, 1998; Schroeder et al., 2002; Ward et al., 1998), including those using IMSS datasets (Da Silveira and Cagliano 2006; Vereecke and Muylle 2006; Da Silveira and Sousa 2010; Thomé et al. 2014a, 2014b). Table 3.4 shows descriptive statistics for the scale items and the measurement model.

Table 3.2: Measurement items for the dimensions of DMI

Constructs	IMSS-V questions	n	$\overline{x}$	$\hat{\sigma}$
DMI				
Products (PR)	**Indicate the effort put into implementing the following action programs in the last three years:**			
	Increasing design integration between product development and manufacturing through e.g. platform design, standardization and modularization, design for manufacturing, design for assembly)	686	3.02	1.20
	Increasing the technological integration between product development and manufacturing through e.g. CAD-CAM, CAPP, CAE, PLM	681	3.00	1.17
	How do you technologically coordinate design and manufacturing:			
	Design for manufacturing/assembly	692	3.13	1.22
People Focused (PF)	**How do you organizationally coordinate design and manufacturing:**			
	Job rotation between design and manufacturing	694	2.16	1.09
	Co-location of design engineers and manufacturing managers	694	2.57	1.28
Tools (TO)	**How do you technologically coordinate design and manufacturing:**			
	Failure Mode and Effect Analysis (FMEA)	688	2.82	1.31
	Quality Function Deployment (QFD)	681	2.58	1.25

Note: All items measured on a five-point scale, with degree of adoption end points 1=None and 5=High

Table 3.3: Measurement items for the Moderators

Constructs	IMSS-V questions	n	$\overline{x}$	$\hat{\sigma}$
Manufacturing Complexity (MNC)	**How would you describe the complexity of the dominant activity?**			
	Many parts/materials, complex bill of material	713	3.72	1.31
	Many steps/operations required	711	3.84	1.09
Uncertainty (UNC)	**To what extent do you agree with the following statements?**			
	Our demand fluctuates drastically from week to week	702	2.78	1.16
	Our supply requirements vary drastically from week to week	702	2.69	1.12
	Our master production schedule has a high percentage of variation in demand	707	3.14	1.14

Note: All items assessed on a five-point scale with degree of adoption end points 1=None and 5=High

Table 3.4: Measurement items for Manufacturing Performance.

Performance Measure	IMSS-V Question	Descriptive Statistics n	$\bar{x}$	$\hat{\sigma}$
How does your current performance compare with your main competitor(s)?				
Cost (*)	Unit manufacturing cost	561	3.13	0.82
	Procurement costs	557	3.14	0.73
	Labor productivity	550	3.34	0.76
	Inventory turnover	536	3.24	0.83
	Capacity utilization	542	3.29	0.81
	Manufacturing overhead costs	541	3.11	0.83
Delivery	Delivery speed	584	3.44	0.79
	Delivery reliability	586	3.49	0.81
	Manufacturing lead time	563	3.36	0.72
	Procurement lead time	556	3.16	0.71
Flexibility	Product customization ability (*)	581	3.56	0.84
	Volume flexibility	579	3.58	0.81
	Mix flexibility	582	3.51	0.79
	Time to market (*)	569	3.31	0.86
Quality	Manufacturing conformance	596	3.49	0.72
	Product quality and reliability	601	3.63	0.79
	Customer service and support (*)	571	3.47	0.81

(*) Excluded in subsequent validation stages.
Note: All items measured on a five-point scale with degree of adoption end points 1=Much worse and 5=Much better

3.2.3. Measurement model assessment

In assessing the measurement model, the first step analyzes the goodness of fit of the model through the use of Confirmatory Factor Analysis. Four indexes of fit used in the literature were adopted:

i) Normed-Chi-Square ($\chi 2$);
ii) The root mean square error of approximation - RMSEA;
iii) Comparative fit index – CFI and
iv) Normative fit index - NFI. (See the Appendix 1 for additional information).

Normed-$\chi 2$ should be close to or higher than 1 and close to or lower than 3 for a good or acceptable model fit to data (Jöreskog and Sörbom, 1993). RMSEA should be close to or lower than 0.05 (Browne and Cudeck, 1993; Hu and Bentler, 1999; Schermelleh-Engel et al., 2003), CFI should be close to or higher than 0.95 (Hu and Bentler, 1999; Schermelleh-Engel et al., 2003) and NFI should be close to or higher than 0.95.

The second step tests the structural relationships among latent variables through convergent validity of the scales that was verified using the three criteria suggested by Fornell and Larcker (1981):

i) All factor loadings should be significant and been close to or above 0.6 (Chin, 1998);

ii) Construct reliability (CR) should exceed 0.6 (Hair et al., 1998).

iii) The Average variance extracted (AVE) should be equal or higher than 0.5.

In addition discriminant validity was established by verifying that shared variances between the pairs of constructs were lower than the square root of the AVE estimates for the individual constructs (Fornell and Larcker, 1981).

The assessment of the measurement model was performed in two parts. First, the second order construct of DMI was validated. The measurement model for DMI had good fit indexes (Table 3.5). Also, the construct met all criteria for convergent validity (see Table 3.6). Second, the full model with all constructs was assessed. An initial model with DMI, manufacturing complexity, market uncertainty and performance constructs resulted in some of the scales not satisfying the requirements of convergent validity, with AVEs below 0.5 (Fornell and Larcker, 1981). The AVE for COST was 0.49 and 0.48 for FLEXIBILITY. Furthermore, the construct of COST presents a lack of discriminant validity where the square root of the AVE for COST was 0.71 while the correlation between COST and DELIVERY was 0.83.

Table 3.5 DMI Fit Indexes Results

Indexes	Result
$\chi 2$/DF	3.0
NFI	0.977
CFI	0.984
RMSEA	0.05
PCLOSE	0.372

Table 3.6: Design- Manufacturing Integration construct measurement model

Latent Variables	Factor Loads	C.R.	AVE	1	2	3	4
1. PRODUCTS (PR)		0.76	0.52	*(0.72)*			
Increasing the technological integration	0.720						
Increasing design integration	0.772						
Design for manufacturing	0.665						
2. PEOPLE FOCUSED (PF)		0.68	0.52	0.63	*(0.72)*		
Co-location	0.715						
Job rotation	0.728						
3. TOOL (TO)		0.77	0.63	0.63	0.47	*(0.79)*	
Failure Mode and Effect Analysis	0.694						
Quality Function Deployment	0.884						

C.R.: composite reliability; AVE: square roots in the main diagonal, in italics and parentheses. Factor loads and correlations obtained with Amos 19.

This first complete model was enhanced through the elimination of COST construct and two items from FLEXIBILITY and one item from QUALITY were equally dropped. Deleted items are marked with an asterisk in Table 3.4. The refined model had good indexes fit estimates (Table 3.7) indicating that the measurement model fits the data reasonably well. It equally satisfies the three conditions for convergent validity recommended for Fornell and Larcker (1981). First, factor loadings are significant and exceed 0.6 with one exception in Market Uncertainty construct, which present one manifest variable with factor load lower than 0.6. This variable was kept in the model due to its theoretical relevance for the concept domain. Second, construct reliability (CR) exceeds 0.6 (Hair et al., 1998). And third, the average variances extracted (AVE) are equal or higher than 0.5 In addition, the square roots of the AVEs are consistently above pairwise correlations among latent variables, confirming convergent and discriminant validity (Table 3.8)

Table3.7 Final Model fit indexes Results

Indexes	Result
$\chi2$/DF	2.247
NFI	0.926
CFI	0.957
RMSEA	0.04
PCLOSE	0.992

Table 3.8: Measurement Model Statistics

Latent Variables	**Factor Loads**	**C.R.**	**AVE**	**1**	**2**	**3**	**4**	**5**	**6**
1. DELIVERY		0.83	0.54	*(0.73)*					
Delivery speed	0.793								
Delivery reliability	0.759								
Manufacturing lead time	0.762								
Procurement lead time	0.675								
2. FLEXIBILITY		0.78	0.64	0.70	*(0.80)*				
Volume flexibility	0.793								
Mix flexibility	0.809								
3. QUALITY		0.75	0.60	0.68	0.57	*(0.77)*			
Manufacturing conformance	0.752								
Product quality and reliability	0.794								
4. DMI		0.81	0.60	0.32	0.32	0.41	*(0.78)*		
Products	0.978								
People Focused	0.659								
Tools	0.645								
5. MANUFACTURING COMPLEXITY		0.76	0.61	0.122	0.09	0.18	0.37	*(0.78)*	
Complex bill of materials	0.779								
Many steps operations	0.784								
6. MARKET UNCERTAINTY		0.78	0.55	0.01	0.02	-0.09	0.04	0.03	*(0.74)*
Demand fluctuates drastically	0.888								
Supply requirements vary drastically	0.770								
Master production schedule has a high % of variation in demand	0.515								

C.R.: composite reliability; AVE: square roots in the main diagonal, in italics and parentheses. Factor loads and correlations obtained with Amos 19.

<u>*Common Method Bias*</u>

Common method biases are a problem because they are one of the main sources of measurement error; which threaten the validity of the conclusions about the relationships between measures. Biases may arise from characteristics of the respondents or items characteristics yielding spurious relationships between two or more constructs. The survey used guaranteed anonymity and confidentiality, and questions/items were described clearly and concisely minimizing biases. (Podsakoff et al., 2003). We tested for the existence of common method bias through Harman's single-component test (Podsakoff et al., 2003). In this test, we allowed all 20 manifest variables to load in one single latent variable. The resulting model fit was poor (Table 3.9) suggesting the absence of common method bias.

Table 3.9 Harman's Single-component Test

Indexes	Result
$\chi 2$/DF	15.54
NFI	0.441
CFI	0.453
RMSEA	0.140
PCLOSE	0.000

3.2.4. Control Variables

Three variables were controlled for in testing the hypotheses to account for possible extraneous effects. Previous research suggests that the size of the firm can significantly affect performance. Firm size was measured by the number of employees in the business unit (SIZE, $\bar{x}$= 1,949.61; S = 8,811.82; N = 715) and was LN-transformed to improve normality (Elango, 2006; da Silveira and Sousa, 2010). Country development was measured by gross domestic product per capita, obtained from the World Bank (2012) Development Indicators (GDP, $\bar{x}$= 29,379.34; S = 17,169.67; N = 725). Market dynamics was measured by the survey respondents' perceptions on a Likert scale ranging from 1 – market declining rapidly to 5 – market growing rapidly (MKT, $\bar{x}$= 2.92; S = 0.91; N = 714). These controls were used by Da Silveira and Sousa (2010) in their research on manufacturing performance using IMSS-IV data, as well as by Thomé et al. (2014a; 2014b), using IMSS-V dataset.

3.2.5. Results

The hypotheses were tested using stepwise multiple linear regressions with control variables, in SPSS 19.0. The variables were obtained by averaging the scores of their manifest or latent variables. Prior to being included in the regression, the variables were mean-centered, which reduce the potential effects of multicollinearity (Jaccard et al., 1990).

Following Da Silveria and Sousa, (2010) stepwise hierarchical regression models entering control variables in step 1, predictors in step 2 and the interaction terms of DMI x MANUFACTURING COMPLEXITY and DMI x MARKET UNCERTAINTY in step 3 were built. The full regression equation was:

$$\begin{aligned}\hat{Y} \;=\; \alpha + \; & (\beta_1 \times GDP_i) + (\beta_2 \times LnSIZE_i) + (\beta_3 \times A2a_i) + (\beta_4 \times DMI_i) \\ & + (\beta_5 \times MANCOMPLEX_I) + (\beta_6 \times MARKUNCERT_i) \\ & + (\beta_7 \times \; DMI \cdot MANCOMPLEX_i) \\ & + (\beta_8 \times DMI \cdot MARKUNCERT_i) + \varepsilon_i\end{aligned}$$

Where:

- $\hat{Y}$: dependent variable (QUALITY, FLEXIBILITY, DELIVERY).
- GDP per capita: control variable
- LnSIZE: control variable
- A2a: market dynamism – control variable
- DMI: Design-manufacturing Integration
- MANCOMPLEX: Manufacturing complexity
- MARKUNCERT: Marketing uncertainty

Control and independent variables were regressed on all three performance variables. Resulting variance inflation factors (VIF) were under 10 and condition indexes (CI) under 30, suggesting the absence of multicollinearity (Kennedy, 2003) (Table 3.10) Histograms and plots of residuals suggested that they were normally distributed. The hypotheses tests were based on the significance of standardized regression coefficients and F-change. The results are presented in table 3.11.

Table 3.10 Collinearity Statistics

Dependent Variable		Flexibility		Delivery		Quality	
Model		Collinearity Statistics		Collinearity Statistics		Collinearity Statistics	
		Tolerance	VIF	Tolerance	VIF	Tolerance	VIF
1	(Constant)						
	LNSIZE	,997	1,003	,993	1,007	,993	1,007
	A2a	,989	1,011	,988	1,012	,984	1,016
	GDP	,988	1,012	,986	1,014	,985	1,015
2	(Constant)						
	LNSIZE	,882	1,134	,880	1,136	,890	1,123
	A2a	,978	1,022	,977	1,024	,968	1,033
	GDP	,932	1,073	,940	1,064	,935	1,070
	DMIMS	,825	1,211	,831	1,203	,835	1,198
	MANCOMPLEXMS	,913	1,095	,914	1,094	,911	1,098
	COMPLSMS	,995	1,005	,994	1,006	,995	1,005
3	(Constant)						
	LNSIZE	,881	1,134	,879	1,138	,890	1,123
	A2a	,975	1,025	,973	1,027	,965	1,036
	GDP	,931	1,075	,938	1,067	,932	1,072
	DMIMS	,823	1,215	,827	1,209	,834	1,200
	MANCOMPLEXMS	,908	1,101	,909	1,100	,908	1,102
	COMPLSMS	,991	1,010	,986	1,015	,992	1,008
	DMIUNCERTMS	,975	1,025	,970	1,031	,980	1,020
	DMIMANCOMPMS	,979	1,022	,980	1,020	,981	1,019

Table 3.11: Regression Coefficients on Manufacturing Performance

Variables	FLEXIBILITY		DELIVERY		QUALITY	
			Hypotheses Tests			
GDP	-0.109	**	-0.192	***	-0.141	**
A2a	0.014		0.059		-0.088	*
LNSIZE	0.077	*	-0.042		0.111	**
F-change	2.887	*	6.367	***	7.162	***
R^2	0.019		0.043		0.046	
Adjusted R^2	0.012		0.036		0.039	
GDP	-0.065		-0.138	**	-0.087	*
A2a	-0.005		0.033		0.059	
LNSIZE	0.017		-0.126	**	0.035	
DMI	0.189	***	0.240	***	0.229	***
MAN COMPLEX	0.024		0.070		0.066	
MARK UNCERT	0.010		-0.016		-0.078	*
F-change	5.059	**	9.129	***	9.820	***
R^2	0.052		0.101		0.105	
Adjusted R^2	0.039		0.088		0.093	
GDP	-0.064		-0.135	**	-0,088	*
A2a	-0.005		0.030		0.060	
LNSIZE	0.016		-0.129	**	0.035	
DMI	0.186	***	0.238	***	0.229	***
MAN COMPLEX	0.026		0.077		0.065	
MARK UNCERT	0.013		-0.012		-0.079	*
DMIxMANCOMPLEX	0.100	**	0.112	**	-0.009	
DMIxMARKUNCERT	-0.057		-0.002		-0.013	
F-change	3.439	**	2.995	**	0.054	
R^2	0.066		0. 113		0.105	
Adjusted R^2	0.049		0.096		0.089	

Note: significance levels **p < 0.1, ** p < 0.05, ***p<0.01.*
Coefficients are unadjusted standardized coefficients

The entering control variable in the first part of Table 3.11 shows that GDP per capita is negatively associated with all three performance outcomes. Market Dynamic and Size appear to be associated with quality but with no statistically significant association with neither flexibility nor delivery

Second part including predictors revealed that Design-Manufacturing Integration had a positive effect on all three performance outcome (flexibility, quality, and delivery) after controlling for the potentially confounding effects of firm's size, country's economic development and market dynamics at a significance level of $p < 0.01$. This result supports H1 (Higher levels of the use of design-manufacturing integration lead to higher levels of manufacturing operational performance). Manufacturing complexity is not associated with any of the three performance outcomes while Market uncertainty is negatively associated with quality.

The third part including interaction terms (moderation tests), showed a partial moderating effect of Manufacturing Complexity on Delivery and Flexibility. There was not a moderating effect observed for quality. Hypotheses H2 (The relationship between DMI and manufacturing operational performance is moderated by manufacturing complexity) is partially supported. Hypothesis H3 (The relationship between DMI and manufacturing operational performance is moderated by market uncertainty) is not supported. Market uncertainty did not appear as a moderator for the relationship between DMI and any of the three outcomes of performance.

4.
Discussions of research findings

The results of this study partially support the principal arguments guiding this thesis, which is that the relationship between the Design-Manufacturing integration and manufacturing operational performance is moderated by manufacturing complexity and partly at least by environmental uncertainty. An interesting finding of this study was the differentiated results regarding the form of the moderated relationship.

The results of the model are discussed. First, the direct effect of DMI on manufacturing operational performance is debated. Second, the relationships between DMI and manufacturing complexity is analyzed, with the back-drop of contingency theory. Third, the lack of moderating effect of market uncertainty on the relationship between DMI and manufacturing operational performance is analyzed.

4.1.
The effect of DMI on manufacturing operational performance

The results provide evidence of a consistent and positive impact of Design-Manufacturing Integration (DMI) on manufacturing operational performance, impacting in all three dimensions of performance. Hypothesis 1 (Higher levels of the use of design-manufacturing integration lead to higher levels of manufacturing operational performance) is supported by evidence and it is consistent with previous research (Stank et al., 1999; Drögue et al., 2004; Swink et al., 2007). According to Stank et al. (1999) DMI positive impact on performance, may seem intuitive. Frequent interaction provides the opportunity to build relationships, influence people and sway perceptions.

Swink et al. (2007) provide further evidence of the positive impact of internal integration on production flexibility. Thus, our results underpin the argument for the need to remove functional barriers, fostering cross-functional integration to improve flexibility (Flynn et al., 2010) It is less in line with few studies that have found only a weak effect of DMI on manufacturing performance (e.g. development time, product innovation, quality) or no effect. (e.g., Swink, 2000; Koufteros et al., 2005). The impact of DMI in the three dimensions of performance is maintained after controlling for market dynamics, level of country development and firm size. This fact emphasizes the key role of Design – Manufacturing Integration in generating manufacturing operational performance.

<u>Control Variables</u>

The effect of GDP per capita was negative and significant for all three dimensions of performance, being consistent with similar studies (Da Silveira and Sousa, (2010); Thomé et al. (2014a, 2014b). They found negative impact in two dimensions of performance (e.g., quality and delivery). The control for size have a positive impact on quality but not on delivery or flexibility consistent with Thomé et al. (2014b) and Da Silveira and Sousa, (2010). Thomé et al. (2014a) found a negative impact of size on one dimension of performance (e.g. delivery). Market dynamics also showed a negative impact on quality being consistent with similar studies (Da Silveira and Sousa, 2010; Thomé et al. 2014a,2014b). The results for control variables are partially consistent with results found in the literature but, it runs contrary to expectations regarding the partial absence of differences attributable to market dynamics. One could expect that companies in fast growing markets would show greater performance improvements. (Landsom, 2000).

4.2.
The moderator role of Market Uncertainty

Some studies have analyzed the uncertainty as a control variable (Nan Cui et al., 2013; Chiang et al., 2014) or included uncertainty as a mediator (Cooper and Kleinschmidt, 1987). The analysis of the moderator role of market uncertainty between DMI and manufacturing operational performance is an original contribution of this Thesis in the context of internal integration practices and contingency theory. The lack of the moderating effect of uncertainty on the relationship between DMI and operational performance is consistent with the mixed results in the literature (Calantone et al., 1997; Song et al., 1997; Souder et al., 1998; Calantone et al., 2002; O´Leary-Kelly and Flores, 2002; Bstieler, 2005; Koufteros et al. 2005; Aronson et al. 2006; Jeong et al, 2006).

A first explanation for this result concerns the measure of uncertainty. Uncertainty measurement referred to as being dificult (Souder et al., 1998; Koufteros et al., 2005), raising concerns about the appropriateness of the measures used here. The use of only market uncertainty instead of including both technology and market uncertainty not covering all dimensions of the construct may be an important alternative explanation for the lack of the moderating effect. Song et al. (1997) posit that uncertainty may be related to changes in technology, customer demand, and competitor action uncertainty. Nonetheless, the measures used here met acceptable convergent validity, reliability, unidimensionality and discriminant validity (Table 3.6). A limitation of the Thesis is the lack of technology uncertainty to measure the uncertainty construct; future research should incorporate both measures.

A second explanation is that DMI practices are decisions of tactical and operational levels in the organization since cooperation starts at the early stages of product development. While looking for customers, vendors and competitors, in order to determine the needs of the customers, affects directly the strategic decision making of the organization. Therefore uncertainty (external forces) might influence performance at the strategic, not at the operational NPD level (Song et al., 1997).

4.3. The moderator role of Manufacturing Complexity

The positive moderating effects of manufacturing complexity upon DMI and two of the three dimensions of manufacturing operational performance (i.e. delivery and flexibility) contribute to the generalization of DMI direct impact on manufacturing operational performance. The moderating effect on delivery and flexibility contribute to the generalization of the moderator role of manufacturing complexity on manufacturing operational performance.

Most studies analyzed the direct effect of complexity on performance (Bozarth et al., 2009) while only a few articles refers to manufacturing complexity as a moderator of the impact of DMI on manufacturing operational performance (Crittenden, 1992; Koufteros et al., 2005).

Manufacturing complexity (complex bill of materials and many steps in operations) has not a moderator effect on the relationships between DMI and quality, one of the dimensions of manufacturing operational performance. However, it moderates the impact of DMI on delivery and flexibility, being consistent with prior research (Kim et al., 1992; Koufteros et al., 2005). The data analyzed suggest that manufacturing complexity may be important in understanding relationships between product development processes, structures, and performance. Understanding the contextual impact of these variables in the product development environment is useful.

Therefore, we can conclude that manufacturing complexity amplifies DMI effect on delivery and flexibility and has no effect on quality. One could hypothesize that DMI would be more effective for a more complex bill of materials and products requiring numerous assembly stages. A possible explanation for the lack of moderating effect on quality is that design and manufacturing in companies with high rates of complexity are already so concerning on improving quality (having established standards of quality) by necessity that increasing integration has no further incremental or detriment impact on quality. This interpretation is consistent with Calantone et al. (2002).

5. Conclusion

This Master Thesis provided the first measure of DMI as a bundle of practices and as a multidimensional, second-order construct (products, people, and tools) with a large international database. An empirical examination of the individual impact of DMI on different dimensions of operational performance was accomplished using rigorous data analysis techniques of structural equation modeling. Operations Management Practices Contingency Research was applied to a relatively new field in industrial engineering and the moderating effects of manufacturing complexity and market uncertainty was tested using techniques of structural equation modeling, confirmatory factor analysis, and hierarchical stepwise multiple regression.

Consistent with previous research, the impact of DMI on manufacturing operational performance was put to test with survey data from the fifth round of the International Manufacturing Strategy Survey (IMSS-V). DMI impacted consistently and significantly upon manufacturing operational dimensions of quality (manufacturing conformance, product quality and reliability), delivery (delivery speed, delivery reliability, manufacturing lead time, procurement lead time) and flexibility (volume and mix flexibility). The fact that results hold after controlling for company size, country economic development and market dynamics/volatility allow for the generalization of results to a large set of industries, albeit restricted to the industrial sector comprised of ISIC 3.1 codes 28-35. By implementing DMI practices described in this study, manufacturers could enhance their operational results, depending on the operational performance dimension being targeted. As a whole, DMI impacts directly upon manufacturing operational performance.

Besides a direct impact on performance, the direct effect of DMI and the moderator role of manufacturing complexity were confirmed for the performance measures of flexibility and delivery but not for quality. The lack of moderator effect of manufacturing complexity on quality is not a surprising result since it is expected that design and manufacturing in companies with high rates of complexity were already so concerned with improving quality (having established standards of quality) by necessity that increasing integration has no further incremental or detrimental impact on quality.

The moderator role of market uncertainty between DMI and manufacturing operational performance is an original contribution of this Thesis in the context of internal integration practices and contingency theory. The lack of the moderating effect of uncertainty on the relationship between DMI and operational performance is partly consistent with the mixed results found in the literature. (Calantone et al., 1997; Song et al., 1997; Souder et al., 1998; Calantone et al., 2002; O´Leary-Kelly and Flores, 2002; Bstieler, 2005; Koufteros et al., 2005; Aronson et al., 2006; Jeong et al., 2006).

This Master Thesis also opens venues for future studies. Far from being a clear improvement for success, DMI can be costly and is context-dependent. Understanding the many factors that can affect the success of their implementation should be thoroughly explored in the areas of different organizational arrangements, market/product environments and concurrent management practices, such as: Lean, JIT, six-sigma and theory of constraints. Approaching Uncertainty and Complexity as contingent variables was a novel contribution from this thesis and its analysis should be pursued further. We suggest the inclusion of technology uncertainty as moderator of the relationship between DMI-Manufacturing operational performance.

Finally, a research agenda comprised of five topics can be derived from the present work: (i) to conduct systematic review of DMI better practices and the impact on performance; (ii) to develop other valid and reliable uncertainty measurement instruments, especially including the two types (market and technology uncertainty) and systematically apply OM-PCR to the DMI field; (iii) to conduct field data collection under the form of case study and survey research on DMI and performance, enlarging the set of DMI practices being used and the performance measures adopted; (iv) to apply similar analysis to different databases from different industries; and (v) to conduct longitudinal analysis with data from regular and periodic survey programs such as IMSS.

It is the outlook at the end of this research that both academics and practitioners could take benefit of the results and possibly mainly of the limitations of this Thesis, in order to advance more in the theory and practice of operations management.

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Appendix 1: Goodness-of-Fit Measures**Descriptive Measures of Overall Model Fit**

Due to the sensitivity of the χ^2 statistic to sample size, alternative goodness-of-fit measures have been developed. Measures of overall model fit indicate to which extent a structural equation model corresponds to the empirical data. These criteria are based on the difference between the sample covariance matrix S and the model-implied covariance matrix$\sum(\hat{\theta})$. The Root Mean Square Error of Approximation, descriptive measure of overall model fit will be explained next (Schermelleh-Engel and Moosbrugger, 2003)

Root mean square error of approximation (RMSEA)

The Root Mean Square Error of Approximation (RMSEA) is a measure of approximate fit in the population and is therefore concerned with the discrepancy due to approximation (Schermelleh-Engel and Moosbrugger, 2003). It let us know how well the model, with unknown but optimally chosen parameter estimates, would fit the population covariance matrix (Hooper et al., 2008). It is one of the most informative fit indices due to its sensitivity to the number of estimated parameters in the model. In other words, for parsimony, RMSEA will choose the model with the lower number of parameters. Recommendations for RMSEA cut-off points have been reduced considerably in the last fifteen years. In the early nineties, an RMSEA in the range of 0.05 to 0.10 was considered as an indication of good fit and values above 0.10 indicated poor fit. (MacCallum et al. 1996). Nevertheless, the last years acceptable values had changed. Values less than 0.05 represent a good fit; values less than 0.08 is a reasonable approximation error in the population; values between 0.08 and 0.10 represents poor fit (Da Silva, 2006).

RMSEA is estimated by $\hat{\varepsilon}_{a,}$ the square root of the estimated discrepancy due to approximation per degree of freedom:

$$\hat{\varepsilon}_a = \sqrt{\max\left\{\left(\frac{F(\mathrm{S}, \sum(\hat{\theta})}{df} - \frac{1}{N-1}\right), 0\right\}}$$

where

F(S, $\sum(\hat{\theta})$) is the minimum of the fit function
$df = s - t$ is the number of degrees of freedom, and
N is the sample size

Descriptive Measures Based on Model Comparisons

Comparison indices also known as incremental fit indices are indices that compare the chi-square value to a baseline model. For these models, the null hypothesis is that all variables are uncorrelated. (Hooper et al. 2008).

Often used measures based on model comparisons are the Normed Fit Index (NFI), the Comparative Fit Index (CFI) which will be explained below.

Normed-fit index (NFI)

The Normed Fit Index (NFI) proposed by Bentler and Bonnett (1980) assesses the model by comparing the X^2 value of the model to the X^2 of the null model. The null model is the worst case scenario as it specifies that all measured variables are uncorrelated. The values for this statistic range between 0 and 1. Bentler and Bonnet (1980) recommend values greater than 0.90 as an indicator of a good fit. Recent suggestions are recommending values greater than 0.95 (Hu and Bentler,1999). This index is sensitive to sample size, underestimating fit for samples with less than 200 cases (Bentler, 1990).

The NFI is defined as:

$$NFI = \frac{\chi_i^2 - \chi_t^2}{\chi_i^2} = 1 - \frac{\chi_t^2}{\chi_i^2} = 1 - \frac{F_t}{F_i}$$

Where

χ_i^2 is the chi-square of the independence model (baseline model)

χ_t^2 is the chi-square of the target model, and

F is the corresponding minimum fit function value

Comparative fit index (CFI)

The comparative fit index (CFI; Bentler, 1990) is a revised form of the NFI, which takes into account sample size (Hooper et al. 2008). This statistic assumes that all latent variables are uncorrelated, just like NFI, and compares the sample covariance matrix with this null model. Values for this statistic range between 0 and 1. To ensure that misspecified models are not accepted, a value of CFI must be equal or higher than 0.95 (Hu and Bentler, 1999)

The CFI is defined as:

$$CFI = 1 - \frac{\max[(\chi_t^2 - df_t),0]}{\max[(\chi_t^2 - df_t),(\chi_i^2 - df_i),0]}$$

Where

Max denotes the maximum of the values given in the brackets,

χ_i^2 is the chi-square of the independence model (baseline model)

χ_t^2 is the chi-square of the target model, and

df is the number of degrees of freedom

PCLOSE

Test the accuracy of the fit, which means, test the hypotheses Ho: RMSEA ≤ 0,05. It must be greater than 0.05 to accept this hypothesis. PCLOSE: it's ideal to be greater than 0.5 (Byrne, 2001).