



UNIVERSITY OF BERGAMO

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FACULTY OF ECONOMICS AND BUSINESS ADMINISTRATION  
RESEARCH DOCTORATE IN LOGISTICS AND SUPPLY CHAIN  
MANAGEMENT

DOCTORAL THESIS

ACHIEVING MULTIPLE-  
PERFORMANCE EXCELLENCE  
THROUGH LEAN MANUFACTURING:  
EMPIRICAL EVIDENCES USING CUMULATIVE  
AND TRADE-OFF MODELS

SUPERVISOR:  
PROF. PIETRO ROMANO

PH.D. CANDIDATE:  
THOMAS BORTOLOTTI

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# 1 INTRODUCTION

The intensification of global competition and the crisis have forced manufacturing companies to explore all available opportunities for reducing their costs without compromising the other operational performance. As a consequence, there has recently been renewed attention towards Lean Manufacturing. This attention doesn't come only from managers, but also from academics.

This thesis has the main purpose to understand the mechanism by which manufacturing companies could achieve multiple-performance excellence through the implementation of Lean Manufacturing.

To obtain this objective I adopted one cumulative model and two trade-off models to empirically demonstrate how Lean Manufacturing could improve operational performance and to highlight possible problems and traps when implementing Lean Manufacturing practices in particular contexts and configurations.

## 1.1 Research questions

What is Lean Manufacturing? Shah and Ward (2007) defined Lean Manufacturing as a *“methodology that aims at eliminating waste by reducing supplier, internal and customer variability through an integrated socio-technical system that involves the simultaneous use of many practices”*.

Starting with this definition, the preliminary step of an empirical research on Lean Manufacturing is to operationalize it into a measurable scale.

Bearing in mind that to make significant academic contributions it is important to study a phenomenon using a commonly accepted and comprehensive measurement scale (McCutcheon and Meredith, 1993), in scientific literature it is possible to note that

Lean Manufacturing is often confused with other methodologies (for example with Just-In-Time, a methodology that is part of Lean Manufacturing, but it doesn't cover all the facets of Lean Manufacturing methodology) and it is measured with a multitude of different scales, thus limiting academic and managerial contributions of previous academic researches (Shah and Ward, 2007).

Since in scientific literature there is a lack of a well defined and comprehensive Lean Manufacturing measurement scale, the first research question that this thesis wants analyze and answer is:

**RQ 1: what are the Lean Manufacturing practices that a comprehensive measurement scale must consider to make relevant theory advancement?**

Going beyond this problem, Shah and Ward (2007) argued that “*the relationships among the elements of Lean Manufacturing are neither explicit nor precise in terms of causality*”.

This statement makes clear that in scientific literature there is a lack of empirical evidences about causality relations and interconnection between Lean Manufacturing practices.

This academic gap arises a managerial problem because it is impossible to understand the right implementation sequence of Lean Manufacturing practices without a strong knowledge about causal relationships between these practices.

The importance of filling this gap is given by John *et al.* (2001) because they told us that an implementation sequence that builds manufacturing capabilities is fundamental if the purpose of a manufacturing company is to have a sustaining competitive advantage, since it is not possible to concentrate all the efforts to introduce a new manufacturing methodology at the same time (Skinner, 1969).

For this reason, the second research question is:

**RQ 2: are Lean Manufacturing practices causal related? How? Why?**

Moreover, most of the empirical studies concerning Lean Manufacturing analyzed the impact of some Lean Manufacturing practices on operational performance measured as a single construct that includes at the same time multiple dimensions (e.g. McKone et al., 2001; Furlan et al., 2011) with the result that it is not clear to what extent the Lean Manufacturing practices can improve individual performance dimensions.

Furthermore, there are empirical studies that operationalized the performances with multiple constructs for multiple dimensions, but without any causal relation between them (e.g. Flynn et al., 1995; Cua et al., 2001; Shah and Ward, 2003; Li et al., 2005).

However, we know that a lot of models about sequence of operational performance dimensions exist in scientific literature (e.g. the sand cone model about cumulative capabilities: Ferdows and De Meyer, 1990). These models, even though are very famous, they are also criticized and not yet effectively proved (Flynn and Flynn, 2004, Rosenzweig and Easton, 2010).

From the abovementioned discussion, a third gap of the literature is a lack of a comprehensive study about the relationships between Lean Manufacturing practices and each operational performance dimension and a fourth gap is the lack of empirical evidences about sequence of performance dimensions (quality, delivery, flexibility and cost).

Thus, this thesis aims at answering to the following two research questions:

**RQ 3: how does Lean Manufacturing improve operational performance? Why?**

**RQ 4: how are operational performances related? Why?**

These first four research questions will be answered by the paper presented in Chapter 2 where I will prove that Lean Manufacturing practices help to dramatically improve operational performances if manufacturing companies follow a precise sequence of implementation to build cumulative capabilities.

From the cumulative model results presented in Chapter 2 may seem that Lean Manufacturing methodology could be universally adopted to obtain maximum results on operational performances.

However, there could be contingent variables or unexplored synergies between practices that lead to trade-off results on performance (e.g. Efficiency vs. Responsiveness).

The two trade-off models presented in Chapters 3 and 4 aim at analyzing these potential effects.

In literature almost all of successful lean stories came from repetitive contexts, where products are standardized and customer demand is stable and predictable (product customization and demand variability represent the contingent variables) (Jina et al., 1997; Lander and Liker, 2007).

The most critical Lean Manufacturing bundle of practices in non-repetitive contexts is Just-In-Time, mainly because demand fluctuations make takt time dynamic and the high product variety inhibits production smoothing (Lander and Liker, 2007; Reichhart and Holweg, 2007).

Just-In-Time practices were firstly developed in Toyota, where the production is highly repetitive, and for many years researchers have thought that this methodology could be applied in contexts characterized by repetitive manufacturing systems only.

Recently some authors have refuted this view, providing empirical evidences that Just-In-Time practices can be successfully implemented also in non-repetitive contexts. However, these evidences came from descriptive and anecdotal case studies, whereas in the literature, studies based on large sample lack, which analyze Just-In-Time impact on performance at varying degrees of repetitiveness.

Thus, the gap of the literature is the lack of a study based on a large sample, which analyze Just-In-Time impact on performance at varying degrees of repetitiveness.

The fifth research question is as follows:

**RQ 5: is Just-In-Time applicable in non-repetitive manufacturing contexts? In particular: how the contingent variables that represent**



**the degree of manufacturing repetitiveness could affect the positive impact of Just-In-Time on operational performances?**

This research question will be answered by the paper presented in Chapter 3 where I will demonstrate that Just-In-Time could be also applied in non-repetitive contexts as long as the variability of the customer demand not exceed a certain value.

As regards the possible synergies between Lean Manufacturing practices, even though the vast majority of researchers argues that Lean Manufacturing in general, and Just-In-Time specifically, dramatically improve operational performances, in literature it is possible to find some authors supporting a lack of significant relationships between some Just-In-Time practices and performance (e.g. Sakakibara et al., 1997; Dean and Snell, 1996; Flynn et al., 1995).

Mackelprang and Nair (2010) argued that the potential (and still unexplored) existence of moderating effects between Just-In-Time practices (e.g.: Just-In-Time manufacturing and Just-In-Time supply) could be an explanation for the contrasting results on the link between Just-In-Time and performance.

As a consequence, in scientific literature there is a lack of empirical evidences about synergies between JIT practices that are part of the Lean Manufacturing methodology.

Thus, the last research question of this thesis is as follows:

**RQ 6: is there a moderating effect between Just-In-Time manufacturing and Just-In-Time supply that could lead to possible trade-offs on operational performances?**

This research question will be answered by the paper presented in Chapter 4, where I will demonstrate that Just-In-Time supply positively moderates the relationship between Just-In-Time manufacturing and delivery performance and this effect lead to trade-off between efficiency and delivery performances in particular Just-In-Time manufacturing – Just-In-Time supply configurations.

## 1.2 Structure of the thesis and methodology adopted

The thesis is composed by three papers that are organized as follows: after a introduction about the specific research, I will present the literature review and, consequently, the theoretical model definition, after that I will describe the methodology adopted. Finally a discussion of the main results will conclude each chapter.

At the end of the thesis, in Chapter 5, I will summarize the academic and managerial contributions in relation with the research questions discussed in this chapter.

The empirical research of this thesis is based on survey methodology. To test the cumulative and trade-off models, I have followed a common structure in all the three papers:

1. Content validity of the variables of interest
2. Confirmatory Factor Analysis to test the measurement model
  - a. Standardization of the data by country and industry
  - b. Assessment of unidimensionality, convergent validity and reliability for the all of the first-order constructs
  - c. Discriminant validity for the first-order constructs assessed by conducting a series of  $\chi^2$  difference tests between nested models for all pairs of constructs
  - d. Convergent validity for the second-order constructs (for the cumulative model)
  - e. Discriminant validity for the second-order constructs (for the cumulative model)
3. Test of the hypotheses with different methods, depending on the specific purpose
  - a. Structural Equation Modeling for the cumulative model (Chapter 2)
  - b. Structural Equation Modeling and Ping (1995)'s 2-step approach to test the moderating hypotheses of the first trade-off model (Chapter 3)

- c. Hierarchical regression method to test the moderating hypotheses of the second trade-off model (Chapter 4)

In every chapter I decided to use slightly different tests to demonstrate my knowledge about the survey methodology, nevertheless trying to keep the methodology discussion lean and easy to read.

### **1.3 Data collection**

I use data from the third round of the High Performance Manufacturing (HPM) project data set (Schroeder and Flynn 2001). The survey questionnaire was distributed by my research group in collaboration with an international team of researchers working in different universities all over the world to a selection of plants from different countries (i.e. Finland, US, Japan, Germany, Sweden, Korea, Italy, Austria, China and Spain). These countries were included because they contain a mix of high performing and traditional manufacturing plants in the selected industries, while providing diversity of national cultural and economic characteristics.

The selected plants operate in machinery (SIC code: 35), electronics (SIC code: 36) and transportation components (SIC code: 37) sectors. As I said before, the plants were randomly selected from a master list of manufacturing plants in each of the countries. Within the research group, for each country, a group of researchers and a person in charge of plant selection process and data collection were identified. Each local HPM research team used different tools for selecting plants. In Italy, we used Dun's Industrial Guide.

The study administrators sent requests to each local HPM research team to include an approximately equal number of high performing and traditional manufacturing plants. This allowed to include in the sample plants that use advanced practices in their industry, i.e. World Class Manufacturing (WCM) plants, as well as traditional (i.e. not

WCM) plants. Finally, all plants had to represent different parent corporations, and have at least 100 employees.

The questionnaire was firstly developed in English, then was translated into the local language by the local research team. Informants were selected based on their skills and expertise on the topic investigated.

Each plant received a batch of questionnaires targeted at the respondents who were the best informed about the topic of the specific questionnaire. In order to reduce the problem of common method bias, each questionnaire was administered to different respondents within each plant.

Researchers involved in HPM project asked the CEOs (or to a coordinator within each plant) to provide us with the name and contact addresses of the respondents for each questionnaire, and to distribute the questionnaires received by individual visits or by post to the respondents.

Each local HPM research team had to provide assistance to the respondents, to ensure that the information gathered was both complete and correct.

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## 2 CUMULATIVE MODEL FOR LEAN MANUFACTURING

### 4.1 Introduction

Lean Manufacturing (LM) is a methodology that involves the simultaneous use of many techniques and tools. Shah and Ward (2003) have developed the measurement scale of LM, identifying four bundles of practices: Just-In-Time (JIT), Total Quality Management (TQM), Human Resource Management (HRM) and Total Productive Maintenance (TPM). In Operations Management (OM) scientific literature LM is defined either as a philosophy that follows strategic principles, such as continuous improvement and waste reduction, or a set of practices, like kanban, cellular manufacturing and so on (Shah and Ward, 2007). To make significant academic contributions it is important to study a phenomenon using a commonly accepted and comprehensive measurement scale (McCutcheon and Meredith, 1993). However, there are very few studies that have investigated LM holistically, causing a problem of generalizability of the results. One of the studies that analyzed LM holistically is Shah and Ward (2007). Shah and Ward (2007) defined LM as “*an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability*”. The authors argued that LM could be viewed in a configurational perspective, since LM practices seems to be inter-related but not clearly causal related, thus LM practices are complementary and synergic rather than sequential, and only the concurrent use of the all set of LM practices leads to a competitive advantage (Shah and Ward, 2007).

From the abovementioned discussion arises a managerial problem. Indeed, the creation of a strategy that builds manufacturing capabilities following a precise sequence of practices is vital to obtain maximum results and a sustaining competitive advantage (John *et al.*, 2001). As a matter of fact, it is not possible to implement at the

same time all the manufacturing practices, since managers typically don't have sufficient resources (Skinner, 1969; Rosenzweig and Easton, 2010). For this reasons, managers need an implementation sequence of tools and techniques that could maximize the impact of these practices on operational performances.

A research stream (Cua *et al.*, 2001; McKone *et al.*, 2001; Furlan *et al.*, 2011), tried to fill this gap studying some causal relationships between LM practices, however these studies firstly didn't analyze together all LM practices and secondly they didn't differentiate the impact of LM on the different dimensions of operational performance. The first problem causes a lack of generalizability of the results, while the second leads to possible errors of implementation sequence of manufacturing capabilities. It is fundamental to study sequence of practices – or manufacturing capabilities – implementation in relation to a precise sequence of operational performance achievement – or competitive capabilities – (Ferdows and De Meyer, 1990). Ferdows and De Meyer (1990) used the “sand cone” model to describe how a manufacturing company could build a sustainable success through a cumulative sequence of capabilities. In particular, the authors stated that manufacturers have to focus on manufacturing capabilities that are able to improve quality (quality conformance), after that on capabilities for quality and dependability (delivery performance), then for quality, dependability and speed (flexibility performance) and finally also for cost reduction.

Starting from the seminal publication of Ferdows and De Meyer (1990), some researchers have studied the relationship between these performance dimensions (e.g. Noble, 1995; Boyer and Lewis, 2002; Flynn and Flynn, 2004; Rosenzweig and Roth, 2004; Großler and Grubner, 2006).

Noble (1995) analyzed through a exploratory survey, based on regression and cluster analyses, the strategies and priorities of 561 companies in North America, Europe and Korea and found out that the manufacturing strategy follows a sequence of priorities that starts from quality, then dependability, delivery, cost, flexibility and innovation.

Boyer and Lewis (2002) studied 110 plants that had implemented Advanced Manufacturing Technologies (AMT) to understand if there are evidences of trade-off between priorities. The authors argued that manufacturers and decision makers need to



set priorities in trade-off, even though the use of AMT guide to cumulative capabilities effects.

Flynn and Flynn (2004) used multiple regression analysis to test in 165 plants located in five countries and operating in three industries whether cumulative capability sequences are country and industry specific. Empirical evidences of this study didn't support the generalizability of the "sand cone" model, since the sequence of capabilities changed for different countries. In addition, the authors argued that manufacturing strategies support the foundation of cumulative capabilities, while they don't for the high-level parts of capabilities.

Rosenzweig and Roth (2004) gave empirical evidences of the "sand cone" model, confirming the sequence of Ferdows and De Meyer (1990) on a restricted sample of 81 plants and explain how manufacturing capabilities lead to business profitability.

Großler and Grubner (2006) proposed an alternative path model to test the accuracy of cumulative capabilities. They assumed that after the sequence of quality and delivery capabilities, delivery has a direct impact on both flexibility and cost, while these capabilities are modeled in trade-off. After a Structural Equation Modeling procedure on a sample of 558 plants operating in 17 countries and 5 industries, the authors concluded that the cumulative part of their theoretical framework is valid, thus quality results as the baseline of the model, followed by delivery capability. Results of this research suggest also that after delivery, companies could improve simultaneously cost and flexibility capabilities. Finally, results cannot support the trade-off nature of cost-flexibility relationship.

From the abovementioned studies, it can be found a substantial agreement on the first two competitive capability dimensions sequence of the "sand cone" model, namely quality and delivery performance, while there is no an universal agreement on the sequence of the last two dimensions: flexibility and cost.

These mixed results could be explained by several argumentations and problems. First of all, there is no consensus about the measures to test the "sand cone" model, as a matter of facts, some authors measured competitive priorities instead of competitive capabilities (Flynn and Flynn, 2004; Rosenzweig and Easton, 2010). The second problem is connected with the sample size: when the sample is restricted, the generalizability of the results is limited. Another problem is the theoretical framework

of reference and the methodology adopted: the analysis of the simple path of competitive capabilities without a comparison of rival models is too limited to assert that an a priori model is acceptable. Moreover, when a theoretical framework refers to manufacturing strategies and their link with competitive capabilities, structural equation modeling has to be preferred in comparison to multiple regression analysis because the latter methodology can't test at the same time all the theoretical framework; this problem goes against fit theory, that requires the presence of all the variables of interest in the same structural model, to verify the different contribution of manufacturing capabilities on competitive capabilities, and at same time test the "sand cone" model.

The aim of this chapter is twofold. On the one hand to give empirical evidences about causality relations and interconnection between LM practices, on the other to propose a cumulative sequence of LM capabilities based on a comprehensive study about the relationships between LM practices and each operational performance dimension and relationships between performances, thus testing the "sand cone" model. As a matter of facts, in this chapter, I consider not only how LM practices are linked together and can affect operational performance, but also how they can trigger a series of performance improvements according to the sequence suggested by Ferdows and De Meyer's (1990) model.

## **4.2 Literature review and hypotheses**

### **2.2.1 Lean Manufacturing**

Shah and Ward (2007) define Lean Manufacturing as a methodology that aims at eliminating waste by reducing supplier, internal and customer variability through an integrated socio-technical system that involves the simultaneous use of many practices. The authors point out the importance of studying LM using commonly accepted and comprehensive measurement scales to make significant academic contributions. Indeed, for example, LM is often confused with Just-In-Time (JIT), while JIT is only a sub-set

of LM practices, and this leads to misalignments between theory and empiricism. To solve this problem Shah and Ward (2007) developed the LM measures, identifying ten distinct dimensions: supplier feedback, JIT delivery by suppliers and supplier development (supplier related constructs); customer involvement (customer related construct); pull, continuous flow, set up time reduction, total productive maintenance, statistical process control and employee involvement (internally related constructs). These LM dimensions could be grouped following four bundles of practices, named: Just-In-Time (JIT), Total Quality Management (TQM), Human Resource Management (HRM) and Total Productive Maintenance (TPM) (Shah and Ward, 2003).

Even though Shah and Ward (2007) have argued that “*the relationships among the elements of Lean Manufacturing are neither explicit nor precise in terms of linearity or causality*”, it is possible to find a stream of literature that studied the causality relations and interconnection between LM practices. Cua *et al.* (2001) revealed the importance of using TQM, JIT and TPM practices simultaneously to maximize operational results, supported by McKone *et al.* (2001) who theorized that JIT and TQM alone cannot improve operational performance, but they act as mediators between TPM and operational performance, in fact TPM practices on the one hand they facilitate the introduction of TQM because reduce process variability, on the other they help JIT because increase plant capacity.

Furlan *et al.* (2011) distinguish two parts of the LM system, the technical part, represented by JIT and TQM tools, and the social part, represented by HRM practices. The authors have proved that JIT and TQM are complementary and HRM acts as an antecedent and enabler that creates the right environment where develop the technical part of the system. As a matter of fact, the combination of TQM and JIT creates additional complexity and makes worker training and skills more important (Snell and Dean, 1992), thus, the implementation of JIT and TQM requires an adequate organizational change because “*technology alone does not provide companies with better performance*” (Challis *et al.*, 2005). Aihre and Dreyfus (2000) argued that the success of the introduction of new quality improvement programs depends not only on the employee’s knowledge and training, but also on a coherent manufacturing strategy. This is due to the fact that a clear manufacturing strategy, based on a continuous improvement foundation, is able to direct all the efforts toward new technical and

managerial directions (Hayes and Wheelwright, 1988). Finally, this manufacturing strategy must be shared with suppliers carefully selected to reinforce the relationship with them, and it must be aligned with the company business strategy to achieve maximum firm results (Flynn *et al.*, 1995; Swink *et al.*, 2005).

Actually, all the aforementioned TPM tools and human and strategic oriented practices (see Table 2.1) are common to both JIT and TQM methodologies. This common set of practices is named in literature Infrastructure (Flynn *et al.*, 1995).

Based on these considerations, I argue that LM is composed by three main bundles: Infrastructure, JIT and TQM, that are related as follows:

*H1a: The Infrastructure is an antecedent of TQM*

*H1b: The Infrastructure is an antecedent of JIT*

**Table 2.1: Lean Manufacturing practices**

| <b>Bundles</b>           | <b>Practices</b>   |
|--------------------------|--|
| JUST IN TIME             | Daily Schedule Adherence<br>Flow Oriented Layout<br>JIT links with suppliers<br>Kanban<br>Setup Time Reduction                                   |
| TOTAL QUALITY MANAGEMENT | Statistical Process Control<br>Process Feedback<br>Top-Management Leadership for Quality<br>Customer Involvement<br>Supplier Quality Involvement |
| INFRASTRUCTURE           | Total Preventive / Autonomous Maintenance<br>Cleanliness<br>Multi-Functional Employees<br>Small Group Problem Solving                            |

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Employee Suggestions  
Manufacturing-Business strategy linkage  
Continuous Improvement  
Supplier Partnership

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### **2.2.2 Operational Performance**

Most of the empirical studies concerning LM analyzed the impact of LM practices on operational performance measured as a single construct that includes at the same time multiple dimensions (e.g. quality, delivery, flexibility and cost) (McKone *et al.*, 2001; Tan *et al.*, 2007; Furlan *et al.*, 2011) or as multiple constructs for multiple dimensions without any causal relation between them (Flynn *et al.*, 1995; Cua *et al.*, 2001; Shah and Ward, 2003; Li *et al.*, 2005). These approaches lead to several problems: using a single construct could generate difficulties in interpreting results because it is impossible to distinguish the contributions on each dimension of performance, while missing causal relationships between performance dimensions decreases the explanatory power of the model and influence the interpretation of the results about the real impact of LM practices on performance.

To solve these problems, this research uses the perspective of the sand cone model (Ferdows and De Meyer, 1990), a very famous model about sequence of cumulative capabilities, but still criticized and not yet effectively proved (Flynn and Flynn, 2004, Rosenzweig and Easton, 2010).

### **2.2.3 In defense of the sand cone model**

Quality conformance represents the baseline of the cumulative sequence described in the sand cone model (Ferdows and De Meyer, 1990; Flynn and Flynn, 2004). Quality conformance is recognized as the most important competitive capability to develop (White, 1996) and the precursor of all the other competitive capabilities – delivery, flexibility and cost – (Schmenner and Swink, 1998) as it builds a stable foundation for

the other competitive capabilities improvements because it makes the production system more stable through a reduction of process variance (Ferdows and De Meyer, 1990). This reduction improves delivery performance because cycle times are shortened by speeding product throughput, thus allowing improved schedule attainment and faster response to market demands (Flynn and Flynn, 2005). Indeed, if quality conformance is high, it is possible to control lead time variances, since rework diminishes (Flynn and Flynn, 2004) and consequently the material moves quickly through the production process.

For these reasons, cycle time is more predictable (Flynn *et al.*, 1999) and the outcome of the process (time and quality) is less uncertain (Schmenner and Swink, 1998), allowing more reliable production scheduling and delivery dates (Rosenzweig and Roth, 2004).

*H2: Quality conformance is the baseline of the sand cone model*

*H2a: Quality conformance directly improves delivery*

Increasing delivery performance through a better knowledge about the production process and a reduction of cycle times improves flexibility (Ferdows and De Meyer, 1990) because the time required to respond to variations in customer demand decreases, thus it is easier to adjust internally production processes, following the changed requirements (Grobler and Grubner, 2006).

If the throughput time is not under control, a company is not sufficiently able to meet the customer demand, and the consequence of this lack of demand reliability is reflected in a worse flexibility capability. Only starting with a delivery improvement (also thanks to a closer relationship with the customer and coordination with suppliers that diminishes demand variability) it is possible to improve flexibility (Rosenzweig and Roth, 2004).

*H2b: Delivery directly improves flexibility*

Flexibility is the ability of changing production volume and mix following the customer demand without safety stocks (Jack and Raturi, 2002) and with little time or

cost penalties (Swink *et al.*, 2005). Consequently, flexibility diminishes the need of inventory buffers that negatively affect cost performance, such as overproduction and obsolete finished products (Avella *et al.*, 2011), having a direct and positive effect on cost (Rosenzweig and Roth, 2004).

On the contrary, delivery is not directly connected with cost reduction because a company could be reliable by using large amounts of inventories, thus producing with extra costs (Schmenner and Swink, 1998). Cost is reduced only if flexibility becomes a routine (Adler *et al.*, 1999) and it represents the most difficult capability to reach, because only when all the other capabilities are improved it is possible to focus on cost reduction (Ferdows and De Meyer, 1990), since cost doesn't influence any other capability, but it is influenced by them (White, 1996).

*H2c: Flexibility directly improves manufacturing cost*

#### **2.2.4 Links between Lean Manufacturing and the sand cone model**

In the first part of the literature review I hypothesized that Lean Manufacturing is composed by three bundles, and that Infrastructure acts as an antecedent of JIT and TQM. In the second part I sequenced the competitive capabilities. In the last part I connect these two parts of the framework depicted in Figure 2.1 to determine how Lean Manufacturing builds its competitive advantage.

TQM methodology includes unique practices that are not shared with JIT. These practices are: Statistical Process Control, Process Feedback, Top-Management Leadership for Quality, Customer Involvement and Supplier Quality Involvement (Flynn *et al.*, 1995; Cua *et al.*, 2001; Shah and Ward, 2003; Prajogo and Sohal, 2006). These TQM unique practices provide tools and approaches for solving quality problems in the production system. The adoption of TQM practices decrease process variability through a reduction of scraps and reworks and the primary outcome of the adoption of TQM practices is a product without defects (Flynn *et al.*, 1995), thus:

*H3a: TQM directly improves quality conformance*

Even though the primary determinant of TQM is quality conformance, TQM practices indirectly improve also delivery, flexibility and cost through the reduction of manufacturing process variance. The use of TQM unique practices has a positive effect on cycle times and delivery reliability because they reduce the number of item produced and the dimension of the lot size. This reduction is due to the fact that TQM unique practices decrease the need of cycle and safety stocks, since they improve the work flow constancy and precision (Flynn *et al.*, 1995).

Delivery performance improves not only for the reduced manufacturing process variance, but also because the presence of suppliers involved in quality efforts permits to reduce the time needed for quality inspections and permits to have supplies more reliable and flexible (Romano, 2002).

The delivery improvements obtained by the concurrent use of TQM unique practices have a positive effect on flexibility, because the increased capability to produce with reduced lead time and lot sizes, permits to have manufacturing processes synchronized with the customer demand without the use of inventories (Work-In-Progress and final products) (Flynn *et al.*, 1995). Thus, also cost improves because there is less need of inventories to protect the production system against external variance (Sim and Curtola, 1999).

*H3b: TQM indirectly improves delivery, flexibility and manufacturing cost through quality conformance in accordance with the sand cone model sequence*

JIT methodology includes unique practices that are not shared with TQM. These practices are: Daily Schedule Adherence, Flow Oriented Layout, JIT links with suppliers, Kanban, Setup Time Reduction (Shah and Ward, 2003; Shah and Ward, 2007; Mackelprang and Nair, 2010; Furlan *et al.*, 2011).

JIT methodology aims at producing the right quantity of products at the right time (delivery reliability). However, JIT improves not only delivery time, but also reduces the variance in quantity and quality of the production processes (Green *et al.*, 2005).



Indeed JIT, by reducing lot sizes, reduces scraps, reworks and failures, improving quality.

JIT directly improves quality conformance because the reduction of inventory reduces the risk of handling damage, reduced lot sizes decreases the number of defects if the process goes out of control, since, with large lot sizes, quality controls are made later and with a higher possibility of defects (Flynn *et al.*, 1995). Thus,

*H4a: JIT directly improves quality conformance*

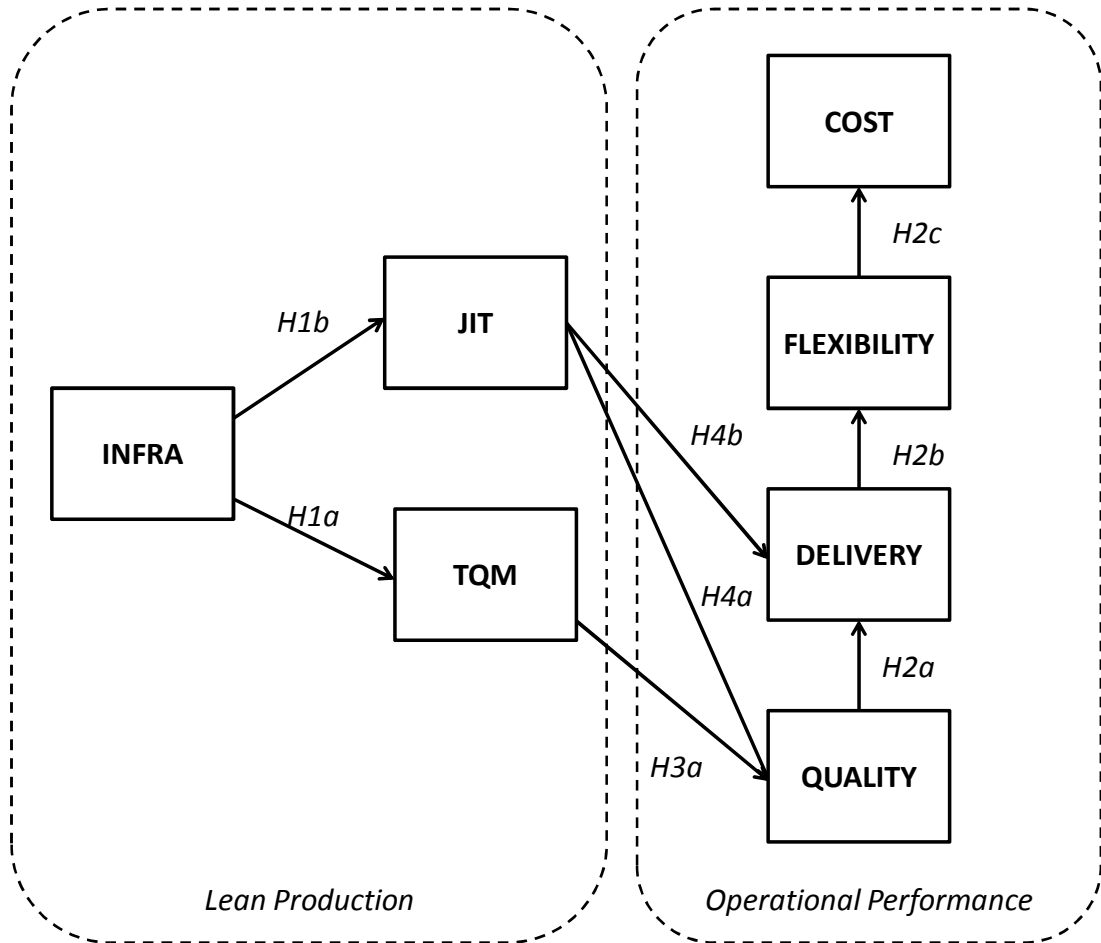
*H4b: JIT directly improves delivery*

JIT, with the introduction of a pull system, permits a closer match between production and customer demand, improving delivery performance. JIT indirectly improves also flexibility: in order to perfectly match the demand, a pull system reduces lot sizes and setup times and uses a little extra capacity to meet unexpected demand and to be more reliable, and through these improvements, also flexibility improves (Flynn *et al.*, 1995).

Moreover, for a pull system it is important to maintain a closer relationship with suppliers to obtain more frequent deliveries to meet the final customer demand. These deliveries not only improve delivery performance, but also flexibility, since the amount of material delivered every time is reduced (reduced inbound lot size) (Sim and Curatola, 1999).

When delivery and flexibility are met, then also costs could be reduced because it is possible to eliminate WIP and final goods inventories (Flynn *et al.*, 1995; Sim and Curatola, 1999). JIT is more than a reduction inventory program. Flexibility is improved and inventories are reduced as the result of a better quality, lead time and delivery performance (Sim and Curatola, 1999; Fullerton *et al.*, 2003). For this reason,

*H4c: JIT indirectly improves delivery, flexibility and manufacturing cost through quality conformance and delivery in accordance with the sand cone model sequence*



**Figure 1: theoretical framework**

## 2.3 Methodology

### 2.3.1 Measurement of variables

This study uses data from the third round of the High Performance Manufacturing (HPM) project data set. The analyses are based on a sample of 317 manufacturing plants, settled in several countries around the world (i.e. Finland, US, Japan, Germany, Sweden, Korea, Italy, Austria, Spain and China), and operating in machinery,

electronics and transportation component sectors. The questionnaires used in the present research are a subset of the whole HPM survey. Respondents within each plant were specifically asked to give answers on Infrastructure, Just-In-Time and Total Quality Management practices adopted and performance obtained.

All the items comprising Infrastructure, Just-In-Time and Total Quality Management constructs were developed from Likert-scaled items, with values ranging from 1 (“strongly disagree”) to 7 (“strongly agree”). As to the items composing the operational performance constructs, we asked respondents to provide their opinion about plant’s performances compared with its competitors on a 5 point Likert scale (1 is for “poor, low” and 5 is for “superior”).

In the literature review section I defined LM as a methodology that includes Infrastructure, Just-In-Time and Total Quality Management. I conceptualized these bundles as second-order factors and measured through distinct first-order factors, corresponding to the associated practices, while each practice was measured with a multi-item scale.

### **2.3.1 Content validity**

An extensive literature review has allowed to select the items that cover all important aspects of each practice, thus ensuring content validity (Nunnally, 1978). The scales included in this chapter are adaptations of existing and commonly used scales in OM literature.

The variables of interest that refers to the Lean Manufacturing bundles (Infrastructure, Just-In-Time and Total Quality Management) were conceptualized as second-order constructs.

Infrastructure was measured including all the common practices shared by JIT and TQM methodologies (Flynn *et al.*, 1995), such as Total Preventive Maintenance (Cua *et al.*, 2001; McKone *et al.*, 2001); cleanliness, multi-functional employees, small group problem solving and employee suggestions, which represent the HRM practices (Snell and Dean, 1992; Aihre and Dreyfus, 2000; Challis *et al.*, 2005; Furlan *et al.*, 2011), manufacturing-business strategy linkage (Hayes and Wheelwright, 1988; Flynn *et al.*,

1995; Swink *et al.*, 2005), Continuous Improvement (Hayes and Wheelwright, 1988), Supplier Partnership (Flynn *et al.*, 1995; Swink *et al.*, 2005).

Just-In-Time was measured with five first-order constructs, namely: daily schedule adherence (Flynn *et al.*, 1995; Cua *et al.*, 2001; Ahmad *et al.*, 2003; Mackelprang and Nair, 2010; Furlan *et al.*, 2011), flow oriented layout (Sakakibara *et al.*, 1997; Ahmad *et al.*, 2003; Shah and Ward, 2003; Shah and Ward, 2007; Mackelprang and Nair, 2010; Furlan *et al.*, 2011), JIT links with suppliers (Sakakibara *et al.*, 1997; Ahmad *et al.*, 2003; Shah and Ward, 2007; Mackelprang and Nair, 2010), kanban (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Ahmad *et al.*, 2003; Shah and Ward, 2003; Shah and Ward, 2007; Mackelprang and Nair, 2010; Furlan *et al.*, 2011) and setup time reduction (Sakakibara *et al.*, 1997; Ahmad *et al.*, 2003; Shah and Ward, 2003; Shah and Ward, 2007; Mackelprang and Nair, 2010; Furlan *et al.*, 2011).

Total Quality Management was measured with five first-order constructs: statistical process control (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Cua *et al.*, 2001; Shah and Ward, 2003; Shah and Ward, 2007), process feedback (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Cua *et al.*, 2001; Ahmad *et al.*, 2003), top-management leadership for quality (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Cua *et al.*, 2001), customer involvement (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Cua *et al.*, 2001; Ahmad *et al.*, 2003; Shah and Ward, 2007) and supplier quality involvement (Flynn *et al.*, 1995; Sakakibara *et al.*, 1997; Cua *et al.*, 2001; Shah and Ward, 2003; Shah and Ward, 2007).

With regard to operational performance, I used four first-order constructs, following the dimensions of Ferdows and De Meyer (1990)'s model: quality conformance and cost were measured as a single item scale, while delivery and flexibility as a two item scales (for details see Appendix A).

### **2.3.2 Unidimensionality, reliability, convergent and discriminant validity of the measurement variables**

To analyze the structural model and test our hypotheses, the items of each Infrastructure, JIT and TQM practice measure were parceled with the aim at reducing

the complexity of the model and to meet the minimum sample size required for structural equation modeling analysis.

For each practice, I computed a single indicator that corresponds to the average of the items' responses. This procedure was adopted in different and important studies in OM literature (e.g. Cua *et al.*, 2001; Sila, 2007).

However, before the analysis of the structural model, I conducted a complete Confirmatory Factor Analysis (CFA) to verify if the second-order factor measurement model was valid and reliable.

I used LISREL 8.80 to perform the CFA. Even if Flynn and Flynn (2004) argued that there are different patterns of cumulative capabilities for different countries and industries, I want to test whether the sand cone model (Ferdows and De Meyer, 1990) is the best sequence of competitive capabilities and if it could be generalized. For this reason, before the CFA, I standardized data by country and industry, since they could affect the measurement and structural models results (Flynn *et al.*, 1990).

Moreover, an iterative modification process permitted to refine the scales and to assess the unidimensionality for the first and second-order constructs. The iterative modification process was conducted to improve the parameters and fit statistics of the construct model. Indeed, when the recommended parameters were not respected, I eliminated one item at time (Joreskog and Sorbon, 1989), until the model parameters were met. If a construct had less than 4 items, the iterative modification process was conducted on a two-constructs model, where the second construct was used as a common basis of reference to have sufficient degrees of freedom to compute fit statistics (Li *et al.*, 2005). Appendix A reports the details about the items and the iterative modification process adopted.

After the iterative modification process, I assessed the model fit for the three Lean Manufacturing bundles of practices. For each bundle, I verified the overall model fit, analyzing absolute (RMSEA), incremental (CFI) and parsimonious ( $\chi^2$ ) indices. All fit indices are above the recommended cutoff points, indicating that the measurement model is acceptable (see Table 2.2, 2.3 and 2.4).

Convergent validity for the first-order constructs is demonstrated when all factor loadings of the observable variables on their first-order latent construct are statistically significant, and, similarly, convergent validity for the second-order constructs is assured

when all factor loadings of the first-order latent constructs on their second-order latent construct are statistically significant (Anderson and Gerbing, 1988).

Convergent validity is assured since all factor loadings of the first and second order constructs are significant at 0.01 level and greater than 0.50. Table 2.2, 2.3 and 2.4 report all factor loadings, t-values and fit indices of the measurement model.

**Table 2.2: Infrastructure factor loadings, t-values and fit indices (part A)**

| Construct                  |       |         | Composite<br>$\alpha$ | Indicator | Factor<br>Loading | t-value |
|----------------------------|-------|---------|-----------------------|-----------|-------------------|---------|
| Employee Suggestions       |       |         | .871                  |           | .78               | 12.685  |
|                            |       |         |                       | I_ES1     | .815              | -       |
|                            |       |         |                       | I_ES2     | .816              | 16.123  |
|                            |       |         |                       | I_ES3     | .723              | 13.804  |
|                            |       |         |                       | I_ES4     | .819              | 16.209  |
|                            |       |         |                       | I_ES5     | .617              | 11.355  |
| Multi-Functional Employees |       |         | .854                  |           | .614              | 9.584   |
|                            |       |         |                       | I_MFE1    | .788              | -       |
|                            |       |         |                       | I_MFE2    | .836              | 15.312  |
|                            |       |         |                       | I_MFE4    | .829              | 15.184  |
|                            |       |         |                       | I_MFE5    | .644              | 11.450  |
| Small<br>Solving           | Group | Problem | .875                  |           | .828              | 11.060  |
|                            |       |         |                       | I_SGPS1   | .66               | -       |
|                            |       |         |                       | I_SGPS2   | .827              | 12.579  |
|                            |       |         |                       | I_SGPS3   | .78               | 12.006  |
|                            |       |         |                       | I_SGPS4   | .83               | 12.606  |
|                            |       |         |                       | I_SGPS5   | .629              | 10.006  |
|                            |       |         |                       | I_SGPS6   | .704              | 11.021  |

**Table 2.2: Infrastructure factor loadings, t-values and fit indices (part B)**

|                                 |      |        |      |        |
|---------------------------------|------|--------|------|--------|
| Manufacturing-Business Strategy | .806 |        | .592 | 8.054  |
|                                 |      | I_MBS2 | .632 | -      |
|                                 |      | I_MBS3 | .724 | 10.317 |
|                                 |      | I_MBS4 | .858 | 11.315 |
|                                 |      | I_MBS5 | .595 | 8.865  |
|                                 |      | I_MBS6 | .567 | 8.528  |
| Cleanliness and Organization    | .886 |        | .743 | 11.236 |
|                                 |      | I_CO1  | .741 | -      |
|                                 |      | I_CO2  | .862 | 15.238 |
|                                 |      | I_CO3  | .877 | 15.473 |
|                                 |      | I_CO5  | .774 | 13.636 |
| Continuous Improvement          | .809 |        | .884 | 12.917 |
|                                 |      | I_CI1  | .746 | -      |
|                                 |      | I_CI2  | .516 | 8.669  |
|                                 |      | I_CI3  | .733 | 12.424 |
|                                 |      | I_CI4  | .64  | 10.816 |
|                                 |      | I_CI5  | .746 | 12.639 |
| Supplier Partnership            | .757 |        | .602 | 8.755  |
|                                 |      | I_SP1  | .765 | -      |
|                                 |      | I_SP2  | .604 | 9.354  |
|                                 |      | I_SP3  | .584 | 9.067  |
|                                 |      | I_SP4  | .702 | 10.554 |
| Total Preventive Maintenance    | .778 |        | .641 | 8.535  |
|                                 |      | I_TPM2 | .661 | -      |
|                                 |      | I_TPM3 | .654 | 9.369  |
|                                 |      | I_TPM5 | .756 | 10.292 |
|                                 |      | I_TPM6 | .666 | 9.489  |

$\chi^2 = 1077.92$ ; d.f. = 621;  $\chi^2/\text{d.f.} = 1.74$ ; RMSEA = .0494 (.0446; .0541); CFI = .979

**Table 2.3: Just-In-Time factor loadings, t-values and fit indices**

| <b>Construct</b>          | <b>Composite <math>\alpha</math></b> | <b>Indicator</b> | <b>Factor Loading</b> | <b>t-value</b> |
|---------------------------|--------------------------------------|------------------|-----------------------|----------------|
| Daily Schedule Adherence  | .843                                 |                  | .754                  | 12.8           |
|                           |                                      | J_DSA1           | .884                  | -              |
|                           |                                      | J_DSA2           | .649                  | 12.793         |
|                           |                                      | J_DSA3           | .881                  | 19.638         |
|                           |                                      | J_DSA6           | .622                  | 12.088         |
| Equipment Layout          | .843                                 |                  | .823                  | 12.104         |
|                           |                                      | J_EL1            | .755                  | -              |
|                           |                                      | J_EL4            | .819                  | 14.116         |
|                           |                                      | J_EL5            | .777                  | 13.428         |
|                           |                                      | J_EL6            | .682                  | 11.719         |
| JIT Delivery by Suppliers | .75                                  |                  | .857                  | 11.497         |
|                           |                                      | J_SUP1           | .712                  | -              |
|                           |                                      | J_SUP2           | .514                  | 8.088          |
|                           |                                      | J_SUP3           | .635                  | 9.821          |
|                           |                                      | J_SUP4           | .554                  | 8.675          |
|                           |                                      | J_SUP5           | .626                  | 9.709          |
| Kanban                    | .815                                 |                  | .600                  | 8.287          |
|                           |                                      | J_KAN2           | .671                  | -              |
|                           |                                      | J_KAN3           | .809                  | 11.704         |
|                           |                                      | J_KAN4           | .849                  | 11.85          |
|                           |                                      |                  |                       |                |
| Setup Time Reduction      | .767                                 |                  | .919                  | 10.251         |
|                           |                                      | J_STR1           | .608                  | -              |
|                           |                                      | J_STR2           | .686                  | 9.34           |
|                           |                                      | J_STR3           | .709                  | 9.539          |
|                           |                                      | J_STR4           | .523                  | 7.629          |

$\chi^2 = 300.21$ ; d.f. = 165;  $\chi^2/\text{d.f.} = 1.82$ ; RMSEA = .0508 (.0415; .0599); CFI = .982



**Table 2.4: Total Quality Management factor loadings, t-values and fit indices**

| Construct                             | Composite $\alpha$ | Indicator | Factor Loading | t-value |
|---------------------------------------|--------------------|-----------|----------------|---------|
| Customer Involvement                  | .794               |           | .738           | 9.143   |
|                                       |                    | T_CUST1   | .639           | -       |
|                                       |                    | T_CUST3   | .708           | 9.869   |
|                                       |                    | T_CUST5   | .702           | 9.809   |
|                                       |                    | T_CUST6   | .753           | 10.259  |
| Feedback                              | .804               |           | .838           | 12.176  |
|                                       |                    | T_FEED1   | .779           | -       |
|                                       |                    | T_FEED2   | .722           | 12.258  |
|                                       |                    | T_FEED3   | .674           | 11.434  |
|                                       |                    | T_FEED4   | .693           | 11.756  |
| Process Control                       | .88                |           | .632           | 9.862   |
|                                       |                    | T_PC2     | .811           | -       |
|                                       |                    | T_PC3     | .854           | 17.39   |
|                                       |                    | T_PC4     | .671           | 12.7    |
|                                       |                    | T_PC5     | .904           | 18.519  |
| Top Management Leadership for Quality | .848               |           | .695           | 9.375   |
|                                       |                    | T_TML1    | .669           | -       |
|                                       |                    | T_TML2    | .822           | 12.298  |
|                                       |                    | T_TML4    | .633           | 9.917   |
|                                       |                    | T_TML5    | .815           | 12.224  |
|                                       |                    | T_TML6    | .702           | 10.849  |
| Supplier Quality Involvement          | .823               |           | .785           | 11.629  |
|                                       |                    | T_SQI1    | .784           | -       |
|                                       |                    | T_SQI2    | .548           | 9.384   |
|                                       |                    | T_SQI3    | .651           | 11.304  |
|                                       |                    | T_SQI4    | .715           | 12.526  |
|                                       |                    | T_SQI5    | .779           | 13.697  |

$\chi^2 = 391.46$ ; d.f. = 204;  $\chi^2$ /d.f. = 1.92; RMSEA = .0536 (.0454; .0616); CFI = .979

Discriminant validity for first and second-order factors was assessed using the Chi-square test (Bagozzi and Phillips, 1991). For each pair of first-order factor constructs two nested models were compared. The first model was set with an unconstrained correlation between the two constructs, whereas in the second model the correlation was fixed to 1. If the difference between the two Chi-squares is significant, then I can conclude that the two constructs are distinct. In these analyses, all differences are significant at  $p < 0.01$ , as the lower delta Chi-square (d.f. = 1) was equal to 43.12, thus ensuring discriminant validity.

The same procedure was followed for the second-order constructs. The results found support the discriminant validity, as the lower delta Chi-square (d.f. = 1) was equal to 172.57, that is statistically significant at  $p < 0.01$ , assuring that all the scales adopted are independent from each other (Bagozzi and Phillips, 1991).

Finally, I assessed the reliability for each first-order construct using composite reliability. The composite reliability values, reported in Tables 2.2, 2.3 and 2.4 are all greater than 0.70, thus indicating that each first-order construct is consistent and free from random errors.

### **2.3.3 Structural model results**

The CFA permitted to assert that the measurement model is acceptable. As I mentioned previously, after the CFA, I parceled the second order factor constructs with the aim at obtaining a simpler model, not over specified, that permits to generalized the results. Figure 2.2 reports the results of the structural model that test the theoretical framework and hypotheses.

Fit indices of confirm the goodness of the structural model:

$$\chi^2 = 705.51; \text{d.f.} = 246; \chi^2/\text{d.f.} = 2.86 < 3; \text{RMSEA} = 0.076 < 0.08; \text{CFI} = .953 > .95$$

Lean Manufacturing infrastructural practices act as an antecedent of JIT ( $\gamma = 0.73$ ; t-test = 9.4) and TQM ( $\gamma = 0.93$ ; t-test = 11.2) unique practices, supporting hypotheses H1a and H1b.

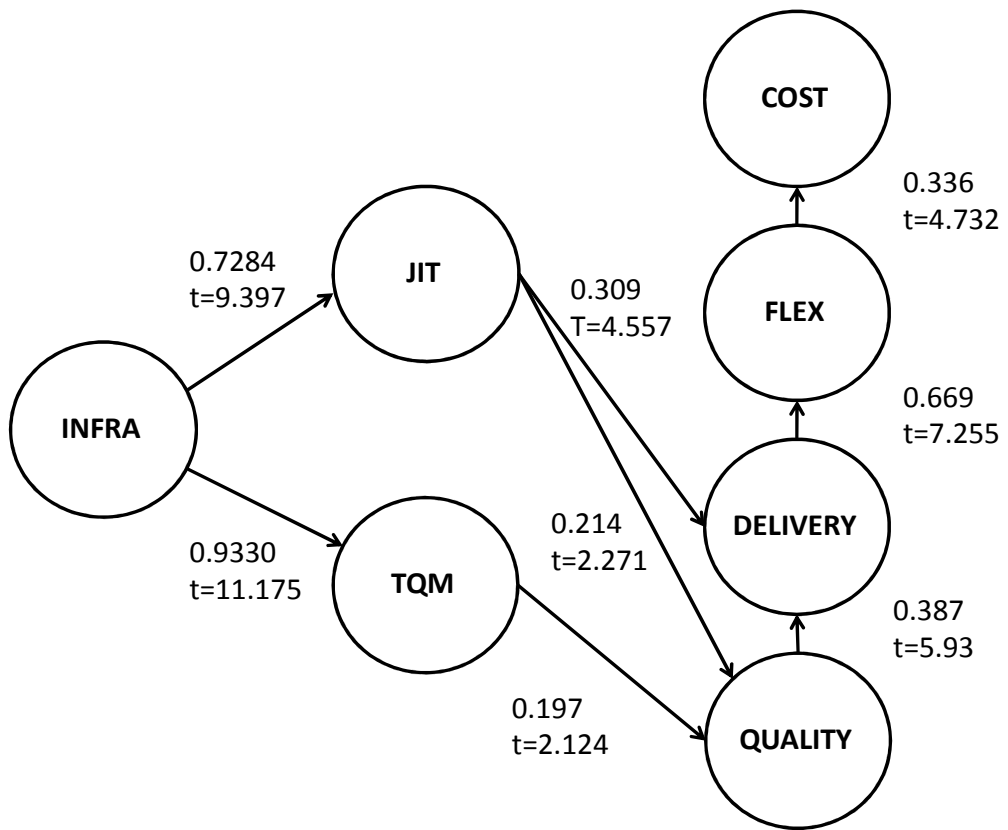
The results confirm also hypotheses H2a, H2b and H2c, since quality conformance has a direct a positive impact on delivery ( $\beta = 0.39$ ; t-test = 5.9), delivery on flexibility ( $\beta = 0.67$ ; t-test = 7.3) and flexibility on cost ( $\beta = 0.34$ ; t-test = 4.7).

Moreover, with these results I can demonstrate that Total Quality Management directly improves quality conformance ( $\beta = 0.2$ ; t-test = 2.1) and indirectly improves the other operational performance (competitive capabilities), while JIT has a direct and positive effect on quality conformance ( $\beta = 0.21$ ; t-test = 2.3) and delivery ( $\beta = 0.31$ ; t-test = 4.6) and a indirect effect on flexibility and cost performance (for all the indirect effects see Table 2.5), supporting all the remaining hypotheses: H3a, H3b, H4a, H4b and H4c.

To test whether the sand cone model sequence of cumulative capabilities could be generalizable and better than the others possible sequence, I test also a rival model, following the most frequently cited rival sequence of the sand cone model, in which quality conformance and delivery are positioned in the same way, while cost and flexibility are opposite related to the sand cone model (delivery improves cost and cost improves flexibility). The results of the rival model are reported in figure 2.3. Even though also in this case the sequence of operational performances is statistically supported, it is possible to compare the models through a evaluation of Model AIC and Model CAIC.

The sand cone model has a Model AIC = 813.51 and a Model CAIC = 1070.49; while the rival model has a Model AIC = 865.13 and a Model CAIC = 1122.11. Since the sand cone model has both model AIC and model CAIC values lower than the rival model, I can assert that the sand cone model describes the best sequence of operational performance.

Moreover, fit indices of the rival model are not acceptable, indeed  $\chi^2 = 754.92$ ; d.f. = 246;  $\chi^2/\text{d.f.} = 3.07$  that is higher than the cutoff value of 3; RMSEA = 0.081, higher than 0.08; CFI = .94, lower than .95.



**Figure 2.2: structural model results of the theoretical framework**

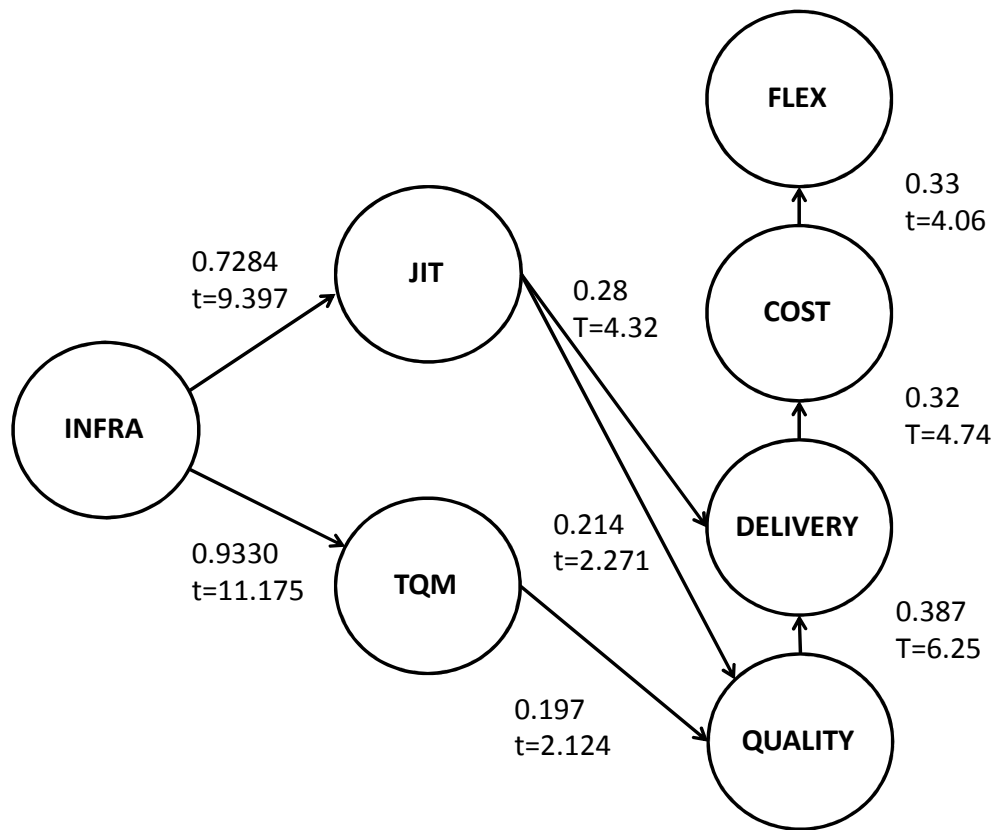


Figure 2.3: structural model results of the rival model

Table 2.5: standardized indirect effects coefficients (t-test value)

|                                 | Quality   | Delivery  | Flexibility | Cost       |
|---------------------------------|-----------|-----------|-------------|------------|
| <b>Infrastructure</b>           | .57 (5.7) | .52 (6.3) | .28 (5.1)   | .14 (3.8)  |
| <b>Total Quality Management</b> | -         | .12 (2.1) | .10 (2.0)   | .09 (1.97) |
| <b>Just In Time</b>             | -         | -         | .30 (4.5)   | .15 (3.5)  |
| <b>Quality</b>                  | -         | -         | .19 (4.9)   | .09 (3.7)  |
| <b>Delivery</b>                 | -         | -         | -           | .26 (4.5)  |

## 2.4 Discussion

The results found provide several implications for theory and practice. This research combines in a broad theoretical framework all LM practices (manufacturing capabilities), how they are grouped in bundles, how they are connected and their impact on operational performance (competitive capabilities). The results confirm that the implementation of all LM practices lead to an overall improvement of operational performances (Shah and Ward, 2003; Shah and Ward, 2007).

However, this research deeply analyses the mechanism by which LM builds a sustainable competitive advantage. Unlike previous empirical studies that measured LM with non comprehensive scales (e.g. Li *et al.*, 2005), or that conclude that LM practices are not clearly causal related (e.g. Shah and Ward, 2007), I further investigated possible LM practices relationships, measuring LM with comprehensive scales and dividing them in three main bundles: Infrastructure, JIT and TQM.

Structural equation results suggest that the Infrastructure acts as an antecedent of JIT and TQM. This means that, when implementing LM, to facilitate at the later stage the implementation of JIT and TQM, managers have to consider as a priority the introduction of HRM practices to prepare the right environment for LM technical tools (Furlan *et al.*, 2011), following a continuous improvement based strategy commonly accepted by the managers of the organization and its key suppliers (Flynn *et al.*, 1995; Swink *et al.*, 2005) and introducing TPM techniques (Cua *et al.*, 2001; McKone *et al.*, 2001).

I decided to adopt the perspective of the “sand cone” model as reference to understand the right sequence of technical bundles adoption, thus to link LM capabilities with competitive capabilities. Ferdows and De Meyer (1990) suggests to build competitive capabilities in sequence and cumulative.

The authors proposes to fix as first objective of a company a improvement of quality capability. When the first objective is sufficiently achieved, the second step of the “sand cone” model sustains to continue to improve quality and at the same time start to improve delivery capability, after that quality, delivery and flexibility, and finally quality, delivery, flexibility and cost all together. In this way manufacturers are able to

overcome the trade-off problem, since they don't have to concentrate on a competitive capability at the expense of another one.

Based on this model, I connected the four dimensions of operational performances and I linked the LM part (manufacturing capabilities) with the operational performances (competitive capabilities). Structural model results demonstrate that the TQM bundle directly improve quality performance that represents the baseline of the competitive capabilities, while the JIT bundle directly improve quality and delivery capabilities.

These results are in line with LM research stream. TQM practices (Statistical Process Control, Process Feedback, Top-Management Leadership for Quality, Customer Involvement and Supplier Quality Involvement) reduce scraps and reworks, resulting in a reduction of process variability and a improvement of quality conformance of the final product (Flynn *et al.*, 1995; Shah and Ward, 2003). JIT practices (Daily Schedule Adherence, Flow Oriented Layout, JIT links with suppliers, Kanban and Setup Time Reduction) reduce lead times, having a direct impact on delivery performance, but also directly improve quality conformance because JIT practices decrease process variability. As a matter of fact, JIT decreases the possibility to produce defects because it reduces the number of production process activities, eliminating errors associated to these activities eliminated (Green and Inman, 2005), and reduces lot sizes, permitting to find scraps and defects rapidly (Flynn *et al.*, 1995).

These findings are fundamental advancements in LM theory and give important insights to managers because clearly demonstrate that LM practices have a optimal sequence of implementation, going beyond the common view based on the configural LM approach supported by Shah and Ward (2007).

If Infrastructure bundle represents the baseline of LM capabilities because antecedes JIT and TQM, the empirical results of this chapter suggest to implement TQM to improve quality conformance capability, and only at the end of the Lean transaction, JIT practices could be introduced to foster the impact on quality and start to improve delivery capability.

Moreover, all three LM bundles have a indirect positive effect on the last two competitive capabilities. Thus, following the implementation sequence suggested, and continuing to leverage on all LM practices, it is possible to achieve multiple – performance excellence, following the “sand cone” model sequence.

Finally, this chapter demonstrates the validity of the “sand cone” model in absolute terms, verifying that the sequence of operational performances are directly and indirectly connected, and in relative terms, comparing the model with the most cited rival sequence and demonstrating that the “sand cone” model fit is statistically better.

## 2.5 Conclusions

LM is a complex system of interrelated socio-technical practices (Shah and Ward, 2007). From an academic point of view it is vital to capture all LM aspects when empirically measuring it with the aim at making significant theoretical contributions (McCutcheon and Meredith, 1983). This research, after an extensive literature review, operationalized LM with three main bundles composed by 17 constructs related to different practices that cover LM globally.

The most common interpretation of LM in OM literature is in a configural way, namely that the more practices are implemented in a certain configuration, the more impact on performances could be obtained. This approach is coherent with the Resource Based View Theory that asserts that combination of unique resources, capabilities and manufacturing competences guides firms to a sustainable competitive advantage since it is difficult to imitate by the competitors (Prahalad and Hamel, 1994).

From a managerial point of view, the difficulties that arise when implementing LM are connected with the typical resource shortage of a manufacturing firm (Skinner, 1969) that inhibits the introduction of the LM practices at the same time. Thus, the importance of understanding the right sequence of LM practices implementation is highly strategic since the introduction of LM must be gradual, not only for the scarcity of the resources, but also because in manufacturing companies it is usual to have cultural resistance to change, mainly due to a lack of employees and managers training and education (Crawford *et al.*, 1988). For these two reasons, LM introduction must be gradual.



However, in literature there are few empirical evidences about sequence of LM practices implementation, indeed Shah and Ward (2007) admitted that there are no clear causal relationships between bundles of LM practices.

From the abovementioned discussion, it is evident the importance to demonstrate empirically that there is a optimal implementation sequence, going a step beyond the configural approach, to support managers when they decide to change their production system toward a Lean approach.

To fill this gap I have taken into account the “sand cone” model (Ferdows and De Meyer, 1990) as reference to demonstrate how LM bundles of practices – the manufacturing capabilities – build sequentially and cumulatively the operational performances – the competitive capabilities – in order to achieve multiple performance excellence.

Nevertheless, even though the cumulative “sand cone” model is very famous and largely cited, it hasn’t been sufficiently validated, and there are some authors that criticize it, suggesting alternative sequences of cumulative capabilities. Thus, this research aimed at validating the “sand cone” model verifying the empirical significant in absolute terms, and in relative terms by comparing it with the most cited alternative sequence.

The results of this research make a important academic contribution since they support and validate the “sand cone” model, indeed the direct and indirect relationships between operational performances are all statistically significant and the model fit indices are better compared with the rival model. Thus the first finding is that the optimal sequence of competitive capabilities is as follows: quality, delivery, flexibility and cost.

The second finding is related to how LM practices are able to follow this sequence. The results provide empirical evidences that the Infrastructure bundle of practices is the antecedent of JIT and TQM bundles, managers have to start the LM journey educating and training employees, managers and selected suppliers about the new methodology to decrease the cultural resistance to change (Crawford *et al.*, 1988), and preparing the right production environment through the introduction of TPM practices (McKone *et al.*, 2001). After that TQM practices must be implemented before JIT practices to build the first part of the cumulative sequence, namely quality conformance.

Only when quality reaches a sufficient level, JIT could be introduced to continue to improve quality and start to have a positive impact on delivery performance.

This sequence tells managers how to implement LM without incurring the typical problems of limited resources and cultural resistance to change and provide an academic contribution because demonstrate that LM bundles are causal related, not only inter-related, as supposed by previous studies.

Limitations and future developments of this study should be considered along with the results. Firstly, our research setting, the firms operating in machinery, electronics and transportation equipment industries, could limit the generalizability of our findings. It is likely that other sectors may show different patterns. Hence, future research should replicate and extend our model to samples drawn from other industries.

Finally, our future plans include an extension of this research, through longitudinal case studies, with the aim of collecting richer information regarding the optimal sequence of LM practices implementation and the operational performances achieved.

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## Appendix A

### Operational performance

Please circle the number that indicates your opinion about how your plant compares to its competitors in your industry, on a global basis: 5 – superior, 4 – better than average, 3 – average or equal to the competition, 2 – below average, and 1 – poor or low

|      |                            |
|------|----------------------------|
| Cost | Unit cost of manufacturing |
|------|----------------------------|

|         |                     |
|---------|---------------------|
| Quality | Quality conformance |
|---------|---------------------|

|          |                              |
|----------|------------------------------|
| delivery | On time delivery performance |
|          | Fast delivery                |

|             |                                   |
|-------------|-----------------------------------|
| flexibility | Flexibility to change product mix |
|             | Flexibility to change volume      |

### Lean Manufacturing practices

Please indicate to what extent you agree/disagree with the following - (circle one number): 1 – strongly disagree, 2 – disagree, 3 – slightly disagree, 4 – neutral, 5 – slightly agree, 6 – agree, and 7 – strongly agree

## JUST IN TIME

### Daily Schedule Adherence

- J\_DSA1 We usually meet the production schedule each day.
- J\_DSA2 Our daily schedule is reasonable to complete on time.
- J\_DSA3 We usually complete our daily schedule as planned.
- J\_DSA4 We build time into our daily schedule to allow for machine breakdowns and unexpected production stoppages.
- J\_DSA5 We build extra slack into our daily schedule, to allow for catching up.
- J\_DSA6 We cannot adhere to our schedule on a daily basis.
- J\_DSA7 It seems like we are always behind schedule.

|             | X <sup>2</sup>  | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | $\alpha$ |
|-------------|---|------|----|-----------|------|------|------|----------|
|             | 129.7   | 0.00 | 14 | .159(.00) | .885 | .843 | .895 | -        |
| Problem     | J_DSA4 lambda = .144 and J_DSA5 lambda = .04: J_DSA5 dropped                        |      |    |           |      |      |      |          |
| Iteration 1 | 69.4  | 0.00 | 9  | .145(.00) | .935 | .905 | .943 | -        |
| Problem     | J_DSA4 lambda = .144: J_DSA4 dropped  |      |    |           |      |      |      |          |
| Iteration 2 | 49.65   | 0.00 | 5  | .168(.00) | .952 | .913 | .957 | -        |
| Problem     | High error correlation between J_DSA6 and J_DSA7 (MI): J_DSA7 dropped (too general) |      |    |           |      |      |      |          |
| Iteration 3 | 0.5   | 0.78 | 2  | .0(.89)   | .999 | .999 | .999 | -        |
| Final       | J_DSA: J_DSA1; J_DSA2; J_DSA3; J_DSA6   |      |    |           |      |      |      | .843     |

### Equipment Layout

- J\_EL1 We have laid out the shop floor so that processes and machines are in close proximity to each other.

- J\_EL2 We have organized our plant floor into manufacturing cells.
- J\_EL3 Our machines are grouped according to the product family to which they are dedicated.
- J\_EL4 The layout of our shop floor facilitates low inventories and fast throughput.
- J\_EL5 Our processes are located close together, so that material handling and part storage are minimized.
- J\_EL6 We have located our machines to support JIT production flow.

|             | X <sup>2</sup>   | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | α    |
|-------------|--|------|----|-----------|------|------|------|------|
|             | 17.7   | 0.04 | 9  | .054(.39) | .98  | .983 | .99  | -    |
| Problem     | J_EL2 lambda = .47 and J_EL3 lambda = .33: J_EL3 dropped |      |    |           |      |      |      |      |
| Iteration 1 | 11.8   | 0.04 | 5  | .066(.25) | .985 | .983 | .991 | -    |
| Problem     | J_EL2 lambda = .44: J_EL2 dropped                        |      |    |           |      |      |      |      |
| Iteration 2 | 3.77   | 0.15 | 2  | .055(.35) | .994 | .991 | .997 | -    |
| Final       | J_EL: J_EL1; J_EL4; J_EL5; J_EL6                         |      |    |           |      |      |      | .843 |

### Just-in-Time Delivery by Suppliers

- J\_SUP1 Our suppliers deliver to us on a just-in-time basis.
- J\_SUP2 We receive daily shipments from most suppliers.
- J\_SUP3 We can depend upon on-time delivery from our suppliers.
- J\_SUP4 Our suppliers are linked with us by a pull system.
- J\_SUP5 Suppliers frequently deliver materials to us.

|       | X <sup>2</sup>                                     | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | α    |
|-------|--|------|----|-----------|------|------|------|------|
|       | 12.38  | 0.03 | 5  | .07(.199) | .973 | .967 | .983 | -    |
| Final | J_SUP: J_SUP 1; J_SUP 2; J_SUP 3; J_SUP 4; J_SUP 5 |      |    |           |      |      |      | .750 |



## Kanban

- J\_KAN1 Suppliers fill our kanban containers, rather than filling purchase orders.
- J\_KAN2 Our suppliers deliver to us in kanban containers, without the use of separate packaging.
- J\_KAN3 We use a kanban pull system for production control.
- J\_KAN4 We use kanban squares, containers or signals for production control.

|             | X <sup>2</sup>   | p    | df | RMSA(p)   | NFI | NNFI | CFI  | α    |
|-------------|--|------|----|-----------|-----|------|------|------|
|             | 46.7   | 0.00 | 2  | .28(.00)  | .93 | .8   | .933 | -    |
| problem     | High error correlation between J_KAN1 and J_KAN2 (MI): J_KAN1 dropped and kanban construct measured with JIT suppliers construct |      |    |           |     |      |      |      |
| Iteration 1 | 38.1   | 0.01 | 19 | .056(.31) | .97 | .977 | .985 | -    |
| final       | J_KAN: J_KAN2; J_KAN3; J_KAN4  |      |    |           |     |      |      | .815 |

## Setup Time Reduction

- J\_STR1 We are aggressively working to lower setup times in our plant.
- J\_STR2 We have converted most of our setup time to external time, while the machine is running.
- J\_STR3 We have low setup times of equipment in our plant.
- J\_STR4 Our crews practice setups, in order to reduce the time required.
- J\_STR5 Our workers are trained to reduce setup time.
- J\_STR6 Our setup times seem hopelessly long.

|             | X <sup>2</sup>  | p    | df | RMSA(p)  | NFI  | NNFI | CFI  | $\alpha$ |
|-------------|---|------|----|----------|------|------|------|----------|
|             | 113.1   | 0.00 | 9  | .20(.00) | .862 | .785 | .871 | -        |
| Problem     | J_STR6 lambda = .48: J_STR6 dropped                                   |      |    |          |      |      |      |          |
| Iteration 1 | 66.7  | 0.00 | 5  | .20(.00) | .89  | .79  | .89  | -        |
| Problem     | High error correlation between J_STR4 and J_STR5 (MI): J_STR5 dropped |      |    |          |      |      |      |          |
| Iteration 2 | 10.8  | 0.00 | 2  | .12(.03) | .96  | .91  | .97  | -        |
| Final       | J_STR: J_STR1; J_STR2; J_STR3; J_STR4                                 |      |    |          |      |      |      | .727     |

## TOTAL QUALITY MANAGEMENT

### Customer Involvement

- T\_CUST1 We frequently are in close contact with our customers.
- T\_CUST2 Our customers seldom visit our plant.
- T\_CUST3 Our customers give us feedback on our quality and delivery performance.
- T\_CUST4 Our customers are actively involved in our product design process.
- T\_CUST5 We strive to be highly responsive to our customers' needs.
- T\_CUST6 We regularly survey our customers' needs.

|             | X <sup>2</sup>   | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | α    |
|-------------|--|------|----|-----------|------|------|------|------|
|             | 27.9   | 0.00 | 9  | .083(.05) | .966 | .961 | .977 | -    |
| Problem     | T_CUST2 lambda = .46: T_CUST2 dropped                                    |      |    |           |      |      |      |      |
| Iteration 1 | 20.2   | 0.00 | 5  | .10(.02)  | .97  | .954 | .977 | -    |
| Problem     | High error correlation between T_CUST1 and T_CUST4 (MI): T_CUST4 dropped |      |    |           |      |      |      |      |
| Iteration 2 | 0.2  | 0.91 | 2  | .0(.95)   | .999 | .999 | .999 | -    |
| Final       | T_CUST: T_CUST1; T_CUST3; T_CUST5; T_CUST6                               |      |    |           |      |      |      | .794 |

## Feedback

- T\_FEED1 Charts showing defect rates are posted on the shop floor.
- T\_FEED2 Charts showing schedule compliance are posted on the shop floor.
- T\_FEED3 Charts plotting the frequency of machine breakdowns are posted on the shop floor.
- T\_FEED4 Information on quality performance is readily available to employees.
- T\_FEED5 Information on productivity is readily available to employees.

|             | X <sup>2</sup>  | p    | df | RMSA(p)  | NFI  | NNFI | CFI  | α    |
|-------------|---|------|----|----------|------|------|------|------|
|             | 57.3  | 0.00 | 5  | .17(.00) | .93  | .87  | .935 | -    |
| Problem     | High error correlation between T_FEED1 and T_FEED5 (MI): T_FEED 5 dropped |      |    |          |      |      |      |      |
| Iteration 1 | 1.02  | 0.6  | 2  | .0(.79)  | .999 | .999 | .999 | -    |
| Final       | T_FEED: T_FEED1; T_FEED2; T_FEED3; T_FEED4                                |      |    |          |      |      |      | .804 |

## Process Control

- T\_PC1 Processes in our plant are designed to be “fooLMroof.”
- T\_PC2 A large percent of the processes on the shop floor are currently under statistical quality control.
- T\_PC3 We make extensive use of statistical techniques to reduce variance in processes.
- T\_PC4 We use charts to determine whether our manufacturing processes are in control.
- T\_PC5 We monitor our processes using statistical process control.

|             | X <sup>2</sup>                    | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | α    |
|-------------|-----------------------------------|------|----|-----------|------|------|------|------|
|             | 17.3                              | 0.00 | 5  | .084(.09) | .98  | .97  | .988 | -    |
| Problem     | T_PC1 lambda = .47: T_PC1 dropped |      |    |           |      |      |      |      |
| Iteration 1 | 1.15                              | 0.56 | 2  | .0(.75)   | .999 | .999 | .999 | -    |
| Final       | T_PC: T_PC2; T_PC3; T_PC4; T_PC5  |      |    |           |      |      |      | .880 |

## Top Management Leadership for Quality

- T\_TML1 All major department heads within the plant accept their responsibility for quality.
- T\_TML2 Plant management provides personal leadership for quality products and quality improvement.
- T\_TML3 The top priority in evaluating plant management is quality performance.
- T\_TML4 Our top management strongly encourages employee involvement in the production process.
- T\_TML5 Our plant management creates and communicates a vision focused on quality improvement.
- T\_TML6 Our plant management is personally involved in quality improvement projects.

|             | X <sup>2</sup>                                | p    | df | RMSA(p)  | NFI  | NNFI | CFI  | A    |
|-------------|---|------|----|----------|------|------|------|------|
|             | 6.8   | 0.65 | 9  | .00(.93) | .999 | .999 | .999 | -    |
| Problem     | T_TML3 lambda = .40: T_TML3 dropped           |      |    |          |      |      |      |      |
| Iteration 1 | 3.2   | 0.66 | 5  | .00(.89) | .999 | .999 | .999 | -    |
| Final       | T_TML: T_TML1; T_TML2; T_TML4; T_TML5; T_TML6 |      |    |          |      |      |      | .848 |

## Supplier Quality Involvement

- T\_SQI1 We strive to establish long-term relationships with suppliers.
- T\_SQI2 Quality is our number one criterion in selecting suppliers.
- T\_SQI3 We use mostly suppliers that we have certified.
- T\_SQI4 We maintain close communication with suppliers about quality considerations and design changes.
- T\_SQI5 We actively engage suppliers in our quality improvement efforts

|       | X <sup>2</sup>                                | p    | df | RMSA(p)  | NFI | NNFI | CFI | $\alpha$ |
|-------|---|------|----|----------|-----|------|-----|----------|
|       | 13.04   | 0.02 | 5  | .07(.21) | .98 | .978 | .99 | -        |
| Final | T_SQI: T_SQI1; T_SQI2; T_SQI3; T_SQI4; T_SQI5 |      |    |          |     |      |     | .823     |

## INFRASTRUCTURE

### Employee Suggestions – Implementation and Feedback

- I\_ES1 Management takes all product and process improvement suggestions seriously.
- I\_ES2 We are encouraged to make suggestions for improving performance at this plant.
- I\_ES3 Management tells us why our suggestions are implemented or not used.
- I\_ES4 Many useful suggestions are implemented at this plant.
- I\_ES5 My suggestions are never taken seriously around here.

|       | X <sup>2</sup>                          | p    | df | RMSA(p) | NFI  | NNFI | CFI  | $\alpha$ |
|-------|---|------|----|---------|------|------|------|----------|
|       | 3.51                                    | 0.62 | 5  | .0(.88) | .999 | .999 | .999 | -        |
| Final | I_ES: I_ES1; I_ES2; I_ES3; I_ES4; I_ES5 |      |    |         |      |      |      | .871     |

### Multi-Functional Employees

- I\_MFE1 Our employees receive training to perform multiple tasks.
- I\_MFE2 Employees at this plant learn how to perform a variety of tasks.
- I\_MFE3 The longer an employee has been at this plant, the more tasks they learn to perform.
- I\_MFE4 Employees are cross-trained at this plant, so that they can fill in for others, if necessary.
- I\_MFE5 At this plant, each employee only learns how to do one job.

|             | X <sup>2</sup>                        | p     | df | RMSA(p)   | NFI  | NNFI | CFI  | α    |
|-------------|---------------------------------------|-------|----|-----------|------|------|------|------|
|             | 7.98                                  | 0.157 | 5  | .042(.52) | .999 | .999 | .999 | -    |
| Problem     | I_MFE3 lambda = .46: I_MFE3 dropped   |       |    |           |      |      |      |      |
| Iteration 1 | 0.2                                   | 0.88  | 2  | .00(94)   | .999 | .999 | .999 | -    |
| Final       | I_MFE: I_MFE1; I_MFE2; I_MFE4; I_MFE5 |       |    |           |      |      |      | .854 |

### Small Group Problem Solving

- I\_SGPS1 During problem solving sessions, we make an effort to get all team members' opinions and ideas before making a decision.
- I\_SGPS2 Our plant forms teams to solve problems.
- I\_SGPS3 In the past three years, many problems have been solved through small group sessions.
- I\_SGPS4 Problem solving teams have heLMed improve manufacturing processes at this plant.
- I\_SGPS5 Employee teams are encouraged to try to solve their own problems, as much as possible.
- I\_SGPS6 We don't use problem solving teams much, in this plant.

|       | X <sup>2</sup>   | p    | df | RMSA(p)  | NFI  | NNFI | CFI  | α    |
|-------|--|------|----|----------|------|------|------|------|
|       | 13.7   | 0.13 | 9  | .04(.57) | .999 | .999 | .999 | -    |
| Final | I_SGPS: I_SGPS1; I_SGPS2; I_SGPS3; I_SGPS4; I_SGPS5; I_SGPS6 |      |    |          |      |      |      | .871 |

## Manufacturing-Business Strategy Linkage

- I\_MBS1      We have a manufacturing strategy that is actively pursued.
- I\_MBS2      Our business strategy is translated into manufacturing terms.
- I\_MBS3      Potential manufacturing investments are screened for consistency with our business strategy.
- I\_MBS4      At our plant, manufacturing is kept in step with our business strategy.
- I\_MBS5      Manufacturing management is not aware of our business strategy.
- I\_MBS6      Corporate decisions are often made without consideration of the manufacturing strategy.

|             | X <sup>2</sup>  | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | $\alpha$ |
|-------------|---|------|----|-----------|------|------|------|----------|
|             | 34.6  | 0.00 | 9  | .10(.00)  | .97  | .96  | .977 | -        |
| Problem     | High error correlation between I_MBS1 and I_MBS2 (MI): I_MBS1 dropped |      |    |           |      |      |      |          |
| Iteration 1 | 8.5   | 0.13 | 5  | .049(.44) | .987 | .99  | .99  | -        |
| Final       | I_MBS: I_MBS2; I_MBS3; I_MBS4; I_MBS5; I_MBS6                         |      |    |           |      |      |      | .806     |

## Cleanliness and Organization

- I\_CO1      Our plant emphasizes putting all tools and fixtures in their place.
- I\_CO2      We take pride in keeping our plant neat and clean.
- I\_CO3      Our plant is kept clean at all times.
- I\_CO4      Employees often have trouble finding the tools they need.
- I\_CO5      Our plant is disorganized and dirty.



|             | X <sup>2</sup>   | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | $\alpha$ |
|-------------|--|------|----|-----------|------|------|------|----------|
|             | 23.56  | 0.00 | 5  | .107(.01) | .98  | .97  | .98  | -        |
| Problem     | High error correlation between I_CO3 and I_CO4 (MI): I_CO4 dropped |      |    |           |      |      |      |          |
| Iteration 1 | 7.4  | 0.03 | 2  | .09(.13)  | .999 | .999 | .999 | -        |
| Final       | I_CO: I_CO1; I_CO2; I_CO3; I_CO5                                   |      |    |           |      |      |      | .886     |

## Continuous Improvement and Learning

- I\_CI1 We strive to continually improve all aspects of products and processes, rather than taking a static approach.
- I\_CI2 If we aren't constantly improving and learning, our performance will suffer in the long term.
- I\_CI3 Continuous improvement makes our performance a moving target, which is difficult for competitors to attack.
- I\_CI4 We believe that improvement of a process is never complete; there is always room for more incremental improvement.
- I\_CI5 Our organization is not a static entity, but engages in dynamically changing itself to better serve its customers.

|       | X <sup>2</sup>                          | p    | df | RMSA(p)   | NFI  | NNFI | CFI  | $\alpha$ |
|-------|---|------|----|-----------|------|------|------|----------|
|       | 6.06                                    | 0.30 | 5  | .027(.66) | .999 | .999 | .999 | -        |
| final | I_CI: I_CI1; I_CI2; I_CI3; I_CI4; I_CI5 |      |    |           |      |      |      | .809     |

## Supplier Partnership

- I\_SP1 We maintain cooperative relationships with our suppliers.
- I\_SP2 We provide a fair return to our suppliers
- I\_SP3 We help our suppliers to improve their quality.
- I\_SP4 Our key suppliers provide input into our product development projects.

|       | X <sup>2</sup>                   | p    | Df | RMSA(p) | NFI  | NNFI | CFI  | $\alpha$ |
|-------|----------------------------------|------|----|---------|------|------|------|----------|
|       | 0.31                             | 0.85 | 2  | .0(.93) | .999 | .999 | .999 | -        |
| Final | I_SP: I_SP1; I_SP2; I_SP3; I_SP4 |      |    |         |      |      |      | .757     |

## Autonomous Maintenance

- I\_TPM1 Cleaning of equipment by operators is critical to its performance.
- I\_TPM2 Operators understand the cause and effect of equipment deterioration.
- I\_TPM3 Basic cleaning and lubrication of equipment is done by operators.
- I\_TPM4 Production leaders, rather than operators, inspect and monitor equipment performance.
- I\_TPM5 Operators inspect and monitor the performance of their own equipment.
- I\_TPM6 Operators are able to detect and treat abnormal operating conditions of their equipment.

|             | X <sup>2</sup>  | p    | df | RMSA(p)   | NFI | NNFI | CFI  | A    |
|-------------|---|------|----|-----------|-----|------|------|------|
|             | 37.9  | 0.00 | 9  | .103(.00) | .93 | .91  | .949 | -    |
| Problem     | I_TPM1 lambda = .46 and I_TPM4 lambda = .21: I_TPM4 dropped |      |    |           |     |      |      |      |
| Iteration 1 | 16.1  | 0.00 | 5  | .084(.09) | .97 | .96  | .98  | -    |
| Problem     | I_TPM1 lambda = .44: I_TPM1 dropped                         |      |    |           |     |      |      |      |
| Iteration 2 | 9.5   | 0.01 | 2  | .10(.06)  | .98 | .945 | .982 | -    |
| Final       | I_TPM: I_TPM2; I_TPM3; I_TPM5; I_TPM6                       |      |    |           |     |      |      | .823 |

### **3. Trade-off model: Assessing the impact of Just-In-Time on operational performance at varying degrees of repetitiveness**

#### **3.1 Introduction**

Lean Manufacturing is a methodology made famous by the seminal books "*The Machine That Change The World*" (Womack *et al.* 1990) and "*Lean Thinking*" (Womack and Jones 1996). Lean Manufacturing is also considered an integrated socio-technical system that involves the simultaneous use of many practices that could be grouped into four bundles, namely: Just-In-Time (JIT), Total Quality Management (TQM), Human Resource Management (HRM) and Total Productive Maintenance (TPM) (Shah and Ward 2003, 2008), or in three bundles: JIT, TQM and Infrastructure, as I suggested in Chapter 2.

While TQM and Infrastructural practices are generally considered universally applicable (Rungtusanatham *et al.* 2005, McKone *et al.* 2001, Abdulmalek *et al.* 2006, Sila 2007), the applicability of JIT practices in different contexts is discussed among researchers and practitioners. Indeed, JIT is considered problematic and sensible either in continuous process (Abdulmalek and Rajgopal 2007) and in discrete but non repetitive process sectors (Jina *et al.* 1997).

JIT traces its origins from the Toyota Production System (TPS) (Biggart and Gargeya 2002), from which it inherits tools and techniques, such as kanban, cellular manufacturing, setup time reduction (or SMED), production smoothing, lot size reduction and JIT supply (Flynn *et al.* 1995, Furlan *et al.* 2010).

It was empirically demonstrated that the application of JIT practices help to dramatically improve operational performance by eliminating all sources of waste from production processes (Womack and Jones 1996, Shah and Ward 2003, Ketokivi and Schroeder 2004, Mackelprang and Nair 2010). However, almost all of successful JIT

stories came from discrete and repetitive production contexts, where products are standardized and customer demand is stable and predictable, due to the high production volumes (Jina *et al.* 1997, Lander and Liker 2007). As a matter of fact, Fullerton and McWatters (2001) analyzed the level of JIT implementation in 95 US firms and discovered that the almost the 80% of the firms that had highly implemented JIT were repetitive production firms.

For many years Lean Manufacturing literature has appeared to converge on the assumption that JIT effectiveness was limited to discrete and repetitive manufacturing contexts, as the automotive industry, where JIT was initially developed. As regards continuous process industry, researchers tend to regret the possibility to implement JIT mainly because the context is characterized by very high volume, low variety and inflexible processes that are unstoppable without increasing production costs.

However, Abdulmalek *et al.* (2006) explained that JIT is applicable also in the continuous process industry. JIT could be implemented to manage the “non-production activities”, such as for those activities related to materials movement, distribution and storage; JIT supply; JIT demand. Moreover it is possible to apply JIT for all the production activities that are discrete, connected with the product assembly and package.

However, the authors continued saying that JIT is not applicable for the process activities that are continuous and inflexible, since they are intrinsically efficient.

JIT techniques like kanban and supermarkets could be introduced where there are Work-In-Progress (WIP) inventories between work-stations, while cellular manufacturing JIT tool cannot easily implemented where the manufacturing flow is continuous (Abdulmalek and Rajgopal 2007).

Concerning the discrete manufacturing context, the general belief is that the implementation of JIT tools is not useful when the demand variability and product customization levels are high, i.e. a non-repetitive context, mainly because demand fluctuations make *takt time* (i.e. the maximum production time needed to meet the customer demand pace) dynamic, and the high product variety inhibits production smoothing (Lander and Liker 2007, Reichhart and Holweg 2007), given the impossibility of keeping all products into the heijunka boxes.

Jina *et al.* (1997) in a theoretical paper claim that the Lean Manufacturing principles have always been historically applied in companies with a medium-low product mix and based on a Assemble-To-Order (ATO) or Make-To-Stock (MTS) production system, where the demand turbulence is lower compared to a non-repetitive context, typically characterized by production systems based on a Make-To-Order (MTO) or Engineer-To-Order (or ETO) logic.

These authors conclude that product customization and demand uncertainty are obstacles that limit the implementation of Lean and JIT to a small percentage of production processes, whereas for other processes JIT tools are not applicable or, at least, they should be adapted to the specific context.

Recently, a debate has arisen on the possible effectiveness of JIT practices outside the repetitive environment. Some empirical studies (one exploratory survey and few descriptive case studies) (Prybutok and White 2001, Crute *et al.* 2003, Lander and Liker 2007) show that even in contexts characterized by low levels of repetitiveness some Lean principles and JIT practices can work and lead to significant performance improvements.

By comparing repetitive and non-repetitive companies through an exploratory survey, Prybutok and White (2001) prove that JIT is applicable in both situations, even if some techniques are less frequently applied in non-repetitive manufacturing systems, and that performance improvements are more evident in a repetitive environment.

Crute *et al.* (2003) describe an example of Lean application in the aerospace sector, characterized by low volumes and MTO production systems. These authors argue that having low volumes per single product is not an obstacle to Lean Manufacturing. On the contrary, low volumes facilitate the implementation of Lean practices because the production system is naturally closer to the concept of one piece flow, and MTO systems follow a pull logic. They conclude that implementing Lean in a non-repetitive context is not more difficult than implementing Lean in a repetitive one: “*the challenges are different but not more difficult*” (Crute *et al.* 2003, p. 925).

It is *different* because Lean and JIT tools were created in Toyota to solve peculiar problems, and thus these tools need modifications to fit into specific contexts, like the non-repetitive ones (Lander and Liker 2007). For this reason, by analyzing a low-volume high-variety handmade decorative tiles manufacturer, Lander and Liker (2007)

argue that a non-repetitive company has to focus on general Lean principles rather than trying to directly apply JIT tools and techniques.

These important examples, however, are mainly descriptive and isolated case studies. They focus on the adaptation of JIT practices in order to apply Lean principles in non-repetitive companies. Instead, in the literature, studies based on large samples which analyze how the impact of JIT practices on performance changes at different degrees of manufacturing context repetitiveness lack.

In particular, this research focuses on two characteristics that the literature associates with manufacturing context repetitiveness, namely demand variability and product customization, and aims to investigate whether these contextual dimensions can negatively moderate the impact of JIT practices on operational performance.

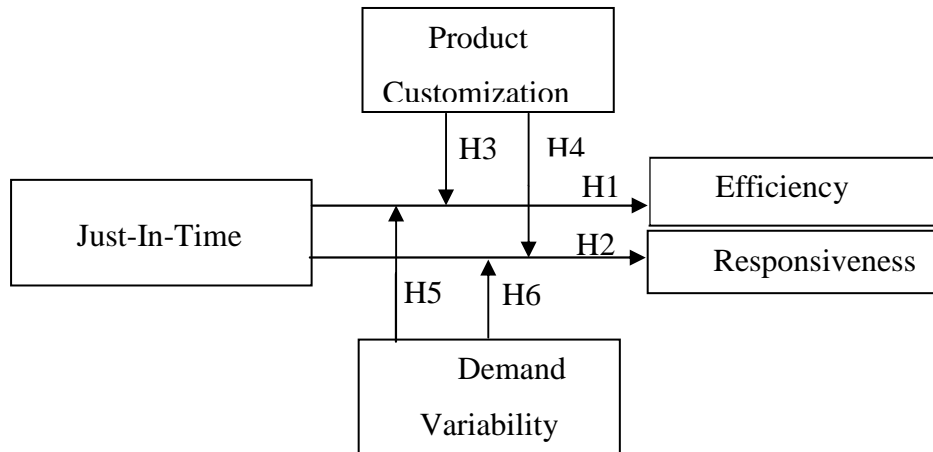
This research intends to contribute to the existing debate in Lean Manufacturing literature concerning the contextual conditions for JIT implementation. Moreover, the analysis of whether the degree of manufacturing repetitiveness can moderate the impact of JIT on performance is crucial to support practitioners, because it can shed some light on JIT adoption benefits, depending on context and competitive priorities.

This chapter is organized as follows. Firstly, I review the existing literature on the main characteristics of non-repetitive manufacturing context and just-in-time, and I define the theoretical framework of this research, focused on the impact of JIT on operational performances and the role of manufacturing repetitiveness on these relationships. Section 3.3 explains the methodology adopted to test the theoretical framework, followed by the structural equation model (SEM) results. In section 3.4, the theoretical and managerial implications of this research are discussed, while conclusions report research limitations and possible directions for future research.

## **3.2 Literature review and theoretical framework**

In this section I firstly provide a review of the characteristics of a non-repetitive manufacturing context, then I describe the key just-in-time concepts. Starting from this

and based on the literature, I build the theoretical framework, which is depicted in Figure 3.1. It assumes that JIT practices can positively impact efficiency and responsiveness, and that this impact can be influenced by product customization and demand variability, that are the main characteristics of non-repetitive manufacturing contexts (see section 3.2.1).



**Figure 3.1: Theoretical framework and hypotheses**

### 3.3.1 Characteristics of non-repetitive manufacturing contexts

#### Product customization

A non-repetitive context is characterized by highly customized products, tailored to meet individual customers' needs (Holweg 2005), and as a consequence by a high product variety and low production volumes for each individual product (Jina *et al.* 1997).

Product customization strongly affects companies' manufacturing strategy, because when the degree of product customization is high, forecast-driven systems are not applicable and thus companies typically rely on MTO or ETO manufacturing strategies. Instead, when customization is achieved by mixing different product modules, then the company operates based on a ATO logic.

Finally, when the products are standardized, then a MTS manufacturing strategy is usually adopted (Olhager 2003). Indeed, product customization increases the difficulty of planning the production based on demand forecast, because it raises product variety, lowers the volumes of each product and amplifies the uncertainty of the materials requirement and scheduling, due to the dynamic and complex bills of materials (White and Prybutok 2001). In order to manage these problems, companies are forced to begin the production process (or even the design process), only after having received the customer order (Amaro *et al.* 1999, Martinez-Olvera 2009).

Non-repetitive manufacturing contexts, where companies produce highly customized products following a MTO or ETO strategy, are characterized by low raw material and finished goods inventories and a large amount of Work-In-Progress (WIP), making companies typically responsive but not efficient. Instead, in the repetitive manufacturing context, WIP inventories are usually low to efficiently streamline the production flow, whereas raw material and finished goods inventories are high (White and Prybutok 2001).

### **Demand variability**

The second main characteristic of non-repetitive manufacturing context is demand variability, intended as a high turbulence for both mix and volume product demand (Jina *et al.* 1997). This turbulence is caused by variations in the quantity and timing of customer demand and leads to excess of inventory or stock outs, depending on the level of the demand (Fynes *et al.* 2004, Bozarth *et al.* 2009).

These problems are amplified along the supply chain, since the demand fluctuation can be distorted in the upstream ordering processes even if the downstream demand varies slightly, due to a lack of coordination between the supply chain actors (Forrester 1961).

For this reason demand variability is considered as one of the main sources of supply chain complexity (Bozarth *et al.* 2009) and in a non-repetitive manufacturing context has an impact even more important because lead times are high (Jina *et al.* 1997) and each customer order represents a significant portion of manufacturing



capacity (Hicks and Braiden 2000), and thus, stock outs or obsolete products can negatively affect operational and financial results.

### 3.3.2 Just-in-time

JIT is a methodology that aims at eliminating waste and continuously improving the manufacturing process (Schonberger 1982, Sakakibara *et al.* 1997). Over the years, several scholars (e.g. Davy *et al.* 1992, Flynn *et al.* 1995, Sakakibara *et al.* 1997) have analyzed the JIT concept and proposed how to operationalize it.

After two decades there is a general agreement on what JIT is and how to measure it. Researchers consider JIT as one of the main bundles of Lean Manufacturing (for a detailed analysis see Shah and Ward, 2003 and 2007) consisting of specific sets of practices and techniques, such as pull production (or Kanban system), production smoothing, daily schedule adherence, small lot size, set-up time reduction, flow oriented layout (or cellular manufacturing) and JIT supply (Flynn *et al.* 1995, Sakakibara *et al.* 1997, Cua *et al.* 2001, Shah and Ward 2003, Furlan *et al.* 2010).

Pull systems refer to the use of kanban cards to control the flow of production throughout the firm, by manufacturing and shipping only what has been consumed downstream (Monden 1981).

Kanban cards are often used with heijunka boxes to level production processes and smooth out short-term demand variability, through the synchronization of the daily production scheduled activities with the takt time, namely the pace of final customer demand (Griffiths *et al.* 2000, Swank 2003).

To reduce setup time, dies' designers rearrange changeover operations increasing external time and minimizing internal set-up time (machines downtime to change dies and equipment) with the aim of reducing lot sizes, thus minimizing overproduction waste, increasing machine utilization ratio and flexibility and lowering cycle time (Shingo 1985, McIntosh *et al.* 2000).

Flow oriented layout is a technique based on the use of "U-shaped configured" manufacturing cells, a group of multi-functional machines dedicated to the production

of component or product families, that allows to make the production flow continuous, by reducing employee and material movements (Hassan 1995, Angra *et al.* 2008).

Finally, authors recommend to extend JIT practices to the upstream supply chain, and according to this, suppliers have to deliver the right quantity of material, directly to the point of consumption, in small lot sizes, following the takt-time of the kanban system according to a pull logic, to reduce inventories and increase production flexibility (Sakakibara *et al.* 1997, Mistry 2005, Hsu *et al.* 2009).

### **3.3.3 Just-in-time and operational performance**

Meckelprang and Nair (2010) conducted a literature review and a meta-analysis on the most important empirical studies about the impact of JIT practices on operational performance and concluded that JIT improves most of performance dimensions, in particular manufacturing costs, inventory turnover, cycle time, on-time delivery, fast delivery, volume flexibility and mix flexibility. According to Liu *et al.* (2009), manufacturing costs, inventory turnover and cycle time can be viewed as indicators referring to firm's efficiency dimension, while Reichhart and Holweg (2007) defined operational responsiveness as a performance dimension that includes on-time delivery, fast delivery, volume flexibility and mix flexibility. In line with these authors, in this study I focus on the impact of JIT on efficiency and responsiveness.

As explained in section 3.2.2, the sets of practices and techniques that are considered part of JIT (i.e. pull production, daily schedule adherence, small lot size, set-up time reduction, flow oriented layout / cellular manufacturing and JIT supply) can concur to increase efficiency, by reducing manufacturing costs, cycle time and inventory levels (raw materials, work-in-progress and finished goods), and responsiveness, by increasing machine flexibility and delivery capabilities (Manoochehri 1984, Brown and Mitchell 1991, Womack and Jones 1996).

Thus, I pose that JIT has a positive impact on operational performance:

*Hypothesis 1: Just-in-time positively impacts on efficiency.*

*Hypothesis 2: Just-in-time positively impacts on responsiveness.*

### **3.3.4 Interaction effects on performance**

#### **The role of product customization**

The first main characteristic of a non-repetitive manufacturing context is product customization. In the literature it is possible to find numerous contributions that list a number of reasons why product customization could be an obstacle to companies that are using JIT practices.

Aigbedo (2007), through a simulation study, analyzed the effect of product customization on the inventory levels of part variants supplied to an automotive OEM company using JIT supply techniques. The author concluded that product customization negatively impacts on efficiency because increases both the minimum inventory level necessary to avoid continuous stock-outs, and the frequency of delivery.

Muda and Hendry (2002) compared MTO companies and World Class Manufacturing (WCM) companies and verified that JIT practices are more effective when applied in a repetitive context, like in a WCM environment, because it is easier to identify product families whereon organize the layout, and the repetitiveness of operations makes it possible to optimize the pull system, linking kanban cards and heijunka boxes to the pace of customer demand.

In addition, companies that produce customized products following a MTO strategy generally accept every order, with the aim of not losing customers, but this practice leads to responsiveness problems, especially for Lean companies that can't rely on inventory and capacity buffers (Wullink *et al.* 2004).

With increasing of product customization, the production activity of reference for the pacemaker tends to be placed upstream, since the pacemaker represents the decoupling point where the customer' orders arrive. This decoupling point divides the downstream activities that should be managed continuously following a "push" production system (e.g. FIFO), and the upstream activities that could follow a "pull" system.

JIT tools and techniques, like heijunka boxes and kanban cards, could be introduced only upstream the pacemaker (Rother and Shook 1999). Therefore, product

customization reduces the portion of the production process in which it is possible to apply JIT, losing part of its effectiveness on cycle time improvement, thus reducing its positive effect on efficiency and responsiveness.

Finally, Jina et al. (1997) suggested to classify the production of parts (or components) depending on their volumes and degree of repetitiveness, and to apply JIT techniques only to produce “runner” components, which are characterized by high volumes and standardization, to recreate the typical conditions to optimize JIT tools. The authors therefore conclude that JIT is applicable only in some production processes, and thus the overall results on efficiency and responsiveness are suboptimal, since some processes cannot be improved.

Based on this literature analysis, I can pose that product customization interacts with JIT practices by negatively moderating the impact of JIT on operational performance, thus:

*Hypothesis 3: Product customization negatively moderates the relationship between just-in-time and efficiency.*

*Hypothesis 4: Product customization negatively moderates the relationship between just-in-time and responsiveness.*

## **The role of demand variability**

The second main characteristic of a non-repetitive manufacturing context is demand variability. In order to maintain an acceptable level of responsiveness, companies generally respond to the variability of demand in two ways. The first solution is to build inventory buffers during periods characterized by low demand volumes in order to be responsive during demand peaks (Olhager 2003); the second solution is to protect production processes with excess of capacity and flexibility in order to quickly respond to any change in demand, for both volume and mix variability (Stratton and Warburton 2003).

A JIT company rarely adopts the first solution because Lean Management identifies in inventories and overproduction the most important source of waste, which must be eliminated, thus, resulting in responsiveness problems (Olhager 2003).

To be responsive, if demand fluctuations are high, companies implementing JIT must protect themselves with excess of production capacity, since WIP inventories are kept to a minimum level only to smooth out small demand variability, and this increases costs. Moreover, the variability in product mix makes JIT systems potentially inefficient since the supermarkets of finished products are likely to have obsolete products (Stratton and Warburton 2003).

Also other scholars pose that JIT methodology needs a stable customer demand to operate effectively. For example Monden (1981) argued that kanban system must be used only with small demand fluctuation because it suffers sudden takt-time changes. On the same vein, Agarwal *et al.* (2006) suggested to implement JIT/Lean systems only to produce standard products in high volumes to guarantee a stable demand.

The abovementioned studies suggest that demand variability could influence the relationship between JIT adoption and operational performance.

Thus, I pose that demand variability interacts with JIT practices by negatively moderating the impact of JIT on operational performance:

*Hypothesis 5: Demand variability negatively moderates the relationship between just-in-time and efficiency.*

*Hypothesis 6: Demand variability negatively moderates the relationship between just-in-time and responsiveness.*

## **3.3 Methodology**

### **3.3.1 Data collection**

To test the theoretical framework hypotheses, I use data from the third round of the High Performance Manufacturing (HPM) project data set (Schroeder and Flynn 2001). Responses from a total of 266 plants were returned and 22 incomplete responses were discarded (less than 10 per cent). Accordingly, this study uses a sample of 244 manufacturing plants to test and analyse the hypotheses.

The questionnaires used in the present research are a subset of the whole HPM survey. Respondents within each plant were specifically asked to give answers on JIT practices adopted, demand variability, product customization and operational performance obtained.

For the perceptual items used in this study, I measured the Interclass Correlation (ICC) index to check the inter-rater agreement within the same organization. All ICC indexes are above 0.70, indicating a high level of agreement between respondents within the same plant. To conduct plant level analysis, I aggregated individual informant responses to the plant level by taking the average of within-plant responses.

### **3.3.2 Measures**

The variables of interest were conceptualized as first-order constructs and were measured by using multi-item scales and objective items. I referred to perceptual scales validated in previous scientific studies for measuring just-in-time, demand variability and efficiency constructs; I used a perceptual scale based on an extensive literature review for the responsiveness construct and an objective scale for the product customization construct. The measurement scales used in this study are reported in the Appendix A.

Just-in-time was measured by a six-item scale. I adapted the Furlan *et al.*'s (2010) scale of internal JIT, that covers pull production systems, cellular layout, lot size

reduction, set-up time reduction and daily scheduled adherence dimensions, by adding an item that refers to JIT deliveries by suppliers, in order to cover all the JIT dimensions commonly accepted by researchers and extensively described in section 3.2.2.

Two items compose demand variability construct. I used the same items of the demand variability scale published by Bozarth *et al.* (2009).

For the items of these two constructs, I asked respondents to indicate on a 7 point Likert scale to what extent they agree or disagree with the sentences about JIT implementation and demand variability reported in the Appendix A of this chapter (1 means “strongly disagree” and 7 “strongly agree”).

To measure product customization, I asked respondents to indicate the percentages of customer orders that fall in the following categories: ad-hoc design activities, customized fabrication, customized assembly, customized product delivery and no customization (standard products).

Similarly to other studies (McKone-Sweet and Lee 2009), I calculated a weighted average by assigning a weight to each type of category from 1 (no customization) to 5 (ad-hoc design activities) (See the Appendix A of this chapter). A high value indicates that the plant produces highly customized products.

With regard to operational performance, efficiency was measured by a three-item scale, already validated and tested by Liu *et al.* (2009), that considers unit cost of manufacturing, inventory turnover and cycle time; while responsiveness was measured by a four-item scale (including on-time delivery, fast delivery, product mix flexibility and product volume flexibility), which is based on the work of Reichhart and Holweg (2007).

These authors defined operational responsiveness as “*its [plant] ability to adjust its output to short-term demand changes. These changes can be due to changes in the product mix (mix responsiveness), the volumes required (volume responsiveness), or the delivery sequence or timing (delivery responsiveness)*” (Reichhart and Holweg 2007, pp. 1150-1151).

For the items composing efficiency and responsiveness constructs, I asked respondents to provide their opinion about plant’s performances compared with its competitors on a 5 point Likert scale (1 is for “poor, low” and 5 is for “superior”).

It is important to note that the sample is not limited only to repetitive manufacturing and JIT companies with high operational performance, but covers all kind of situations, since the minimum and maximum values of the constructs are close to the extremes of the scales, and the means are close to the central value.

This is very important because the purpose of this research is to study the effectiveness of JIT at varying levels of repetitiveness, not only in plants that have high values of product customization and demand variability.

Table 3.1 reports the descriptive statistics on the distributions of the variables of interest.

**Table 3.1 Descriptive statistics**

| <b>Construct</b>             | <b>Minimum</b> | <b>Maximum</b> | <b>Mean</b> | <b>Std. Deviation</b> |
|------------------------------|----------------|----------------|-------------|-----------------------|
| <b>JIT</b>                   | 2.79           | 6.41           | 4.77        | 0.65                  |
| <b>Demand Variability</b>    | 2.08           | 6.67           | 4.10        | 1.07                  |
| <b>Product Customization</b> | 1              | 5              | 3.05        | 1.05                  |
| <b>Efficiency</b>            | 1.67           | 5              | 3.34        | 0.66                  |
| <b>Responsiveness</b>        | 2              | 5              | 3.83        | 0.63                  |

### **3.3.3 Measurement model**

I used confirmatory factor analysis (CFA) using LISREL 8.80 to test the measurement model.

Coherently with several other studies (Huang *et al.* 2008, Bozarth *et al.* 2009, Kristal *et al.* 2010), in order to control for industry and country effects, I standardized the individual items by country and industry. CFA results are reported in Table 3.2.

Convergent validity is assured because all observable variables load significantly at 0.01 level on their respective latent constructs and all standardized factor loading coefficients are greater than 0.50 (Anderson and Gerbing 1988).



Moreover fit indexes indicate that the measurement model is acceptable:

$$\chi^2(96) = 180.29; \chi^2/\text{d.f.} = 1.87 < 3; \text{RMSEA} = 0.06 < 0.08; \text{CFI} = 0.944 > 0.90$$

I follow the method proposed by Bagozzi *et al.* (1991) to assess discriminant validity using the Chi-square test that consists on the comparison of two nested models for each pair of constructs.

The first model was set with an unconstrained correlation between the two constructs, whereas in the second model the correlation was fixed to 1. If the difference between the Chi-square of the two models is significant, then I can conclude that the two constructs are distinct. Delta Chi-squares between all pairs of constructs resulted statistically significant at 0.01 level, confirming discriminant validity (Table 3.3).

On the diagonal of Table 3.3 the composite reliability values are also reported, except for the product customization construct, since reliability for a single item scale cannot be calculated (Koufteros *et al.* 1998).

All composite reliability values are greater than 0.71, thus ensuring the reliability of the constructs.

**Table 3.2: Results of CFA**

| <b>Latent variable</b>            | <b>Indicator</b> | <b>Factor Loading</b> | <b>t-value</b> |
|-----------------------------------|------------------|-----------------------|----------------|
| <b>Just-In-Time (JIT)</b>         | JIT1             | .67                   | -              |
|                                   | JIT2             | .76                   | 8.95           |
|                                   | JIT3             | .51                   | 6.65           |
|                                   | JIT4             | .53                   | 6.82           |
|                                   | JIT5             | .63                   | 7.90           |
|                                   | JIT6             | .51                   | 6.65           |
| <b>Demand Variability (DV)</b>    | DV1              | .89                   | -              |
|                                   | DV2              | .71                   | 12.32          |
| <b>Product Customization (PC)</b> | CUST1            | .89                   | -              |
| <b>Efficiency (EFF)</b>           | EFF1             | .52                   | -              |
|                                   | EFF2             | .68                   | 5.74           |
|                                   | EFF3             | .78                   | 5.78           |
| <b>Responsiveness (RESP)</b>      | RESP1            | .77                   | -              |
|                                   | RESP2            | .71                   | 9.12           |
|                                   | RESP3            | .52                   | 7.08           |
|                                   | RESP4            | .63                   | 8.34           |

**Table 3.3: delta  $\chi^2$  and composite reliability coefficients (on the diagonal)**

|             | <b>JIT</b> | <b>CUST</b> | <b>DV</b> | <b>EFF</b> | <b>RESP</b> |
|-------------|------------|-------------|-----------|------------|-------------|
| <b>JIT</b>  | .78        |             |           |            |             |
| <b>CUST</b> | 118.41     | -           |           |            |             |
| <b>DV</b>   | 264.65     | 97.12       | .80       |            |             |
| <b>EFF</b>  | 70.56      | 159.62      | 111.96    | .71        |             |
| <b>RESP</b> | 130.35     | 106.47      | 215.49    | 65.41      | .78         |

### 3.3.4 Structural equation modeling results

To test the hypotheses on the direct and moderation effects represented in Figure 1, I employed a structural equation modeling (SEM) approach. In particular, I used the Maximum Likelihood Method, and followed the two-step procedure suggested by Ping to test moderation in SEM models (Ping 1995).

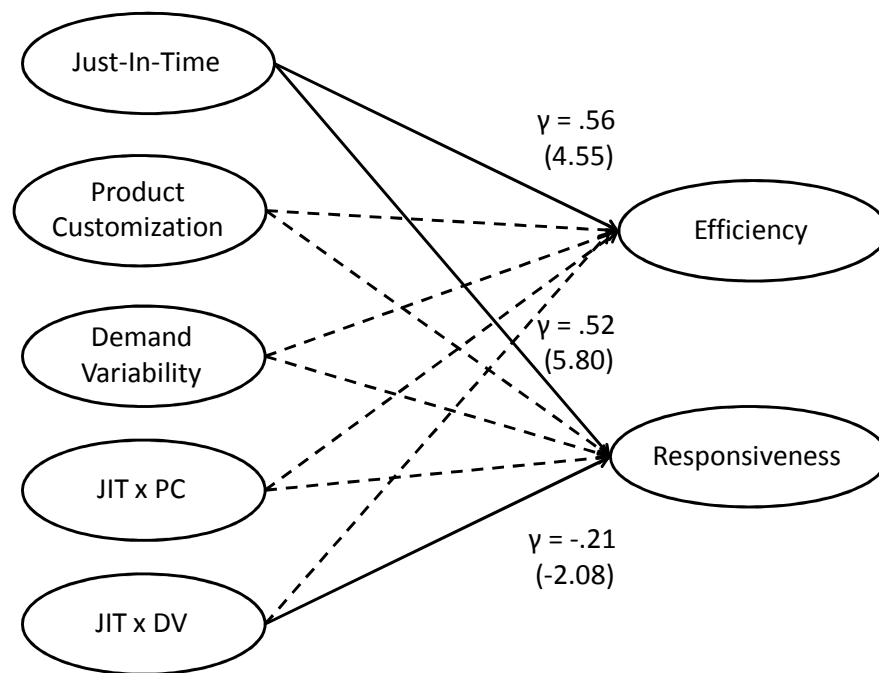
I decided to use this method, instead of using multi-group procedures, because it permits to analyse how JIT impacts on operational performance at varying degrees of repetitiveness in the continuous, since the variables that determine the production repetitiveness are continuous, not discrete.

Moreover, Ping (1995) procedure allow to control measurement errors and correlations between equation errors, unlike Baron and Kenny's (1986) approach (Iacobucci *et al.* 2007).

Having standardized the data by country and industry I eliminated biased results due to multicollinearity effect. The first step of Ping's procedure requires to analyse the main effects of just-in-time, product customization and demand variability on efficiency and responsiveness. Then, I inserted into the model the interaction terms (step 2 of the procedure), each measure as a single-item variable calculated by multiplying the sum of the items composing JIT, by the sum of the items composing demand variability, or product customization.

Appendix B of this chapter deepens the methodological aspects of the Ping's procedure used in this chapter.

Figure 3.2 summarizes the SEM output for the model with interaction, where dotted arrows indicate relationships not statistically significant.



**Figure 3.2: SEM results**

Fit indices of the structural model, based on the Lisrel output, are acceptable:

$$\chi^2(126)=227.02; \chi^2/d.f.=1.8<3; RMSEA=0.057 (0.044;0.069)<0.08; CFI=0.934>0.90$$

These fit indices indicate that data have a good fit. Three of the six hypotheses of our theoretical framework are supported. In particular, our analysis indicates that JIT has a positive and statistically significant impact on efficiency ( $\gamma = 0.55$ ;  $t\text{-value} = 4.55$ ;  $p\text{-value} < 0.01$ ) and responsiveness ( $\gamma = 0.52$ ;  $t\text{-value} = 5.80$ ;  $p\text{-value} < 0.01$ ), supporting hypotheses 1 and 2.

Instead, the main effects of product customization and demand variability on both performance dimensions are not statistically significant. These two effects are not related to any hypothesis, but are computed because they are required by the two-step Ping's methodology.

More interesting, the results reveal that product customization doesn't moderate neither the relationship between JIT and efficiency nor the relationship between JIT and responsiveness, and thus hypotheses 3 and 4 are not held.

Finally, I can note that demand variability negatively moderates the relationship between JIT and responsiveness ( $\gamma = -0.21$ ; t-value = -2.03; p-value < 0.05), whereas it doesn't moderate the impact of JIT on efficiency (i.e. hypothesis 6 supported, and hypothesis 5 not supported).

### **3.4 Discussion**

The results found provide several implications for theory and practice. Firstly, our results confirm the literature on the positive impact of JIT on efficiency and responsiveness. This result is consistent with the stream of studies supporting that the concurrent adoption of JIT techniques, such as cellular manufacturing, SMED, small lots, kanban and heijunka, and JIT deliveries from suppliers, increases efficiency and responsiveness performance (Manoocheri 1984, Brown and Mitchell 1991, Womack and Jones 1996).

However, this research delves more deeply into the impact of JIT on firm's performance, by investigating whether the impact of JIT varies depending on the degree of repetitiveness of manufacturing systems. Results found prove that JIT practices can be successfully implemented also in non-repetitive contexts, as well as in contexts with high degree of repetitiveness.

Unlike previous empirical contributions based on descriptive case studies (Muda *et al.* 2002, Crute *et al.* 2003, Agarwal *et al.* 2006, Lander and Liker 2007), I verified this assumption in a large sample including plants with different degrees of manufacturing repetitiveness.

In addition to this, the research of this chapter distinguishes between two main characteristics of a non-repetitive environment (i.e. demand variability and product customization), and studies separately the effect of each of these variables on the relationship between JIT and operational performance, since literature shows that these characteristics are not necessarily related.

In fact, although they are often together, it is not necessary the presence of both to characterize a context as non-repetitive. For example Boeing, even if it is a very complex airplane, with about 367,000 components, has a low level of customization but the demand is unpredictable and volumes are very low (Venables 2005).

From these results it emerges that while demand variability has an effect on the JIT-responsiveness link, product customization does not significantly moderate the relationship between JIT and firm's performance, both in terms of efficiency and responsiveness.

It is important to note that, differently from studies focused on JIT implementation in repetitive contexts, that support the positive impact of JIT on firm's performance in general, these results highlight that when I consider the degree of repetitiveness of the context, it is important to distinguish between efficiency or responsiveness.

As a matter of fact, our study shows that the impact of JIT on efficiency and responsiveness is not the same in all the contexts, as demand variability reduces the positive effect of JIT on responsiveness, whereas does not necessarily alter the benefits of JIT on efficiency.

With changes in customer demand, JIT companies don't suffer in terms of efficiency because they don't hold large amounts of inventories (raw materials, WIP, finished goods) and they produce only with real orders (kanban and Pull system), and for this reason, they rarely hold obsolete WIP or finished products when the customer demand decreases.

However they suffer high levels of demand variability in terms of responsiveness due to the fact that JIT companies use only extra-capacity to protect themselves for small demand fluctuations, but the use of JIT methodology exposes to a greater risk of stock outs and, in general, to delivery problems, because it avoids inventories and overproduction that are recognized as the main solutions when the customer demand suddenly grows up (Griffiths *et al.* 2000; Stratton and Warburton 2003; Agarwal *et al.* 2006).

Instead product customization does not significantly moderate the effect of JIT on operational performances because the concurrent use of other methods, such as variety reduction programs, modularity and mass customization, can solve the negative effects of product customization.

Indeed, the standardization of components reduces the need of a minimum inventory level for each part in the heijunka boxes, increases the volume for each component, thus recreating the optimal conditions for a JIT application (Jina *et al.* 1997), and facilitates the identification of product families to optimize the cellular layout and the pull system, therefore addressing the problems identified by Muda *et al.* (2002) and Aigbedo (2007).

The above research findings not only have interesting implications for theory but can also provide insightful hints for managers. In fact they can support decision making on the implementation of JIT practices, depending on some contextual variables that characterize the degree of repetitiveness of contexts.

Results found suggest to managers that JIT has a positive impact on operational performance independently from the level of product customization, while it has limited effects on responsiveness with increasing levels of demand variability. In particular, it could be even counterproductive with very high levels of demand fluctuations (for values of demand variability greater than  $\frac{0.52}{0.21} = 2.48$  standard deviations, based on the results of this study, summarized in Figure 3.2).

For example, with  $DV = 3$  and  $JIT = 1$ , I obtain:

$$\text{Responsiveness} = 0.52 * JIT - 0.21 * JIT * DV = 0.52 - 0.21 * 3 = -0.11.$$

As a consequence, with the increase of demand variability, when implementing JIT, managers have to consider the trade-off between efficiency and responsiveness, that the moderating effect highlighted in this research makes evident. In fact, in case of high demand variability, JIT has a positive effect on efficiency but not on responsiveness. This trade-off requires to managers to choose whether to apply JIT depending on their competitive priorities.

### **3.5 Conclusions and limitations**

The study of this chapter intends to contribute to the debate on the implementation and effect of JIT practices in non-repetitive contexts, giving insights about a possible trade-off on performances when introducing JIT in manufacturing systems, recognized as the most critical bundle of Lean Manufacturing in such contexts.

In this research, I investigated not only whether JIT in general positively affects efficiency and responsiveness performance, but also whether the effect of JIT could be negatively moderated by product customization and demand variability, that are two pivotal characteristics of non-repetitive contexts.

Results found highlight that while in general JIT practices positively affect both efficiency and responsiveness performance, in contexts characterized by a high level of demand variability, the impact of JIT on responsiveness could be modest or even negative.

This study is the first empirical work that tests in a large sample the applicability of JIT in non-repetitive manufacturing systems, and represents an useful guideline for practitioners, since it provides insightful evidence on how some of the main characteristics of non-repetitive contexts, i.e. product customization and demand variability, can affect the relationship between JIT and operational performance.

Limitations and future developments of this study should be considered along with the results. This research is subject to the normal limitations of a survey research. This study used a selection of medium and large enterprises operating in machinery, electronics and transportation components sectors that could limit the finding generalizability.

Thus, future studies should include firms operating in other industries and/or small enterprises to find possible different results and patterns, for example supporting hypotheses H3, H4 and/or H5.

Indeed, the plant dimension could affect the results because large companies have more power to influence and force suppliers and customers to implement JIT, but they could suffers in terms of internal agility and capability to introduce JIT practices themselves (Biggart and Gargeya 2002). I standardized data by industry and country,



however I didn't control other contextual factors that might affect our results (e.g. number of employees, sales volumes, number of years of JIT implementation, etc.). Future studies should analyse the effect of these contextual factors.

Another interesting future development is to measure the demand variability in relation to the plant competitors rather than measuring it on the extent of agreement with the assertions that composed the construct. In addition, even if this study investigates the most important bundle of lean practices in non-repetitive contexts (i.e. just-in-time), future research could focus on the implementation of other aspects of Lean Manufacturing in these contexts, such as supplier integration, Total Quality Management and Human Resource Management.

Finally, future studies could expand the research focus and further investigate JIT implementation in non-repetitive supply networks, connecting these results with the "Lean and Agile" supply chain research field, to understand if the position in the supply chain could affect the results found in this research on the applicability of JIT methodology.

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## APPENDIX A

### Just-in-time

Please indicate to what extent you agree/disagree with the following - (circle one number): 1 – strongly disagree, 2 – disagree, 3 – slightly disagree, 4 – neutral, 5 – slightly agree, 6 – agree, and 7 – strongly agree

|      |   |
|------|---|
| JIT1 | We usually complete our daily schedule as planned.                            |
| JIT2 | The layout of our shop floor facilitates low inventories and fast throughput. |
| JIT3 | Suppliers frequently deliver materials to us.                                 |
| JIT4 | We use a kanban pull system for production control.                           |
| JIT5 | We have low setup times of equipment in our plant.                            |
| JIT6 | We emphasize small lot sizes, to increase manufacturing flexibility.          |

### Product Customization

|   |  |
|---|--|
| Overall, what percent of your customer orders fall into the following categories? |  |
| PC1 %   | Ad-hoc design activities                         |
| PC2 %   | Customized fabrication                           |
| PC3 %   | Customized assembly                              |
| PC4 %   | Customized product delivery                      |
| PC5 %   | No customization – standard products are shipped |

Product Customization was calculated as a weighted average by assigning a weight to each type of above mentioned categories, from 1 (no customization- standard products are shipped) to 5 (ad-hoc design activities), according to the following formula:

$$PC = PC1 \times 5 + PC2 \times 4 + PC3 \times 3 + PC4 \times 2 + PC5 \times 1$$

### **Demand Variability**

Please indicate to what extent you agree/disagree with the following - (circle one number): 1 – strongly disagree, 2 – disagree, 3 – slightly disagree, 4 – neutral, 5 – slightly agree, 6 – agree, and 7 – strongly agree

|     |  |
|-----|--|
| DV1 | Manufacturing demands are stable in our firm. ( <i>reverse scored</i> )                |
| DV2 | Our total demand, across all products, is relatively stable. ( <i>reverse scored</i> ) |

### **Efficiency**

Please circle the number that indicates your opinion about how your plant compares to its competitors in your industry, on a global basis: 5 – superior, 4 – better than average, 3 – average or equal to the competition, 2 – below average, and 1 – poor or low

|      |   |
|------|---|
| EFF1 | Unit cost of manufacturing                  |
| EFF2 | Inventory turnover                          |
| EFF3 | Cycle time (from raw materials to delivery) |



## **Responsiveness**

Please circle the number that indicates your opinion about how your plant compares to its competitors in your industry, on a global basis: 5 – superior, 4 – better than average, 3 – average or equal to the competition, 2 – below average, and 1 – poor or low

|       |                                   |
|-------|-----------------------------------|
| RESP1 | On time delivery performance      |
| RESP2 | Fast delivery                     |
| RESP3 | Flexibility to change product mix |
| RESP4 | Flexibility to change volume      |

## APPENDIX B

Ping's test, used to analyze moderating effects in SEM models, is based on a two-step approach. The first step requires examining the SEM linear model (without interaction) and saving the resulting unstandardized values of lambdas, phis, and theta-deltas related to the exogenous variables. The second step requires to insert the potential interactions effects. I introduced in our model the interaction terms "JIT\_X\_DV" and "JIT\_X\_PC", each measured as a single-item variable calculated by multiplying the sum of the items composing JIT ( $x_{JIT1} + x_{JIT2} + x_{JIT3} + x_{JIT4} + x_{JIT5} + x_{JIT6}$ ) by the sum of the items composing Demand Variability ( $x_{DV1} + x_{DV2}$ ), and Product Customization ( $x_{PC}$ ), respectively. The procedure requires setting the unstandardized lambda and theta-delta of the single items that form the "JIT\_X\_DV" and "JIT\_X\_PC" latent variables to two precise values. The lambda value can be calculated starting from the  $\lambda_x$ -coefficients estimated in the linear model ( $\lambda_{JIT1,1}, \dots, \lambda_{JIT6,1}$  refer to the  $\lambda_x$  -coefficients for the JIT construct,  $\lambda_{DV1,2}, \lambda_{DV2,2}$  to the  $\lambda_x$  -coefficients for the DV construct, and  $\lambda_{PC1,3}$  to the  $\lambda_x$  -coefficient for the PC construct). The theta-delta is calculated by using the phi matrix and theta-delta results, as well as the  $\lambda_x$  -coefficients derived from the linear model. The following equations report in details how the value of each single item composing each interaction term, i.e  $x_{JIT\_X\_DV}$  and  $x_{JIT\_X\_PC}$ , and the corresponding lambda and theta-delta were calculated; where subscript 1 refers to the just-in-time latent variable, subscript 2 to the demand variability latent variable and subscript 3 refers to the product customization latent variable.

*The interaction between JIT and Demand Variability,  $\lambda^x$  and  $\theta^\delta$*

$$x_{JIT\_X\_DV} = (x_{JIT1} + x_{JIT2} + x_{JIT3} + x_{JIT4} + x_{JIT5} + x_{JIT6}) * (x_{DV1} + x_{DV2}) \quad (1)$$

$$\lambda_{JIT\_X\_DV} = (\lambda_{JIT1,1} + \lambda_{JIT2,1} + \lambda_{JIT3,1} + \lambda_{JIT4,1} + \lambda_{JIT5,1} + \lambda_{JIT6,1}) * (\lambda_{DV1,2} + \lambda_{DV2,2}) \quad (2)$$

$$\begin{aligned}
& \theta^{\delta}_{JIT\_X\_DV} = \\
& (\lambda_{JIT1,1} + \lambda_{JIT2,1} + \lambda_{JIT3,1} + \lambda_{JIT4,1} + \lambda_{JIT5,1} + \lambda_{JIT6,1})^2 \phi_{1,1}(\theta^{\delta}_{DV1,DV1} + \\
& \theta^{\delta}_{DV2,DV2}) + (\lambda_{DV1,2} + \lambda_{DV2,2})^2 \phi_{2,2}(\theta^{\delta}_{JIT1,JIT1} + \theta^{\delta}_{JIT2,JIT2} + \theta^{\delta}_{JIT3,JIT3} + \\
& \theta^{\delta}_{JIT4,JIT4} + \theta^{\delta}_{JIT5,JIT5} + \theta^{\delta}_{JIT6,JIT6}) + (\theta^{\delta}_{JIT1,JIT1} + \theta^{\delta}_{JIT2,JIT2} + \theta^{\delta}_{JIT3,JIT3} + \\
& \theta^{\delta}_{JIT4,JIT4} + \theta^{\delta}_{JIT5,JIT5} + \theta^{\delta}_{JIT6,JIT6})(\theta^{\delta}_{DV1,DV1} + \theta^{\delta}_{DV2,DV2}) \quad (3)
\end{aligned}$$

*The interaction between JIT and Product Customization,  $\lambda^x$  and  $\theta^{\delta}$*

$$x_{JIT\_X\_PC} = (x_{JIT1} + x_{JIT2} + x_{JIT3} + x_{JIT4} + x_{JIT5} + x_{JIT6}) * (x_{PC}) \quad (4)$$

$$\lambda_{JIT\_X\_PC} = (\lambda_{JIT1,1} + \lambda_{JIT2,1} + \lambda_{JIT3,1} + \lambda_{JIT4,1} + \lambda_{JIT5,1} + \lambda_{JIT6,1}) * (\lambda_{PC1,3}) \quad (5)$$

$$\begin{aligned}
& \theta^{\delta}_{JIT\_X\_PC} = \\
& (\lambda_{JIT1,1} + \lambda_{JIT2,1} + \lambda_{JIT3,1} + \lambda_{JIT4,1} + \lambda_{JIT5,1} + \lambda_{JIT6,1})^2 \phi_{1,1}(\theta^{\delta}_{PC,PC}) + \\
& (\lambda_{PC1,3})^2 \phi_{3,3}(\theta^{\delta}_{JIT1,JIT1} + \theta^{\delta}_{JIT2,JIT2} + \theta^{\delta}_{JIT3,JIT3} + \theta^{\delta}_{JIT4,JIT4} + \theta^{\delta}_{JIT5,JIT5} + \\
& \theta^{\delta}_{JIT6,JIT6}) + (\theta^{\delta}_{JIT1,JIT1} + \theta^{\delta}_{JIT2,JIT2} + \theta^{\delta}_{JIT3,JIT3} + \theta^{\delta}_{JIT4,JIT4} + \theta^{\delta}_{JIT5,JIT5} + \\
& \theta^{\delta}_{JIT6,JIT6})(\theta^{\delta}_{PC,PC}) \quad (6)
\end{aligned}$$

## **4. A second trade-off model: JIT-production, JIT-supply and performance, investigating the moderating effects**

### **4.1 Introduction**

In the last years, the intensification of global competition and the crisis that has affected firms in many sectors have forced manufacturing companies to explore all available opportunities for reducing their costs, without compromising customer satisfaction. As a consequence, there has recently been renewed attention towards Lean Manufacturing, and in particular, Just-In-Time (JIT) practices, that are usually considered a powerful tool to reduce waste and inefficiency, speed up production processes, and increase delivery performance.

Although the contribution of JIT in improving operational performance is widely recognized (Motwani, 2003; Shah and Ward, 2003), some authors found a lack of significant relationships between some JIT practices and performance (Sakakibara *et al.*, 1997; Dean and Snell, 1996; Flynn *et al.*, 1995). Mackelprang and Nair (2010) argue that the potential (and still unexplored) existence of moderating effects between JIT practices could be an explanation for the contrasting results on the link between JIT and performance.

These moderating effects could manifest when certain JIT practices affect the relationship between other JIT practices and performance. Therefore, the investigation of moderating effects is crucial to predict the impact of JIT practices on operational performance.

In this chapter I focus on moderating effects between JIT production and JIT supply practices and on their impact on efficiency and delivery performance. JIT production refers to the adoption of practices aimed at reorganizing shop floor and streamlining production flows within production plants (Furlan *et al.*, 2010). JIT supply concerns

receiving from suppliers frequent deliveries of small lots according to the pull logic (Sakakibara *et al.*, 1993).

Some authors argue that JIT production requires fast throughputs and low inventories, and in this context, JIT supply is crucial to maintain the continuous flow of raw materials / components from upstream (Hsu *et al.*, 2009; Panizzolo, 1998). Although this evidence suggests that JIT production and JIT supply are strictly interconnected practices and that operations can benefit from their joint implementation, empirical studies investigating this linkage are lacking.

The aim of this research is twofold. On the one hand, it intends to investigate whether JIT production and JIT supply have a significant positive effect on efficiency and delivery performance. On the other hand, it aims to analyze whether JIT supply positively moderates the “JIT production-efficiency” and “JIT production-delivery” relationships.

This research puts forth a set of research hypotheses on these relationships and empirically tests them using plant-level data from 207 plants across seven countries.

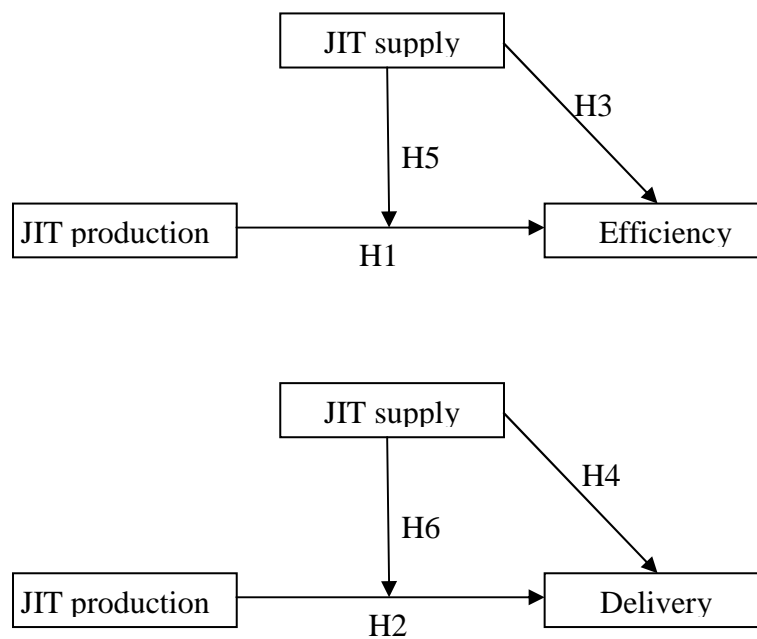
This research intends to contribute to the academic debate on lean management by examining the different weight and impact of JIT production and JIT supply practices on different aspects of performance improvement, the existence of synergies among these practices that a firm could/must exploit to achieve higher levels of performance, and under what conditions in terms of JIT supply JIT production impact can be heightened or hindered.

These results could also be useful for practitioners as a guidance on how to balance efforts on each JIT practice over time in order to better allocate scarce resources and maximize the impact on efficiency and delivery performance.

This chapter is organized as follows. First, it analyzes the existing literature on the impact of JIT practices on operational performances and develops a set of hypotheses. The research design section introduces data collection, measurements and the methodology employed to test hypotheses. This is followed by the analyses and discussion of the results found. Finally the conclusions are presented, with research limitations and possible future studies.

## 4.2 Literature review and hypotheses

The research framework developed in this study is shown in Figure 4.1. The framework proposes that JIT supply moderates the impact of JIT production on efficiency and delivery performance. A detailed description of JIT production and JIT supply constructs is provided in the following subsections. Based on the extant literature, then I discuss and develop hypotheses about the main impact of JIT practices on efficiency and delivery performance (main effect) and about the interactions between JIT production and JIT supply and their impact on operational performance (interaction effect).



**Figure 4.1: Theoretical framework with hypotheses and propositions**

### **4.2.1 JIT practices**

JIT has been intensively studied by researchers, and pioneers in this effort defined and measured the central constructs underlying JIT (Sakakibara *et al.* 1993; Mehra and Inman, 1992). In some cases JIT has been defined as a managerial or manufacturing philosophy (Upton, 1998), while others prefer to operationalize it in terms of practices and techniques that both implement and support lean philosophy (Narasimhan *et al.*, 2006; Flynn *et al.*, 1995).

Some JIT practices are aimed at streamlining production flows, and authors label them as JIT production (Mehra and Inman, 1992) or Internal JIT (Furlan *et al.*, 2010). Some commonly JIT production practices include set-up time reduction, small lot size, daily schedule adherence, kanban-based pull systems, U-shaped cell layout and heijunka boxes (MackeLMrang and Nair, 2010; Motwani, 2003).

However, as JIT production started gaining widespread acceptance in practice, scholars began to emphasize the relevance of JIT in other contexts such as purchasing and inbound logistics (Mistry, 2005; Kaynak, 2002). JIT deliveries from supplier (Sakakibara *et al.*, 1993) or JIT supply (Koh *et al.*, 2007; Lamming, 1993) include practices such as vendor- kanban for raw materials and outsourced components and pull systems for inbound logistics.

#### **JIT production**

Cua *et al.* (2001) conducted a detailed analysis and review of the practices employed in TQM, JIT and TPM programs. They identify a set of practices that are common to all three programs, and some practices – referred as “basic techniques” – that are program specific. JIT basic techniques are five: set-up time reduction, equipment layout, pull systems production, daily schedule adherence, and JIT delivery by suppliers. The first four concern the JIT production area while the last one refers to JIT supply.

Set-up reduction is at the core of JIT practices related to shop floor activities (Sakakibara *et al.*, 1997). SMED programs, aiming at single digit set-up times through the rearrangement of changeover elements into external time and the compression of

internal set-up time, result in speeding up throughputs, increasing machine utilization ratio and flexibility, and decreasing lot size (McIntosh *et al.*, 2000; Shingo, 1985).

As concerns the shop-floor level layout, cellular manufacturing is a commonly adopted practice in JIT production systems. A manufacturing cell is a group of different and multifunctional machines placed together and dedicated to the production of families of components or products (Angra *et al.*, 2008; Flynn and Jacobs, 1987). In a manufacturing cell employees and machines are typically moved into a U-shaped configuration to minimize movement times and costs (Brown and Mitchell, 1991).

Pull systems refer to the use of kanban cards or other pull signals to control the flow of production throughout the factory by manufacturing and shipping only what has been consumed downstream (Monden, 1981). According to Sakakibara *et al.* (1997, p.1247), the term “JIT production system” originally identified the pull production logic, described as “only the necessary products, at the necessary time, in the necessary quantity”.

Pull systems are often complemented with daily schedule adherence practices aiming at synchronizing production activities with the pace of final customer demand. For instance, standard work and heijunka boxes, by establishing the work sequence and comparing the cycle speed against the required takt time, facilitate production levelling across the various manufacturing phases and smooth out the variability of the day-to-day customer demand (Motwani, 2003; Griffiths *et al.*, 2000).

## **JIT supply**

The idea of implementing JIT practices upstream along the supply chain is probably as old as the JIT concept. In his book on the *Toyota Production Systems*, Monden (1983) reports the problems the company had with unions and the Japanese Communist Party in 1977 when implementing kanban pull system on deliveries by suppliers.

In a detailed analysis and review of JIT practices, Cua *et al.* (2001) explicitly mention JIT delivery by suppliers and identify five seminal studies including this practice among those commonly associated with JIT.



One of these studies, Sakakibara *et al.* (1993), defines JIT deliveries from suppliers as the extent to which the plant is receiving shipments from vendor on a JIT basis, namely, according to a pull logic which typically involves small lot sizes, frequent/fast deliveries directly to the point of their consumption, and the use of vendor-kanban. The ability of suppliers to coordinate their orders with manufacturing demand is greatly facilitated by kanban cards and containers. Suppliers should be allowed to access the kanban card rack at the customer plant. This way, as containers of raw materials and outsourced components are empty suppliers can autonomously notice that there is need for replenishment (Monden, 1983).

When JIT deliveries with kanban cards and containers involve many suppliers “milk run” is a commonly used practice to synchronize and aggregate multiple shipments. According to this technique, the buyer picks up, from some suppliers located in a narrow area, small lots of materials placed in kanban containers at regular and short intervals, following the daily ordering system connected with the real pace of demand (Jones *et al.*, 1997).

### **Main effects on performance**

The primary goal of JIT is commonly indicated in the continuous reduction and ultimately elimination of all forms of waste (Womack and Jones, 1996; Monden, 1983). Recently, Mackelprang and Nair’s (2010) have conducted a meta-analytic investigation of empirical studies on the relationship between JIT practices and performance and have concluded that this relation is significant and positive when considering operational measures such as manufacturing costs, inventory costs, cycle time, speed and on-time delivery.

According to Liu *et al.* (2009) these performance measures reflect two different underlying dimensions: the first three refer to overall efficiency, while the last two are related to delivery.

Also Sakakibara *et al.* (1993) suggest to treat cycle time and lead time (i.e. delivery speed) separately, because the latter can be affected by the planning policy (e.g. make-

to-order vs. make-to-stock). Therefore, in this study I focus on the impact of JIT production and JIT supply on efficiency and delivery separately.

As regards the impact of JIT production practices, research indicates that concurrent use of cellular manufacturing, set-up time minimization, pull systems and daily schedule adherence allows a continuous flow of materials to be achieved throughout production lines, thus minimizing work-in-process inventory and unnecessary delays in flow time, decreasing manufacturing costs, speeding up activities and improving on-time delivery performance (Brown and Mitchell, 1991; Manoocheri, 1984).

Mackelprang and Nair (2010) demonstrate that the positive association between JIT production and efficiency and delivery performances generally holds over different empirical studies. Therefore I can posit that the implementation of JIT production practices will have a positive impact on operational performance:

*Hypothesis 1: JIT production is positively related to efficiency performance*

*Hypothesis 2: JIT production is positively related to delivery performance*

As regards the impact of JIT supply practices, several authors agree that implementing JIT at the manufacturer-supplier interface can significantly contribute to streamlining procurement and production planning processes, thus speeding up material flows and saving costs (Jones *et al.*, 1997; Lamming, 1993; Helper, 1991).

Mistry (2005) conducted some interviews in an electronics manufacturing company and found that, besides inventory reduction, a further important benefit of the JIT supplier delivery program was the simplification of receiving activities for the manufacturer. After JIT supply implementation material handlers were no longer required at the buying company's plant, with resulting savings in personnel salaries.

Mackelprang and Nair (2010) indicate that JIT deliveries from suppliers are positively associated with inventory, cycle time and delivery performance.

Green *et al.* (2011) study the impact of JIT outbound logistics, but their explanations can be extended also to JIT deliveries from suppliers (inbound logistics). These authors maintain that JIT suppliers assure steady and reliable deliveries, being responsible for delivery date rather than ship date.

In the same vein, Jones *et al.* (1997) argue that JIT linkages with suppliers on the one hand improve efficiency because of better shipment scheduling and removal of extra-costs due to emergency shipments, and on the other hand, reduce the overall lead time, exploiting the benefits deriving from manufacturer-supplier synchronization.

From the discussion above I propose the following hypotheses on the positive impact of JIT supply on efficiency and delivery performance:

*Hypothesis 3: JIT supply is positively related to efficiency performance*

*Hypothesis 4: JIT supply is positively related to delivery performance*

### **Interaction effects on performance**

Mackelprang and Nair (2010) consider the investigation of interactions between JIT practices and their impact on operational performance a significant opportunity to advance theory in lean management research. Their meta-analysis reveals that nearly 50% of all the associations between JIT practices and performance examined are subject to moderating factors, being a “moderator” a variable that influences the link between JIT practices and performance.

In agreement with Mackelprang and Nair’s (2010) comments, I believe that an interesting opportunity to better understand the impact of JIT on performance lies in the examination of the interaction effect between JIT production and JIT supply practices.

This investigation would be insightful to explain the different roles, weights and contributions of JIT practices to efficiency and delivery performance, to explore the existence of better conditions or even sequences of implementation of JIT practices to achieve higher payoffs, and to identify situations that can hinder or even cancel the impact on performance.

Several studies extended the analysis of JIT practices beyond the company’s boundaries and considered JIT production and JIT supply as strictly interconnected practices.

Kannan and Tan (2005) argue that JIT production implementation depends on the coordination of production schedules with supplier deliveries and the efforts to improve materials flows through JIT practices can be facilitated by linking also supplier systems, thus creating an integrated JIT material flow.

Similarly, Furlan *et al.* (2010) investigate interactions among JIT practices and find that JIT linkages upstream and downstream in the supply chain should be implemented if the firm is seeking to maximize operational performance. This external JIT focus should complement the implementation of JIT manufacturing practices. According to Hsu *et al.* (2009) and Panizzolo (1998), JIT supply can magnify the benefits of JIT production.

In fact, the adoption of JIT practices in the manufacturing area usually leads to efficient but also vulnerable production systems, basically because production can no more rely on overproduction and stocks. Therefore, to be effective JIT production requires a faster and more intense transmission of information and a greater degree of co-ordination with suppliers.

The extension of JIT practices upstream allows companies to effectively align deliveries from suppliers with manufacturers' needs, thus avoiding inefficiencies and disruptions in the supply of raw materials and components.

From the discussion above, it seems that JIT supply could interact with JIT production practices and influence the magnitude of their impact on performance. Thus, I advance the following hypotheses:

*Hypothesis 5: JIT supply positively moderates the relationship between JIT production and efficiency performance*

*Hypothesis 6: JIT supply positively moderates the relationship between JIT production and delivery performance*

It should be noted that while several authors (Mackelprang and Nair, 2010; Furlan *et al.*, 2010; Hsu *et al.*, 2009; Panizzolo, 1998) advocate the need for studying interactions between JIT supply and JIT production, some others (Kannan and Tan, 2005) claim that JIT production could depend on JIT supply, thereby suggesting the existence of a causal link.

This study focuses on interaction effects, as literature agrees that this represents a fascinating area of research with interesting implications both for theory and practice (Mackelprang and Nair, 2010). However, the intention of this research is not to cover all the potential effects that could exist among JIT production, JIT supply, efficiency and delivery. In Appendix A of this chapter, I discuss some further potential effects that can contribute to depicting a more complete picture of the relationships among the variables studied.

## **4.3 Methodology**

### **4.3.1 Data collection and sample**

The hypotheses have been tested using data from the third round of the High Performance Manufacturing (HPM) project. The items used in the present research are a subset of the whole HPM survey, and were targeted to the production control manager, the inventory manager and the plant manager. Respondents gave answers on JIT production and JIT supply practices implemented and operational performances obtained. For each item I checked the inter-rater agreement within the same organization by measuring the Interclass Correlation (ICC) index (Boyer and Verma, 2000). For all the items used in this research, the ICC indexes are above 0.70, indicating an acceptable agreement among different informants within a plant. To conduct plant level analysis, I aggregated individual informant responses to the plant level by taking the average of within-plant responses.

Approximately 65 percent of plants contacted agreed to administer the survey and filled the questionnaires. Data from 207 plants were returned. This high response rate was obtained by personally contacting each plant's manager by phone in order to obtain the plant agreement for participation before the mail survey was delivered, and by promising a feedback report as a benefit to the participating plants.

Because of the relatively high response rate, non-response bias does not appear to be a serious concern (Flynn *et al.*, 1990). However, HPM research team assessed non-response bias, comparing the plant size and annual revenue of the responding and non-responding plants (Mishra and Shah, 2009). This test did not reveal any systematic non-response bias. The sample is stratified to approximate equal distribution across all three sectors (Tables 4.1 and 4.2). The mean number of employees for the sample was 608.44 (number of hourly plus salaried personnel). I use size and industry as control variables later in the analysis to test whether these had any impact on performance.

In addition, since the data was collected from different countries, I ran ANOVA analyses (univariate one-way ANOVA, Tukey’s test) on the constructs reported in Table 4.3 with country as factor, in order to check for potential country biases. Results show that there are no significant differences across countries ( $p$ -value > 0.05), neither in aggregate terms nor in pairwise comparisons.

**Table 4.1: Demographics for sample plants**

|   | Electronics | Machinery  | Transportation Equipments | Total      |
|---|-------------|------------|---------------------------|------------|
| Number (percentage) of plants   | 69 (33.3%)  | 69 (33.3%) | 69 (33.3%)                | 207 (100%) |
| Annual sales volume (\$000) (average)   | 290,027     | 269,785    | 448,935                   | 334,050    |
| Plant size (total number of hourly and salaried personnel employed) (average) | 529.87      | 467.17     | 836.66                    | 608.44     |
| Percentage of sales from customers in the home country (average)              | 56.71       | 74.14      | 70.85                     | 67.16      |
| Percentage of purchases from the home country (average)                       | 51.53       | 46.20      | 58.28                     | 52.13      |
| Number of final product configurations (average)                              | 751.81      | 984.38     | 1,187.93                  | 971.41     |

**Table 4.2: Frequency count by industry and country**

|             | Austria | Finland | Germany | Italy | Japan | Sweden | US | Total |
|-------------|---------|---------|---------|-------|-------|--------|----|-------|
| Electronics | 10      | 14      | 9       | 10    | 10    | 7      | 9  | 69    |
| Machinery   | 7       | 6       | 13      | 10    | 12    | 10     | 11 | 69    |
| Transp.eq.  | 4       | 10      | 19      | 7     | 13    | 7      | 9  | 69    |
| Total       | 21      | 30      | 41      | 27    | 35    | 24     | 29 | 207   |

### 4.3.2 Variables and measurement scale assessment

Four multi-item constructs were considered in this chapter, referred to as JIT production (JITpro), JIT supply (JITsup), efficiency (EFF) and delivery (DEL) (Table III).

I used scales validated in previous studies and based on an extensive literature review. The measurement scales are fully displayed in Appendix B of this chapter.

*JIT production* is a five-item scale previously developed and validated by Furlan *et al.* (2010). It measures the adoption of a set of practices commonly associated to JIT production programs (Zelbst *et al.*, 2010; Cua *et al.*, 2001) including set-up time reduction, JIT scheduling, lot size reduction, kanban, pull system production and layout for fast throughput.

To operationalize the *JIT supply* construct I referred to Sakakibara *et al.* (1993) who define JIT deliveries from suppliers in terms of extent to which the plant is receiving shipments from vendors according to a pull logic which typically involves frequently filling small kanban containers rather than purchasing orders.

Hence the JIT supply scale incorporates three items used in prior studies (Furlan *et al.*, 2010; Sakakibara *et al.*, 1993) and measures the adoption of practices such as pull deliveries from suppliers, use of vendor kanban containers and inbound logistics schedule with daily shipments.

All the items comprising the JIT production and JIT supply constructs were developed from Likert-scaled items, with values ranging from 1 (“strongly disagree”) to 7 (“strongly agree”) (see Appendix B of this chapter).

The constructs *efficiency* (EFF) and *delivery* (DEL) are the two operational performances considered in this study.

EFF includes three items that measure: the unit cost of manufacturing, inventory turnover and cycle time (from raw materials to delivery).

DEL encompasses two items: on-time delivery and fast delivery. These items could be measured in absolute terms.

However, in accordance with several authors (Flynn *et al.*, 1995; Sakakibara *et al.*, 1993), since it is difficult to compare the performance of plants operating in different industries, I decided to focus on perceptual and relative measures of performance, by asking respondents to compare their performance with that of competitors on a 5-point Likert scale (from 1 indicating “poor, low” to 5 “superior”).

These performance scales have been previously developed and validated by Liu *et al.* (2009) who distinguish between efficiency and delivery performance and use the same items applied in this research.

Confirmatory factor analysis (CFA) using LISREL 8.80 was run to assess the reliability and validity of our constructs. A model was created including four latent variables: “JITpro”, “JITsup”, “EFF” and “DEL”, that were assumed to underlie specific observed variables which emerged from the literature. The overall fit indexes of the CFA were:  $\chi^2 = 148.971$ , relative  $\chi^2 = 2.52$ , CFI = 0.923 and RMSEA = 0.078.

As suggested by Hair *et al.* (2006), generally a relative  $\chi^2$  between 1 and 3, a CFI value greater than 0.90, and values of RMSEA lower than 0.08 indicate a reasonable fit.

All the standardized estimates of the observed variables exceed 0.500 and the corresponding t-values are statistically significant at  $p < 0.001$  (see Table 4.3). The significant and substantial item loadings provide statistical evidence of convergent validity.

In addition, for each latent construct I checked that the composite reliability were greater than 0.700, indicating high reliability (Table 4.4).



**Table 4.3: Results of CFA**

| <b>Construct</b>           | <b>Item</b>  | <b>Lambda*</b> | <b>t-value</b> |
|----------------------------|--|----------------|----------------|
| JIT production<br>(JITpro) | We usually complete our daily schedule as planned                            | 0.522          | -              |
|                            | The layout of our shop floor facilitates low inventories and fast throughput | 0.626          | 5.928          |
|                            | We use a kanban pull system for production control                           | 0.615          | 5.874          |
|                            | We have low setup times of equipment in our plant                            | 0.545          | 5.479          |
|                            | We emphasize small lot sizes, to increase manufacturing flexibility          | 0.501          | 4.608          |
| JIT supply<br>(JITsup)     | Suppliers fill our kanban containers, rather than filling purchase orders.   | 0.811          | -              |
|                            | We receive daily shipments from most suppliers.                              | 0.849          | 10.568         |
|                            | Our suppliers are linked with us by a pull system                            | 0.542          | 7.412          |
| Efficiency<br>(EFF)        | Unit cost of manufacturing   | 0.508          | -              |
|                            | Inventory turnover   | 0.729          | 6.257          |
|                            | Cycle time (from raw materials to delivery)                                  | 0.804          | 6.302          |
| Delivery<br>(DEL)          | On time delivery performance   | 0.892          | -              |
|                            | Fast delivery  | 0.649          | 5.445          |

\*Completely standardized values

To assess discriminant validity I followed the method used by Huang *et al.* (2008). I formed all possible pairs of latent constructs and tested discriminant validity by comparing the model with the free correlation between the two constructs to the model with the correlation set to 1.00.

A significant  $\chi^2$  difference between these two nested models indicates that the two constructs are distinct. In these tests, all the  $\chi^2$  differences were statistically significant ( $p < 0.001$ ), confirming the discriminant validity of the constructs.

Finally, as suggested by Podsakoff *et al.* (2003), I assessed the severity of the common method variance (CMV), through single factor CFA.

This analysis with all items loading on one factor resulted in a poor fit ( $\chi^2 = 406.039$ , relative  $\chi^2 = 6.24$ , CFI = 0.707, RMSEA = 0.184). This confirms that in this research common method bias is not a problem. In addition, to further assess the impact of CMV, I used the post hoc method recommended by Lindell and Whitney (2001).

To acquire a reliable and conservative estimate of CMV I selected the second-smallest positive correlation among the manifest variables in this study (rM2=0.015). For each couple of constructs under investigation I calculated the CMVadjusted correlation and its significance.

The results indicate that all the originally significant correlations remained significant even after controlling for CMV and that none of the original correlations were significantly different from their CMV-adjusted counterparts, implying that CMV biases are not substantial.

Table 4.4 shows the correlations between the constructs (PHI matrix values) and basic statistics for each construct, as well as the composite reliability and delta  $\chi^2$  indexes for discriminant validity.

**Table 4.4: Correlation Analysis, delta  $\chi^2$  and composite reliability coefficients**

| Constructs | (Mean; std dev) | Composite reliability | Correlations (Delta $\chi^2$ for discriminant validity) |                       |                      |
|------------|-----------------|-----------------------|---|-----------------------|----------------------|
|            |                 |                       | JITsup  | EFF                   | DEL                  |
| JITpro     | (4.70; 0.70)    | 0.700                 | 0.610***<br>(38.887)                                    | 0.529***<br>(110.451) | 0.382***<br>(93.567) |
| JITsup     | (3.62; 1.03)    | 0.785                 |   | 0.243*<br>(81.294)    | 0.119<br>(68.852)    |
| EFF        | (3.33; 0.68)    | 0.727                 |   |                       | 0.518***<br>(85.959) |
| DEL        | (3.78; 0.77)    | 0.752                 |   |                       | -                    |

\* Significant at the 0.05 level

\*\*\* Significant at the 0.001 level (Pearson probabilities)

In this research, I considered two control variables: industry and plant size. The industry was inserted in the analyses, by creating two dummy variables (i.e. the variable DUMMY 1 refers to electronics sector; and DUMMY 2 to transportation equipment sector). The form of dummy variable coding used was ‘indicator coding’, which means that the regression coefficients for the dummy variables represent deviation from the comparison group. The mechanical sector was arbitrarily taken as the baseline/comparison group.

In addition, I decided to control for size effects, because plants differing in size may vary in the amount of resources available, and resource availability can affect performance. The number of employees is a commonly used measure for plant size. As in Liu *et al.* (2006), I operationalized plant size (SIZE) as the log of the sum of the number of hourly and salaried employees.

### **4.3.3 Hierarchical regression and expert analysis**

To test the research hypotheses, the procedure recommended by Jaccard and Turrisi (2003) was preferred over other methodologies (e.g. structural equation modeling, simulation etc.) because it allows not only to detect on a large sample of plants the existence of significant moderating effects of JIT practices on performance, but also to plot the impact of JIT production on performance for varying levels of JIT supply adoption (see section 4), thus providing powerful information on the conditions that can heighten or hinder its impact on performance.

I employed a hierarchical regression procedure, by using SPSS 17.0 (linear regression module; entering method: by blocks; deletion method: listwise). For each operational performance (EFF and DEL), firstly, control variables (i.e. industry and SIZE) were considered in the regression model. Then, main independent variables - i.e. JITpro and JITsup - were introduced as a block, followed by the interaction term (JITpro·JITsup). The following equation describes the logic of moderated regression (Jaccard and Turrisi, 2003):

$$y = \beta_0 + \beta_1 \cdot x + \beta_2 \cdot z + \beta_3 \cdot x \cdot z + \varepsilon \quad (1)$$

where  $x$  is the focal independent variable (i.e. JITpro),  $z$  the moderating variable (i.e. JITsup) and  $y$  the performance (i.e. EFF or DEL).

As suggested by Jaccard and Turrisi (2003), when the  $\beta_3$ -coefficient of the product term  $x \cdot z$  is statistically significant, and  $R^2$  increases when this term is introduced in the model, the existence of a moderated effect on  $x$ - $y$  relationship is demonstrated.

As recommended, to address the problem of multicollinearity, the independent variables were mean-centered (Danese and Romano, 2011). Then, multicollinearity diagnostics were examined, by checking the variance inflation factor (VIF).

Finally, I discussed the statistical results found with three experts with a great deal of experience on JIT practices, who did not participate in the HPM project as survey respondents, with the aim of refining our interpretation of the interaction between JITpro and JITsup and the relationship between JIT practices and operational performance.

In particular, I interviewed: a consultant with expertise in the area of lean supply (Informant 1), the CEO of an Italian company, pioneer in the application of JIT production and JIT supply and founder of the Italian Lean Enterprise Center, the Italian branch of Jim Womack's Lean Global Network ([www.lean.org](http://www.lean.org)) (Informant 2), and finally, the lean manager of a large multinational with four plants in Italy, with decades of experience in JIT production and JIT supply (Informant 3).

## 4.4 Results of hierarchical regression

The results of the hierarchical regression analyses are shown in Tables 4.5 and 4.6. Model 0 represents the first step of the hierarchical regression. As reported, industry (DUMMY1 and DUMMY2) does not result as significantly related to EFF and DEL. Similarly the variable SIZE has not a significant effect on DEL. Instead, it significantly and positively affects efficiency performance. These effects remain stable also in the models 1 and 2.

More interestingly, when the independent variables: JITpro and JITsup are added to the regression models (models 1 in Tables 4.5 and 4.6), the significant values of  $\beta_1$ -coefficients in the main-effect models support hypotheses 1 and 2 regarding the positive relationship between JITpro and EFF, and JITpro and DEL.

On the contrary, JITsup does not result as significantly related to EFF and DEL. Thus, I found that hypotheses 3 and 4 are not held, and therefore in general it is not possible to conclude that JITsup always improves efficiency and delivery.

Models 2 in Table 4.5 and 4.6 report the interaction result, along with changes occurring to the main variables when the product term is introduced. The non-significant value of  $\beta_3$ -coefficient in the interaction-effect model of Table 4.5 does not support hypothesis 5 on the moderating role of JITsup on the JITpro-EFF relationship.

Instead, the significant and positive  $\beta_3$ -coefficient in Table 4.6 suggests that it is possible to confirm the existence of a positive interaction effect on DEL, deriving from the combination of JITpro and JITsup (hypothesis 6 supported).

Additional support is the significant increase of  $R^2$  when the interaction effect is introduced in the model (from 0.073 to 0.095).

The  $R^2$  values can be considered acceptable according to the minimum  $R^2$  threshold proposed by Hair *et al.* (2006). Similar values of  $R^2$  can be found in other studies (e.g. Bozarth *et al.*, 2009) and they are not surprising when considering that efficiency and delivery performance can be explained by a large number of variables and practices. It is worth noting that the aim of this chapter was not to build a powerful global model to explain the whole variability in efficiency and delivery, but to detect the possible

statistically significant influence of the independent variables considered (i.e. JITpro and JITsup).

**Table 4.5: Hierarchical Regression Analysis (Dependent Var. = EFF)**

|                               | Control variables | Main effects | Interaction effect |
|-------------------------------|-------------------|--------------|--------------------|
|                               | MODEL 0           | MODEL 1      | MODEL 2            |
| Constant                      | 2.681***          | 2.779***     | 2.793***           |
| DUMMY 1 (Electronics)         | -0.104            | -0.178       | -0.179             |
| DUMMY 2 (Transp. Equip.)      | -0.076            | -0.177       | -0.179             |
| SIZE                          | 0.120*            | 0.111*       | 0.111*             |
| JITpro ( $\beta_1$ )          |                   | 0.396***     | 0.398***           |
| JITsup ( $\beta_2$ )          |                   | -0.063       | -0.057             |
| JITpro · JITsup ( $\beta_3$ ) |                   |              | -0.023             |
| R <sup>2</sup>                | 0.031             | 0.171        | 0.171              |
| R <sup>2</sup> Adjusted       | 0.014             | 0.146        | 0.142              |
| $\Delta R^2$                  | 0.031             | 0.139        | 0.001              |
| $\Delta F$                    | 1.845             | 14.290***    | 0.156              |

The value reported are unstandardized regression coefficients

\* p-value <0.05 level

\*\*\* p-value <0.001 level

VIF (Variance Inflation Factor) below 1.745

**Table 4.6: Hierarchical Regression Analysis (Dependent Var. = DEL)**

|                               | Control variables | Main effects | Interaction effect  |
|-------------------------------|-------------------|--------------|---------------------|
|                               | MODEL 0           | MODEL 1      | MODEL 2             |
| Constant                      | 3.734***          | 3.769***     | 3.693***            |
| DUMMY 1 (Electronics)         | -0.016            | -0.071       | -0.066              |
| DUMMY 2 (Transp. Equip.)      | -0.035            | -0.104       | -0.096              |
| SIZE                          | 0.009             | 0.008        | 0.010               |
| JITpro ( $\beta_1$ )          |                   | 0.350***     | 0.338***            |
| JITsup ( $\beta_2$ )          |                   | -0.089       | -0.125 <sup>†</sup> |
| JITpro · JITsup ( $\beta_3$ ) |                   |              | 0.138*              |
| R <sup>2</sup>                | 0.000             | 0.073        | 0.095               |
| R <sup>2</sup> Adjusted       | -0.017            | 0.047        | 0.063               |
| $\Delta R^2$                  | 0.000             | 0.073        | 0.021               |
| $\Delta F$                    | 0.024             | 6.821***     | 4.007*              |

The value reported are unstandardized regression coefficients

<sup>†</sup> p-value <0.10 level

\* p-value <0.05 level

\*\*\* p-value <0.001 level

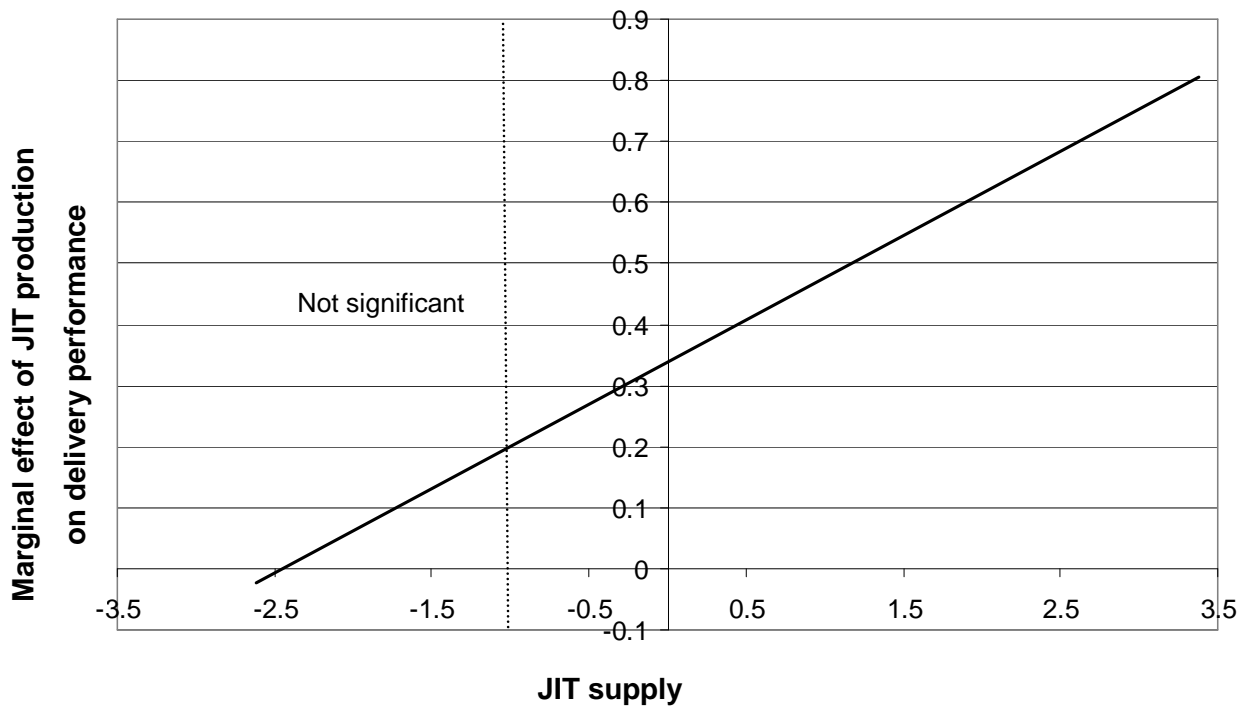
VIF (Variance Inflation Factor) below 1.703

By considering the coefficients of Table 4.6 (model 2), I can calculate that the marginal effect of JITpro on DEL depends on JITsup, according to the following formula:

$$\frac{\partial DEL}{\partial JIT_{pro}} = 0.338 + 0.138 \cdot JIT_{sup} \quad (2)$$

where the variable JITsup is centered. As recommended by Brambor *et al.* (2006), it is necessary to know the standard error for the coefficient represented by equation (2). The test of significance of this coefficient takes the form of a t-test, where the standard error is a function of JITsup. I have verified that the t-test is significant at a 0.05 level for the values of JITsup greater than -1.0.

Figure 4.2 shows how the marginal effect of JITpro varies when JITsup increases. It is easy to see that JITpro has an increasing and positive impact on DEL for increasing values of JITsup. It also reveals that, in particular circumstances (i.e. JITsup at a low level), the impact of JITpro could be almost nil, or even negative.



**Figure 4.2: The influence of JIT supply on the marginal effect of JIT production on delivery performance (Equation:  $\frac{\partial DEL}{\partial JIT_{pro}} = 0.338 + 0.138 * JIT_{sup}$ )**

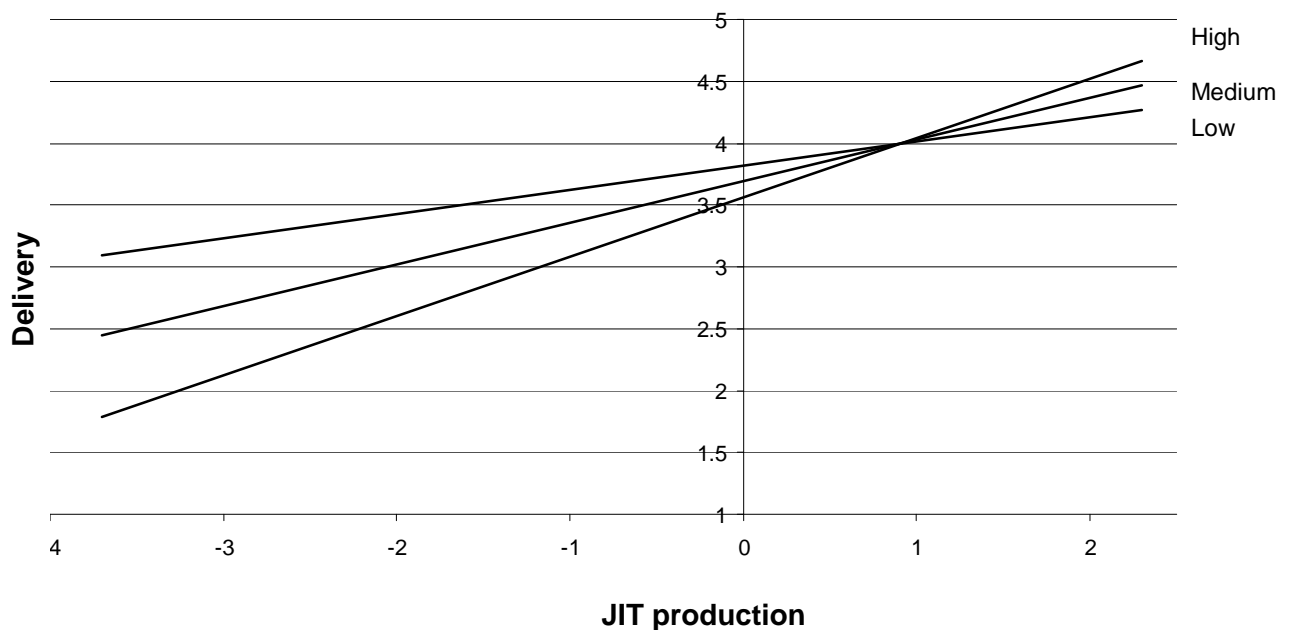


Finally, to gain an intuitive understanding of the interaction effect between JITpro and JITsup, I computed and graphed the slope of DEL on JITpro at a few different values of JITsup.

A suggested strategy is to evaluate the effect of JITpro on DEL at “low”, “medium” and “high” values of JITsup, where “low” might be defined as one standard deviation below the mean JITsup score, “medium” as the mean JITsup score, and “high” as one standard deviation above the mean (Cohen and Cohen, 1983).

Starting from the coefficients of model 2 in Table 4.6 and by considering the three mentioned values of the variable JITsup, three linear equations of DEL performance, depending on JITsup, were created.

The visual pattern of Figure 4.3 confirms that the effect of JITpro on DEL is greater when JITsup increases; while this effect is mitigated when JITsup is at a low level.



**Figure 4.3: Delivery performance slope at low, medium and high levels of JIT supply (Equation is:**

$$DEL = 3.693 + 0.338 * JITpro - 0.125 * JIT\ sup + 0.138 * JITpro * JIT\ sup ;$$

**the three linear equations were created by setting the values of JITsup to: JITsup=-1.03; JITsup=0; JITsup=+1.03, respectively)**

## 4.5 Discussion and implications

This study provides several outcomes with interesting academic and managerial implications.

### Theoretical implications

A first result is that JIT production practices positively affect both efficiency and delivery performance (hypotheses 1 and 2 held). This is consistent with the stream of studies supporting that the concurrent adoption of JIT manufacturing techniques, such as cellular manufacturing, SMED, small lots, kanban and heijunka, increases efficiency and delivery performance (Womack and Jones, 1996; Brown and Mitchell, 1991; Manoocheri, 1984).

Instead, these findings do not support hypotheses 3 and 4 since JIT supply practices do not have a significant positive effect on efficiency and delivery. Thus, this research does not confirm previous studies on the positive effect of JIT supply on performance (e.g. Jones *et al.*, 1997; Lamming, 1993; Helper, 1991), but rather is consistent with those authors who are more cautious about this main positive effect (e.g. Kros *et al.*, 2006; Sakakibara *et al.*, 1993; Panizzolo, 1998).

Even though not all previous studies fully agree on the positive relationship between JIT supply and performance, the lack of a positive relationship is somewhat surprising. A possible interpretation is that while JIT production practices directly impact on plant's performance, JIT supply is not directly responsible of plant's efficiency or delivery, as these are influenced also by the plant's production system.

From this, one can argue that the impact of JIT supply on performance depends on JIT production, and for instance that low levels of JIT production can vanish it. Though this moderating role of JIT production can be plausible, further research is necessary to corroborate this hypothesis, because in practice companies use to implement first JIT production and then extend JIT over the supplier network (Furlan *et al.*, 2010; Helper, 1991). Therefore, it is unusual that a company adopts JIT supply without having successfully in place a JIT production system.

An alternative explanation for the lack of a significant relationship between JIT supply and performance is to some extent suggested by the analysis of correlations in Table 4.4.

The relevant correlation coefficient (0.610,  $p\text{-value} < 0.001$ ) between JITsup and JITpro shows that these variables are strongly related. As discussed earlier, many previous studies (Mackelprang and Nair, 2010) explicitly recommend to study the interaction effect between JIT supply and JIT production.

Nevertheless, more in general, some authors (Kannan and Tan, 2005) suggest that JIT production could depend on JIT supply. Accordingly, I set out to explore the hypothesis that JIT supply can play a role as a precursor of JIT production. Additional analyses to study this effect are reported in Appendix A of this chapter.

They suggest that JIT supply, rather than having no effect on delivery and efficiency performance, is strongly related to JIT production, which in turn significantly affect delivery and efficiency performance. The additional analyses reported in Appendix A can contribute to depicting a more complete picture of the JIT implementation issue and at the same time recommend more research on the role of JIT supply in improving performance.

In any case, it is interesting to note that the three experts revealed that the impact of JIT supply on performance, especially on efficiency, should not be taken for granted. They provided several practical examples of why JIT supply does not always affect efficiency.

They agreed that cost benefits usually led by JIT supply (e.g. reduction of raw material/component inventories, removal of extra-costs due to rush shipments, simplification of receiving activities for the manufacturer) can be offset by 1) the increased costs of purchases, due to the use of a local supplier network instead of

sourcing from distant but low-cost suppliers, and 2) the additional costs due to the complex coordination of JIT deliveries (e.g. through the milk-run practice). This interpretation is confirmed also by the literature on JIT supply (e.g. Nellore *et al.*, 2001; McIvor, 2001; Lamming, 1996).

As to the complexity of JIT delivery management, Informant 2 explains how the milk run is a particularly tough practice, since it requires the synchronization of suppliers' deliveries with the manufacturer's production, high delivery frequency, and a careful routing definition to collect goods from different suppliers, while maximizing truckloads.

A delay in the production of a single supplier could cause a redefinition of the routing, a non-optimal transportation utilization or the delay of the entire milk run. To avoid these problems, manufacturers usually ask JIT suppliers to continuously maintain a certain level of safety stocks, to guarantee the availability of components/raw materials, when the truck reaches the supplier's facility. All these complications negatively impact on efficiency performance, limiting the positive effect of JIT supply.

However, further insightful results on the contribution and weight of JIT supply in improving performance derive also from the analysis of its potential moderating effect. These findings only partially confirm studies on the positive moderating effect of JIT supply (Furlan *et al.*, 2010; Hsu *et al.*, 2009; Panizzolo, 1998), and complement them by emphasizing the need for a distinction between efficiency and delivery performance.

Firstly, it emerges that there is no significant moderating effect when considering the impact on efficiency (hypothesis 5 not supported). This suggests that companies adopting JIT production achieve significant efficiency improvements, whatever the level of JIT supply be.

From the comments of Informants 2 reported above, a possible interpretation is that the implementation of JIT supply can feed JIT production systems with a more stable and continuous material flow, but also more expensive. As a consequence the effect of JIT production on efficiency does not result magnified in presence of high levels of JIT supply. In line with Informant 2, Informant 3 pointed out that JIT deliveries from suppliers can often determine inefficiencies (e.g. inventories of raw material at the customer-supplier interface).

In particular, this happens when both customer and supplier production systems are not balanced to follow the real demand pace. This means that suppliers must not only be able to simply supply, but also produce JIT. In this case, suppliers can ensure JIT deliveries without the need of huge stocks neither at customer-supplier interfaces nor in their production systems.

Secondly, these findings indicate that the implementation of JIT supply positively moderates the relationship between JIT production and delivery (hypothesis 6 supported), and thus companies can significantly improve their delivery performance by leveraging on JITsup as well as on JITpro. For instance, from equation (2) it is easy to calculate that one-point increment in JITpro increases delivery performance of 0.196 if a company adopts JIT supply practices at a low level (e.g. JITsup is one standard deviation below its mean value).

Instead, if a company implements JIT supply at a high level (e.g. JITsup is one standard deviation above its mean value) delivery performance increases of 0.481. In the second situation, delivery improvement is almost 2.5 times higher, thus highlighting the key role of JIT supply as a driver to improve this performance. This result is in line with those empirical studies (Hsu *et al.*, 2009; Panizzolo, 1998), which maintain that JIT deliveries from suppliers are fundamental to fully exploit the benefits of JIT manufacturing systems. In fact JIT production is a vulnerable system that does not rely on stocks to satisfy customer requests, but rather on fast throughput and pull production logic.

If supplier and manufacturer are not sufficiently aligned through a JIT supply logic, delays in deliveries can occur, that can, in part, lessen the benefits of JIT production on delivery performance. Informant 3 reported his personal experience with managing JIT production in his company before the implementation of the milk run pull system and kanban with suppliers. Since suppliers used to deliver every two weeks according to a fixed order frequency and variable quantity reorder point rule, any shortcoming by suppliers in filling customer orders resulted either in two-week late deliveries or in rush orders. In both cases this destabilized the JIT manufacturing system's performance negatively affecting deliveries to customers.

After the milk run, kanban and pull implementation, this problem has been significantly stemmed as suppliers possess information on stock level at the customer

facility and organize deliveries of small lots every two days. This means that most of the shortcomings in filling customer orders during one milk run are usually recovered during the next one, which occurs two days later.

It is interesting to note that delivery improvements could have an effect also on efficiency, thanks to less frequent rush deliveries and emergency situations due to inventory stock outs.

The correlation between DEL and EFF performance (Table 4.4) and previous studies on the “sand cone” effect of improvements in manufacturing performances (Ferdows and De Meyer, 1990) suggested us to explore an additional potential effect, i.e. the DEL-EFF link.

The analyses reported in Appendix A show that JITpro impacts on EFF both directly and indirectly through DEL, while the impact of JITpro\*JITsup on DEL can in turn determine also an improvement in the EFF performance. This finding identifies a path that can link JIT supply also to efficiency performance.

Finally, this research does not only provide empirical evidence that JIT supply moderates the JIT production-delivery link, but analyzes in detail the effect of JIT production for varying levels of JIT supply adoption (see Figures 2 and 3). This can offer further interesting implications for theory.

On the one hand, the result that a very low adoption of JIT supply can act as a barrier that limits the impact of JIT production on delivery (see the left side of Figure 2) provides an explanation of why JIT production efforts do not necessarily lead to significantly improved delivery, as reported by Mackelprang and Nair (2010). On the other hand, the finding that the positive effect of JIT production on delivery increases with increasing level of JIT supply adoption provides empirical evidence supporting the existence of complementary effects in the lean field, as argued by Furlan *et al.* (2010).

## **Practical implications**

From this research some practical implications can be derived that clarify what is the individual contribution of JIT production and JIT supply on performance and how to balance efforts on each JIT practice over time. These managerial guidelines can be

particularly valuable because JIT implementation is not cost free and companies have limited resources and must choose the most effective deployment of these resources.

Firstly, our outcomes advise managers that decisions on JIT production and JIT supply implementation should differ according to the performance companies intend to improve. In particular, when efficiency is the priority, companies should direct their efforts on JIT production. Instead, when their aim is to improve delivery, they should invest on both JIT production and JIT supply. As discussed earlier, improving delivery performance can in turn contribute to improve efficiency.

Thus, when considering delivery performance, managers need some practical advices on how taking correct decisions about balancing investments in JIT supply and JIT production over time.

Literature agrees that JIT production implementation should precede JIT supply (Furlan *et al.*, 2010). However, to ensure that JIT production positively affects delivery, this study strongly recommends managers to implement some JIT supply practices during the early stages of JIT production programs. The total absence of any JIT linkages with suppliers could cause significant disruptions in the production system, and in turn limit delivery improvement.

In addition, once JIT production streamlines and stabilizes manufacturing processes, managers should simultaneously lever on JIT production and JIT supply to foster interaction, rather than investing and acting on JIT production only.

## **4.6 Conclusions**

This chapter intends to contribute to the debate on the relationship between JIT practices and performance. In analyzing this link, I investigated not only whether JIT production and JIT supply practices positively affect efficiency and delivery performance, but also whether their interaction will yield greater performance benefits.

Results found highlight that JIT production practices positively affect both efficiency and delivery.

Instead, the implementation of JIT supply practices positively moderates the relationship between JIT production and delivery, whereas there is no significant moderating effect when considering the impact on efficiency. It also emerges that the role of JIT supply as moderator is twofold.

On the one hand, it interacts with JIT production strengthening the positive impact of JIT production on delivery through a complementary effect. On the other hand, a low level of adoption of JIT supply practices can hinder and – for extremely low levels - cancel the impact of JIT production practices on delivery.

### **Limitations of the study and future research**

Limitations and future developments of this study should be considered along with the results.

Firstly, our research setting, the firms operating in machinery, electronics and transportation equipment industries, could limit the generalizability of our findings. Though I have no evidence to claim otherwise, it is possible that other sectors may show different patterns.

Hence, future research should replicate and extend our model to samples drawn from other industries. Moreover, I focused our analysis on the moderating role of JIT supply practices but several other variables may act as moderators and deserve further research (e.g. structural characteristics of supplier network, such as the number of suppliers and their geographical dispersion).

Further opportunities for delving more deeply into the relationships between JIT supply, JIT production and performance lie in the adoption of different research methodologies and approaches that could corroborate as well as complement the results found in this research.

For instance, specific methods of analysis could allow to test simultaneously in an integrated model both the interaction and the causal link between JIT production and JIT supply. In addition, the hypotheses advanced in this research could be further studied by using simulation techniques in order to identify whether some contextual



variables exist that can modify the effectiveness of JIT practices in improving performance, or whether the model investigated still holds in specific contexts.

Also the way performance is operationalized in this study could be reconsidered in future research. Efficiency and delivery are measured as feedback of managers' perceptions, but they could be more accurately evaluated by using objective indicators. In addition, the practical examples provided by the three informants interviewed on the difficulties of managing a JIT supply system and its implications for efficiency performance, suggest the need to study the impact of JIT supply on the different dimensions of efficiency separately (e.g. purchasing costs, manufacturing costs, inventory, etc.) and at different tiers in the supply chain (i.e. at suppliers' and customers' plants). Moreover, they indicate the need to distinguish between suppliers that simply supply, or also produce JIT.

Finally, future studies could shed additional light on interactions between JIT supply and JIT production by further examining some results emerging from this research. In fact Figure 4.2 highlights that for extremely low levels of JIT supply, the impact of JIT production on delivery performance could even be negative. According to the experts interviewed, this result is worthy of note, but deserves further research, since I calculated that below the JIT supply threshold value of -1.00, the marginal effect of JIT production is not statistically significant.

## 4.7 References

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## Appendix A

In order to increase the robustness of the results found through hierarchical regression, I applied the Structural Equation Modeling (SEM) method to examine the effects of JIT supply, JIT production and their interaction on delivery and efficiency performance. Compared to hierarchical regression, SEM allows the simultaneous analysis of the different equations that make up the model, as opposed to performing independent regression analyses for each performance dimension. To test moderation, I employed the two-step approach suggested by Ping (1995). The first step requires examining the linear model (without interaction) and saving the resulting unstandardized values of lambdas, phis, and theta-deltas related to the exogenous variables. In the second step, I introduced the interaction term JITpro\*JITsup into the model, measured as a single item variable calculated by multiplying the sum of the items composing JITpro by the sum of the items composing JITsup. As suggested by Ping, the procedure requires setting the unstandardized lambda and theta-delta of the single item that forms the JITpro\*JITsup latent variable to two precise values calculated starting from the lambda-coefficients, the phi matrix and theta-delta results estimated in the linear model. SEM outputs reveal that the fit statistics are good: ( $\chi^2 = 153.048$ ,  $df=78$ ,  $df/\chi^2 = 1.962$ , CFI=0.935, RMSEA=0.0649). Confirming results found through hierarchical regression, SEM analyses suggest that JITpro is positively related to both

DEL ( $\gamma = 0.430$ ,  $p < 0.001$ ) and EFF ( $\gamma = 0.654$ ,  $p < 0.001$ ). Moreover, the interaction term JITpro\*JITsup is significantly related to DEL ( $\gamma = 0.154$ ,  $p < 0.05$ ).

Interestingly enough, SEM analyses can allow also to investigate further potential effects between the variables considered in this study, thus contributing to depict a more complete picture of the JIT implementation issue and identifying opportunities for future studies on JIT. An additional effect that is suggested by the analysis of correlations in Table 4.4 and is also theoretically plausible concerns the relationship between EFF and DEL. The well-known sand cone model by Ferdows and De Meyer (1990) states that cost improvements are a consequence of resources and management efforts invested in the improvement of delivery. Thus I have introduced the link between DEL and EFF. The fit indices indicate that this model fits the data well ( $\chi^2 = 143.716$ ,  $df=77$ ,  $df/\chi^2 = 1.866$ , CFI=0.943, RMSEA=0.0623). The paths from JITpro to DEL ( $\gamma = 0.404$ ,  $p < 0.001$ ), from JITpro to EFF ( $\gamma = 0.468$ ,  $p < 0.01$ ) and from JITpro\*JITsup to DEL ( $\gamma = 0.155$ ,  $p < 0.05$ ) remain significant. Moreover, a relevant link is present between DEL and EFF ( $\gamma = 0.279$ ,  $p < 0.05$ ), and compared with the first model, it is interesting to note that the path coefficient for the JITpro-EFF link drops from 0.654 to 0.468. To understand which is the best-fit model, I used the Chi-square test. The second model results better than the first model given that the Chi-square difference is statistically significant ( $\chi^2 = 9.332$ ,  $p\text{-value} = 0.002$ ). Combining these findings, I can conclude that JITpro impacts on EFF both directly and indirectly through DEL. In addition, the impact of JITpro\*JITsup on DEL can in turn determine also an improvement in the EFF performance.

Finally, a further effect that can be interestingly studied is the link between JITpro and JITsup. Table IV suggests that these variables are significantly correlated. While several authors (see Mackelprang and Nair (2010)) explicitly suggest to study the interaction effect between JIT supply and JIT production, some others (for example Kannan and Tan (2005)), more in general, advocate that JIT production could depend on JIT supply. Thus, I have analyzed a model that considers JIT supply as a precursor to JIT production, as well as the link between DEL and EFF.

I have reported the AIC index of this model (AIC= 225.233), and compared it with the AIC index of the second model (AIC= 224.480). The lowest AIC score identifies the model with the best fit, i.e. the model of Figure 5. Nevertheless, SEM results reveal that the fit indices of the last model are good: ( $\chi^2 = 173.776$ ,  $df=71$ ,

$df / \chi^2 = 2.447$ , CFI=0.909, RMSEA=0.0768). The path coefficients show that JITsup is significantly related to JITpro ( $\gamma = 0.203$ ,  $p < 0.05$ ) and, as expected, JITpro impacts on DEL, and EFF both directly and indirectly. Thus, in addition to the interaction effect between JITpro and JITsup, also the causal link between JITsup and JITpro can be valuable to explain the impact of JIT on firm's performance, and thus I think that the additional analyses reported on the JITsup-JITpro link can represent an interesting starting point for future studies on JIT issue. It is important to note that Ping's test is usually applied to analyze interaction effects between exogenous variables, whereas its application to moderated mediation models is questioned by several researchers. Thus, it was not possible to analyze a model that includes both the interaction between JIT production and JIT supply and the causal link between JIT production and JIT supply.

## **Appendix B**

### **JIT production**

Please indicate to what extent you agree/disagree with the following - (circle one number): 1 – strongly disagree, 2 – disagree, 3 – slightly disagree, 4 – neutral, 5 – slightly agree, 6 – agree, and 7 – strongly agree

JITPRO1 We usually complete our daily schedule as planned.

JITPRO2 The layout of our shop floor facilitates low inventories and fast throughput.



JITPRO3 We use a kanban pull system for production control.

JITPRO4 We have low setup times of equipment in our plant.

JITPRO5 We emphasize small lot sizes, to increase manufacturing flexibility.

### *JIT supply*

Please indicate to what extent you agree/disagree with the following - (circle one number): 1 – strongly disagree, 2 – disagree, 3 – slightly disagree, 4 – neutral, 5 – slightly agree, 6 – agree, and 7 – strongly agree

JITSUP1 Suppliers fill our kanban containers, rather than filling purchase orders.

JITSUP2 We receive daily shipments from most suppliers.

JITSUP3 Our suppliers are linked with us by a pull system.

### *Efficiency*

Please circle the number that indicates your opinion about how your plant compares to its competitors in your industry, on a global basis: 5 – superior, 4 – better than average, 3 – average or equal to the competition, 2 – below average, and 1 – poor or low

EFF1 Unit cost of manufacturing.

EFF2 Inventory turnover.

EFF3 Cycle time (from raw materials to delivery).

### *Delivery*

Please circle the number that indicates your opinion about how your plant compares to its competitors in your industry, on a global basis: 5 – superior, 4 – better than average, 3 – average or equal to the competition, 2 – below average, and 1 – poor or low

DEL1 On-time delivery performance.

DEL2 Fast delivery.

## 5. CONCLUSIONS

In Chapter 1 I highlighted the research questions that guided the empirical studies reported in Chapters 2, 3 and 4. In this chapter I want to resume these questions to stress the academic and managerial contributions of this thesis.

**RQ 1: what are the Lean Manufacturing practices that a comprehensive measurement scale must consider to make relevant theory advancement?**

In this thesis I combined in the cumulative model discussed in Chapter 2, after an extensive literature review, the most relevant Lean Manufacturing practices and I grouped them into three main bundles (Infrastructure, Just-In-Time and Total Quality Management).

The three bundles were operationalized as a second order factor, while the 17 practices as a first order factor. This measurement scale permits to consider all the socio-technical practices that characterize the complexity of the Lean Manufacturing methodology. Following the suggestion of McCutcheon and Meredith (1983), only using this comprehensive scale it is possible to make relevant theory advancements, thus the first academic contribution is the creation and test of the Lean Manufacturing scale, that is composed by these bundles and practices:

- Infrastructure: Total Preventive / Autonomous Maintenance, Cleanliness, Multi-Functional Employees, Small Group Problem Solving, Employee Suggestions, Manufacturing-Business strategy linkage, Continuous Improvement, Supplier Partnership;

- Total Quality Management: Statistical Process Control, Process Feedback, Top-Management Leadership for Quality, Customer Involvement and Supplier Quality Involvement;
- Just-In-Time: Daily Schedule Adherence, Flow Oriented Layout, JIT links with suppliers, Kanban and Setup Time Reduction.

## **RQ 2: are Lean Manufacturing practices causal related? How? Why?**

The results presented in Chapter 2 demonstrate that the Infrastructure bundle acts as an antecedent of JIT and TQM bundles. This means that the Lean Manufacturing practices are causal related instead of only inter-related.

The academic contribution of this finding is related to the advancement of knowledge about how and why Lean Manufacturing bundles interact, going a step further in relation to the common vision based on a configural perspective, although not denying it.

Both of these perspectives are coherent with the Resource Based View Theory, since in both cases the combination of unique capabilities lead to a sustainable competitive advantage (Prahalad and Hamel, 1994). However, knowing that the implementation of the Infrastructural practices must precede the TQM and JIT ones because are causal related can give a clear view about how introduce the Lean Manufacturing methodology. As a matter of facts, the Infrastructure bundle permits to prepare the right production environment for the introduction of the TQM and JIT methodologies because it decreases the barriers related to the employees and managers cultural resistance to change (Crawford *et al.*, 1988).

The managerial contribution is that practitioners don't have to put all the efforts to implement all the Lean Manufacturing together, but they have to follow a precise sequence. This aspect is even more important when the company resources are scant (Skinner, 1969).

### **RQ 3: how does Lean Manufacturing improve operational performance? Why?**

### **RQ 4: how are operational performances related? Why?**

These two research questions are strongly related, because the answer to the first question depends on the answer to the second one. Indeed, there are not only causal relationships between Lean Manufacturing practices and operational performances, but also between operational performances themselves.

The results of the Chapter 2 demonstrate that the operational performances are causal related following the “sand cone” model (Ferdows and De Meyer, 1990). Quality directly improves delivery and indirectly improves flexibility and cost; delivery directly improves flexibility and indirectly improves cost; flexibility directly improves cost.

Lean Manufacturing improves operational performance in different ways: Infrastructural practices directly improve all the performance dimensions through Total Quality Management and Just-In-Time practices; Total Quality Management practices directly improve quality, while indirectly improve delivery, flexibility and cost; finally, Just-In-Time practices directly improves quality and delivery, while indirectly improve flexibility and cost.

These findings have academic and managerial contributions. The academic contribution is related to the empirical evidences given to support the “sand cone” model, a very famous model but strongly criticized and not proved yet. The managerial contribution is linked to how Lean Manufacturing practices are able to build a sustainable competitive advantage through a cumulative positive impact on operational performances and it is connected with the managerial contribution related to the second research question. As a matter of facts, if Infrastructure bundle represents the baseline of LM capabilities because antecedes JIT and TQM, the results suggest to implement the TQM practices to improve quality, and only at the end, the JIT practices could be introduced to foster the impact on quality and start to improve delivery capability. When all the Lean Manufacturing practices are introduces, managers have to continue to leverage on all the bundles, since all of them have indirect positive effects on the other performance dimensions.

**RQ 5: is Just-In-Time applicable in non-repetitive manufacturing contexts? In particular: how the contingent variables that represent the degree of manufacturing repetitiveness could affect the positive impact of Just-In-Time on operational performances?**

With the cumulative model I demonstrate the mechanism by which Lean Manufacturing can achieve maximum results on the operational performances.

However, there are circumstances where it is possible to find some weaknesses of the Lean Manufacturing system, especially as regards the Just-In-Time bundle of practices.

The results of the first trade-off model presented in Chapter 3 provide several implications for academics and practitioners. Even though the results confirm that Just-In-Time could be implemented in contexts characterized by a high degree of repetitiveness, and provide evidences about the positive effect of Just-In-Time on operational performances also in non-repetitive contexts, the same results highlight a possible problem of the methodology applicability when the demand variability is very high, while Just-In-Time is robust when considering the level of product customization. As a matter of fact, this study shows that the impact of Just-In-Time on efficiency and responsiveness is not the same in all the contexts, as demand variability reduces (negatively moderates) the positive effect of Just-In-Time on responsiveness, whereas does not necessarily alter the benefits of Just-In-Time on efficiency. Instead product customization does not significantly moderate the effect of Just-In-Time on operational. These findings can support managers that operate in non-repetitive contexts when they have to decide whether to implement or not Just-In-Time.

Just-In-Time has a positive impact on operational performance independently from the level of product customization, while it has limited effects on responsiveness with increasing of the demand variability level. As a consequence, managers have to consider the trade-off between efficiency and responsiveness because when the demand variability level is very high, Just-In-Time has a positive effect on efficiency but not on responsiveness. This trade-off requires to managers to choose whether to apply JIT depending on their competitive priorities.

**RQ 6: is there a moderating effect between Just-In-Time manufacturing and Just-In-Time supply that could lead to possible trade-offs on operational performances?**

The problems that arise when implementing Just-In-Time are not only related to contingent factors, such as the repetitiveness of the manufacturing context, but also could derive from particular practices interaction with the result of a non linear impact on operational performances.

The second trade-off model presented in Chapter 4 analyzed the interaction between Just-In-Time manufacturing and Just-In-Time supply practices to understand the effects of the application of Lean Manufacturing tools outside the firm's boundaries.

First of all, the results confirm that Just-In-Time manufacturing positively impact on efficiency and delivery performance. This is consistent with the stream of studies supporting that the concurrent adoption of many Lean Manufacturing practices has a positive effect on operational performance (Shah and Ward, 2007).

However, an interesting academic contribution is that Just-In-Time supply doesn't directly impact on operational performances, not confirming the common academic view. Instead, Just-In-Time supply acts as moderator on the relationship between Just-In-Time manufacturing and delivery. This means that for a practitioner point of view, it is important to leverage on Just-In-Time supply during the early stages of Just-In-Time manufacturing, but only when a certain level of Just-In-Time manufacturing is achieved managers have to strongly improve the level of Just-In-Time supply. In the contrary case, the practices shared with suppliers may not be useful. Moreover, the results suggest that the implementation of Just-In-Time supply doesn't affect efficiency neither directly nor interacting with Just-In-Time manufacturing.

This effect explain why I assert that the results highlight a possible trade-off between the two practices and their effect on efficiency and delivery performance. As a matter of fact, when efficiency is the priority, companies should direct their efforts only on Just-In-Time manufacturing. Instead, when their aim is to improve delivery, they should invest on both Just-In-Time manufacturing and Just-In-Time supply, bearing in mind that, managers to implement some Just-In-Time supply practices during the early stages of Just-In-Time manufacturing. Indeed, the total absence of any Just-In-Time

supply practice could cause significant disruptions in the production system, and in turn limit delivery improvement.

In summary, Just-In-Time supply interacts with Just-In-Time manufacturing strengthening the positive impact of Just-In-Time manufacturing on delivery through a complementary effect. Moreover, a low level of adoption of Just-In-Time supply practices can hinder and – for extremely low levels - cancel the impact of Just-In-Time manufacturing practices on delivery.

These academic and managerial contributions are in line with the other ones explained above.

Lean Manufacturing is a methodology that permits to achieve maximum results on all the dimensions of operational performance, but this happens only when managers understand the right sequence of Lean Manufacturing practices implementation, and only when they have clearly defined their priorities and understood in what kind of context they operate.

Infrastructural practices are the precursor of any other practice introduction because prepare the right environment for the production system change. After that, Total Quality Management practices could be introduced to improve the baseline of the competitive capabilities (i.e. quality performance). Then, Just-In-Time could be introduced or not depending on the manufacturing context. Indeed, if demand variability is very high, the impact of Just-In-Time could be negative on responsiveness (delivery and flexibility). Moreover, even though the demand is stable, managers that want to implement Just-In-Time, have to consider again the right introduction sequence as explained before.

However, if the only priority of a company is cost reduction (and efficiency), and the resources are very scant, my results suggest to introduce only Just-In-Time manufacturing, because this bundle alone could have a positive effect on this performance.

But to compete global competitors, a company have to consider multiple priorities. Thus, a sustainable competitive advantage could be achieved leveraging with all the Lean Manufacturing practices.

Limitations and future research are discussed at the end of every chapter.

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[2] "Lean first, then automate": a framework for process improvement in pure service companies. A case study. *Production Planning & Control*, ISSN: 0953-7287, DOI:10.1080/09537287.2011.640040 (in press) (in collaboration with P. Romano)

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[3] *Lean First, Then Automate: An Integrated Model for Process Improvement in Pure Service-Providing Companies*. In: Bruno Vallespir, Thecle Alix. Advances in production management systems. New challenges, new approaches IFIP Advances in Information and Communication Technology, 2010, Volume 338/2010, pp. 579-586, doi: 10.1007/978-3-642-16358-6\_72, Springer ISSN 1868-4238 (APMS2009 Best Paper Award) (in collaboration with P. Romano e B. Nicoletti).

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