POLITECNICO DI MILANO
School of Industrial and Information Engineering
Master of Science in Management Engineering

Is Lean Manufacturing the vaccine against disruption?
A study based on SEM technique

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Academic Year: 2018/2019

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude and admiration for my supervisor, Professor Paolo Trucco, for giving me the opportunity to work on this topic. Your guidance, competence and valuable advices during our meetings were essential for carrying out the thesis.

Particularly, I want to thank my co-supervisor, Fabiana Dafne Cifone. Besides being an extremely knowledgeable practitioner, your passion, words of encouragement and relentless support really made a difference in the final outcome.

I want to thank my family for giving me the possibility to pursue my dreams. Everything you did for me made me the person that I am today and I will be forever grateful to you.

Lastly, I want to thank all my friends, mainly from Italy and Spain. Thank you for the great memories and experiences shared together, I feel blessed to have you by my side.

In my life, my personal motto has always been:

"Without commitment you never start,

without consistency you never finish."

However, in these years I have learnt an important lesson:

"Without your loved ones, you go nowhere."

ABSTRACT

Purpose: In the last few years the frequency and the severity of disruptions have increased, thus negatively affecting the performance objectives of firms. Within this context, the role played by Lean Manufacturing is still ambiguous. The thesis aims at unfolding the adequacy of efficiency-driven operations strategies for the management of operational disruptions, leveraging on the resilience concept and operationalisation.

Design/methodology/approach: The research method consists of an empirical assessment of critical incidents suffered by firms with a purely statistical approach. In particular, the adopted technique is the Structural Equation Modelling that allows the evaluation of relationships between production paradigms, namely Lean Manufacturing and resilience, and the performance variation upon disruption.

Findings: First and foremost, the study refutes the common misconception that a Lean company is more sensitive to disruptions. The analysed firms indeed show a direct positive relationship between Lean and performance under disruption. In particular, the implementation of internally-related practices mitigates the performance variation in a significant way. Moreover, there is no evidence of relationship between Lean Manufacturing and operational resilience which, instead, gives importance to the role of collaboration with partners as the most effective mean for responding to a disruption. Finally, an analysis of contingent effects shows lack of strategic approach with regards to resilience, largely attributable to a low maturity level.

Limitations and future developments: Secondary-data collection and insufficient sample size do not allow to properly investigate and uncover all the existing relationships and stratify the analysis. The use of complementary approaches is advocated.

Practical implications: Findings provide guidelines to firms about which management practices are more impactful under disruption and which contextual factors are to be considered when making design decisions.

Value: The study contributes in the research field of risk and disruption management shedding light on the apparent paradox of Lean approach in a disruptive context through empirical quantitative evidence.

ABSTRACT (Italiano)

Obiettivo: Negli ultimi anni la frequenza e l'intensità delle disruptions sono aumentate, compromettendo quindi gli obiettivi di performance delle aziende. All'interno di questo contesto, il ruolo della produzione Lean è tuttora ambiguo. La tesi mira a spiegare l'adeguatezza di strategie operative guidate dall'efficienza per la gestione di disruptions, facendo leva sul concetto e operazionalizzazione della resilienza.

Progettazione/metodologia/approccio: Il metodo di ricerca consiste in una valutazione empirica di incidenti critici sofferti da aziende con un approccio puramente statistico. In particolare, si adotta la tecnica di Structural Equation Modelling che consente la valutazione di relazioni tra paradigmi produttivi, ovvero produzione Lean e resilienza, e la variazione di performance a seguito di una disruption.

Risultati: Innanzitutto, lo studio confuta il comune pregiudizio che una compagnia Lean è maggiormente sensibile a disruptions. Le aziende analizzate mostrano infatti una diretta relazione positiva tra Lean e performance in disruption. In particolare, l'implementazione di pratiche interne all'azienda mitiga la variazione di performance in maniera significativa. Inoltre non c'è evidenza di una relazione tra produzione Lean e resilienza operativa che, invece, dà importanza al ruolo della collaborazione con i partner come il mezzo più efficace per rispondere a una disruption. Infine, un'analisi degli effetti contingenti mostra un mancato approccio strategico per quanto riguarda la resilienza, dovuta soprattutto a uno scarso livello di maturità.

Limitazioni e sviluppi futuri: La raccolta di dati secondari e la dimensione del campione insufficiente non permettono di studiare e scoprire propriamente tutte le relazioni esistenti e di stratificare l'analisi. L'utilizzo di approcci complementari è raccomandato.

Implicazioni pratiche: I risultati forniscono linee guida alle aziende riguardo quali pratiche manageriali hanno un maggiore impatto in disruption e quali fattori di contesto devono essere considerati quando si prendono decisioni di progettazione.

Valore: Lo studio dà un contributo nel campo di ricerca sulla gestione del rischio e della disruption facendo luce sull'apparente paradosso dell'approccio Lean in un contesto di disruption attraverso un'evidenza empirico-quantitativa.

SUMMARY

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

1 INTRODUCTION

Today’s business environment is becoming increasingly complex and turbulent. Markets are indeed integrated into a global economy that leads to high level of interconnection among organisations. Transactions are facilitated by technological advancements and customers are more and more demanding in terms of requirements fulfilment. Moreover, uncertainty can be observed through the occurrence of disruptive events that cannot be predicted, but still have serious consequences for the businesses.

Within this operating scenario, the unit of analysis for the research is the efficiency-oriented firm adopting the Lean Manufacturing paradigm. The firm is hence challenged to cutting costs in order to stay competitive while simultaneously guaranteeing the continuous generation and delivery of value regardless of disruptions. The purpose of the research is, therefore, uncovering the role of Lean Manufacturing in a disruptive operating context.

The contents of the research are organized as follows. In Chapter 2, literature review is presented, constituting the basis on which the research is designed. The production paradigms of Lean Manufacturing and operational resilience are here introduced and explained, from the historical origin to the main principles and formative elements. In addition, the Contingency theory is also introduced explaining how it fits the two production paradigms. Chapter 3 introduces the research framework in which the research objective and research hypotheses are formulated after having defined the frame of reference and the operationalisation of constructs. In Chapter 4 all the necessary phases for carrying out the analysis are introduced, from the introduction of the model to its specification and assessment, passing through the phase of data collection. Chapter 5 contains the findings of the research which are then deeply discussed in Chapter 6 through an explanation of the outcomes and a comparison with the existing literature to identify similarities or discrepancies. The research process concludes with Chapter 7 in which implications of the research from theoretical and practical perspectives are reviewed with special attention to the limitations and the future steps.

2 LITERATURE REVIEW

2.1 Lean Manufacturing

Since the first time the concept of Lean was introduced, more than thirty years ago, lean manufacturing has become so widespread that even its critics admitted that lean was going to be the universally accepted standard for manufacturing activities (Shah and Ward, 2007).

In this research lean manufacturing is meant as a comprehensive system made of multiple managerial practices, more than just being a set of tools (Rüttimann and Stöckli, 2016). In particular, it can be defined as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability" (Shah and Ward, 2007, p. 791).

2.1.1 History

The term "Lean" was coined by Krafcik (1988), researcher at the Massachusetts Institute of Technology (MIT) for the International Motor Vehicle Program (IMVP), in order to refer to a manufacturing approach that uses less resources of everything compared to mass production.

However, it was an already existing concept given that it originally appeared in the 1940's in Japan, within the Toyota Production System (TPS).

During and after the World War II, the Toyota Motor Company (TMC) found itself in a fiercely competitive context imposed by mass production systems. Then, it started a thorough study of the American automobile industry, eventually resulting into an alternative production system referred to as the TPS (Ohno, 1988). The main idea lying behind the TPS is that only a small fraction of the total time and effort employed to process a product adds value to the end customer (Melton T., 2005).

The Just-in-Time (JIT) philosophy was developed in the framework of this new production system that contradicted the consolidated production paradigms in the Western world, based on the mass production philosophies originally developed by Henry Ford in 1913. Mass production systems tend to maintain long production runs with standard designs in order to achieve a lower cost for the customer. Alternatively, Lean producers are able to reduce the human effort thanks to automated systems which allow to produce larger volumes with higher product variety.

Taiichi Ohno, founder of the TPS, kept on working on its development supported by the continuous technological breakthroughs in the 1980s and companies gradually started to apply this model to their production systems (Monden, 1998; Sanchez and Perez, 2001).

The advent of computer played a key role in the shift to LM since customers set stricter standards whose satisfaction was possible through a new paradigm able to guarantee large product variety, high quality and quick responsiveness at low costs (Spencer and Guide, 1995).

The early 1980's carried out new research in the manufacturing field whose main topic was "Lean manufacturing" (LM), a fresh manufacturing philosophy capable of leading to operational excellence. However, there was a blurred line between the TPS, first introduced by Toyota, and LM, which proposes itself as an original production paradigm.

Womack et al., (1990) in the book "The Machine That Changed the World" clarified the issue regarding the relationship between leanness and its predecessors. The authors acknowledge the paternity to TMC in initiating the TPS and the JIT principle and LM is not presented as a substitute, but rather as an improved version.

Evidence of communality can be found by comparing the definitions of JIT and LM provided by the American Production and Inventory Control Society (APICS) Dictionary. JIT is defined as:

> a philosophy of manufacturing based on planning elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product from design engineering to delivery and including all stages of conversion from raw material onward. The primary element of JIT is to have only the required inventory when needed; to improve quality to zero defects; to reduce lead times by reducing set-up times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum costs.

On the other hand, LM is defined as:

> a philosophy of production that emphasizes the minimization of the amount of resources (including time) used in the various activities in the enterprise. It involves identifying and eliminating non-value adding activities in design, production, supply-chain management, and dealing with the customers. Lean procedures employ teams of multi-skilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety.

As can be observed, JIT and LM present common features such as flexibility, elimination of waste, optimization, monitoring of process and involvement of people, as expressed by Womack in defining the concept of "Lean Thinking" in his follow-on book (Womack and Jones, 2003).

If "The Machine That Changed the World" compares the TPS with the traditional Western mass production systems highlighting the superior performance of the former (Melton, 2005), "Lean Thinking" summarises the main principles to be followed when implementing the Lean philosophy (Melton, 2005).

This work goes one step further by summarizing the main principles that have to be followed inside an organisation in order to implement the Lean philosophy in a correct way (Melton T., 2005). Another important contribution made by this last book is the demonstration of the universal applicability of the Lean approach that can be applied in various industries other than the automotive one.

In conclusion, the introduction of the Lean production was able to disrupt the until-then-accepted mass production practices in the automotive sector, but it also triggered the rethinking of manufacturing and service operations system beyond the high-volume low-variety environment (Holweg, 2007).

2.1.2 Types of waste

As stated by Shah and Ward (2007), the main goal of Lean Manufacturing is the elimination of waste. Waste, also called "Muda" in Japanese, consists of any resource-consuming activity that does not create value for the customer (Holweg and Maylor, 2018). According to literature, there are seven main types of waste that appear in manufacturing processes and overall supply chains (SCs). Additionally, the list considers an eighth type of waste, which is related to the skills of the workers in the organisation and not directly connected to the manufacturing process.

The eight wastes are the following:

1. Transport: unnecessary movement of products and materials from a location to another or between operators that does not create value to the customer since the product is not being processed.

2. Waiting: waiting time for people, equipment or products for the processing operation that does not represent an added value to the customer.

3. Motion: excessive physical movement of a machine or person non-value adding or excessive movement of data, decisions and information.

4. Inventory: stock of finished goods, work in progress and raw materials subject to the obsolescence risk while waiting for a customer order.

5. Overprocessing: any activity, such as rework of defects and reprocessing of obsolete inventory, not required by the customers.

6. Overproduction: production that is more than needed or before it is needed or development of a product, process or manufacturing facility that has no additional value

7. Defects: process errors that require either re-work or additional work

8. Skills: underutilisation of people's talent, skills and knowledge.

The elimination of waste is possible by means of a continuous improvement process in which it is essential to identify the root cause, not just the symptom (Melton, 2005). Generally, waste reduction means less defects and reworked pieces, fewer process breakdown, more empowered and satisfy employees and lower level of inventories. As a consequence, manufacturing cost are reduced, customer satisfaction improves and profits increase.

2.1.3 Lean principles

In order to eliminate in a systematic way the eight sources of waste through continuous improvement, there are five actions to be pursued, called “Lean Principles” (see Figure 1) (Womack and Jones, 1996). The first principle is to specify the value as perceived by the customer. Then, the second principle establishes the identification of the value stream for each product. The third principle refers to the creation of a continuous flow within the system. The fourth principle seeks for a flow that is pulled by the customer. Finally, the fifth principle consists of the pursuit of perfection. The Lean principles need to be applied on an iterative way, coherently with the continuous improvement logic.

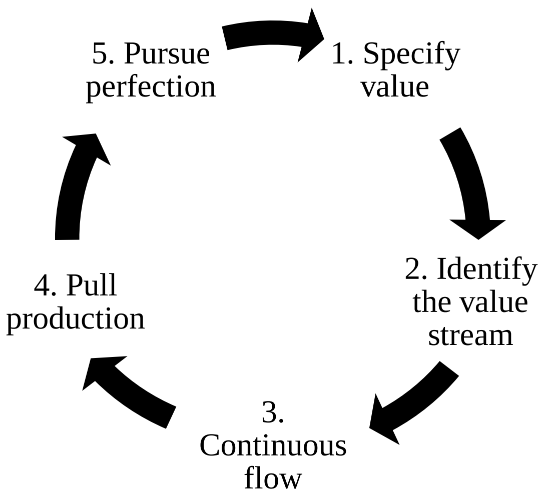

Figure 1. The five "Lean principles"

2.1.3.1 Specify value

According to Melton (2005), the starting point for the application of the Lean philosophy is the identification from the customer of value that represents what he is actually willing to pay for. The value is therefore no more defined from an internal perspective that accounts for the cost structure, but from an external one that, in accordance with the perception of the customer, sets the maximum level of costs the company can afford.

Customer can be either external, so the one to which the product is sold, or internal, such as other departments within the organization or legal and regulatory authorities. Anything that has no value for the customer is a waste.

2.1.3.2 Identify value stream

The second step after defining what is valuable for the customer is to map the value stream, that is the flow of interconnected transformation activities required to provide value for the customer (Lovelle , 2001). There are three main flows which create value for customers: developing and introducing new products and services; managing information from customer's order to delivery; managing product or service realization from the input elements to the final output.

Each activity can be classified into three categories: value adding, non-value adding unavoidable in the short-term that should be optimised and non-value adding avoidable in the short-term that should be eliminated. After the third category has been eliminated, the second category should be addressed through flow, pull and perfection techniques (Womack and Jones, 1996).

2.1.3.3 Continuous flow

Once the non-value adding activities are eliminated, the remaining activities have to be arranged in a flow, able to guarantee a flawless delivery of products without delays, waiting or any other interference. According to Womack and Jones (1996), the flow must focus on the product ignoring job boundaries and departments and requires the redesign of work practices to eliminate backflow, scrap and stoppages that prevent a smooth flow from raw material to finished product.

2.1.3.4 Pull production

Pull means that no one upstream should produce anything until the client downstream asks for it (Womack and Jones, 1996). This concept contrasts with the logic of push system that lies on the forecast of the demand, but, given the inaccuracy of forecast, this way of operating generates waste.

The lean philosophy shifts the attention from the improvement of forecast to the increase of response capacity that enable the adjustment of the production to the level of the demand. A system should ideally produce only when the customer makes the order, thus the production must be pulled by the actual market demand (Spearman and Zazanis, 1992) by means of tools such as kanban and supermarkets.

2.1.3.5 Pursue perfection

The systematic and recurrent application of the aforementioned four principles is the requirement for the achievement of perfection. In particular, it is important to define step-wise goals and projects to accomplish the ideal vision of perfection assuming a day-by-day perspective (Womack and Jones, 1996)

2.1.4 The house of lean

Lean Manufacturing is a multi-dimensional managerial approach aimed at creating a streamlined system that produces high-quality finished products consistently with the customer demand and with little or no waste (Shah and Ward, 2003). True enhancement is obtained when the wide variety of management practices are synergistically exploited within an integrated system (Womack et al., 1991). A list of the most popular Lean tools and techniques implemented by companies is presented in Table 1 below.

Lean tool / technique	Description
5S	Organised approach to housekeeping that ensures tools, parts and other objects are in know, optimum locations.
Value stream mapping	Visual description of material and information flow within the value chain in order to identify waste.
SMED	Method for the reduction of downtime and cost related to the setup process.
Poka Yoke	Mechanism for the prevention of the occurrence of mistakes and defects.
Work standardisation	Degree of formalisation of roles, work specifications and procedures to reduce variation in the work method.
Kanban	Scheduling system in which the production order is triggered when items are withdrawn from a downstream process
Visual management	Visual representation of targets, standards and specifications through signs, signals and controls.
One-piece flow	Movement of a single workpiece among operations within a workcell with no accumulation of inventory.

Table 1. List of Lean tools and techniques

In an endeavour to summarise the philosophy and the principles of lean thinking, LM is graphically described by Liker and Jeffrey (2004) as a house (Figure 2). The roof of the house, representing the objectives that LM intends to pursue are sustained by two pillars: Just-in-Time and Jidoka. The middle area consists of continuous improvement achievable through the empowerment and collaboration of people and a systematic process of waste reduction. The foundations of the house are represented by two main concepts that are Levelled Production (Heijunka) and Stable and Standardized Processes.

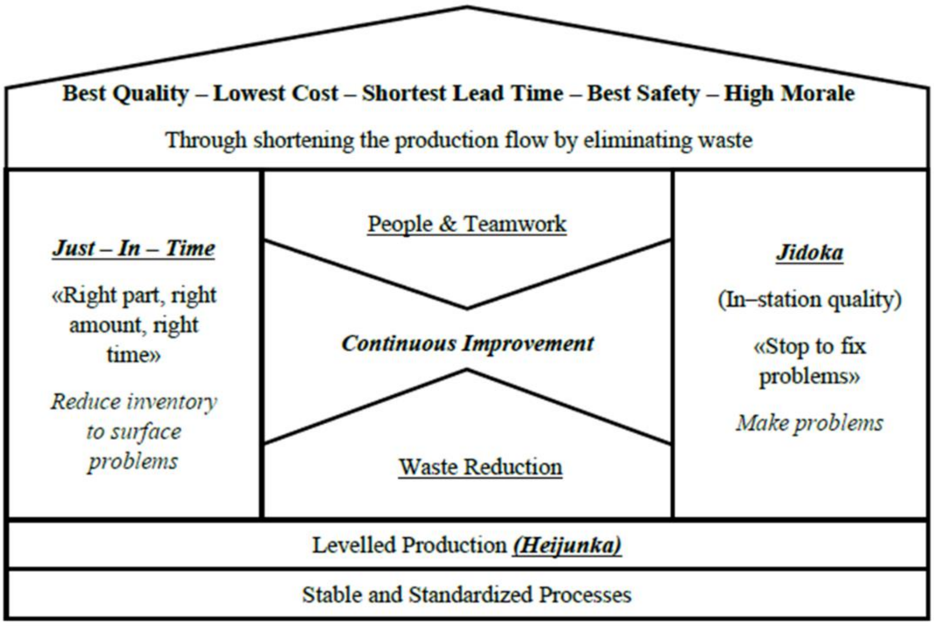

Figure 2. The House of Lean (Liker, 2004)

Such representation evokes the idea of integrated system in which all parts work together in order to guarantee the equilibrium of the whole system. A single flawed component is enough to make the system unstable.

2.1.5 Lean management in the value chain

Given the consolidated evidence of LM bearing a direct relationship with improvement in operational performance (Birkie et al., 2017; McKone et al., 1999; Shah and Ward, 2003; Shah and Ward, 2007), companies started to change their production methods and management practices to become leaner (Bhasin and Burcher, 2006).

Nevertheless, different cases of failed Lean implementation occurred because companies did not seize the true nature of LM. In fact, Womack et al. (1990) spread the concept of LM, but there was lack of details about the methods for its achievement (Bhasin and Burcher, 2006).

In particular, a “cocktail of factors” are needed for a successful implementation of Lean (Bhasin and Burcher, 2006, p. 56) . First of all, it is important for companies to embrace most of the available Lean practices and techniques, such as kanban, cellular manufacturing, single minute exchange of die (SMED), 5S and value stream mapping. Aside from the technical requirements, the corporate culture require a radical transformation as well. The organisation has to foster a learning environment, develop lean leadership, empower employees with responsibilities and granted decisional power and nurture relationships with external players out of the boundaries of the company.

Furthermore, another important aspect to take into account is that Lean cannot be universally applied, but it is necessary to consider contingent aspects related to the operating environment since some practices are dependent on the context (Sousa and Voss, 2002). Examples of factors that require attention when implementing LM are the firm size (Azadegan et al., 2013; Shah and Ward, 2003; White, 1993), the national context and culture (McKone et al., 1999; Zhang et al., 2012) and the firm age (Azadegan et al., 2013; Shah and Ward, 2003, Zhang et al., 2012).

For these reasons, researchers aimed at developing classification schemes and As the focus on leanness was continuously gaining momentum the need arose for a specific roadmap that could guide companies through their attempt to achieve the adoption of the lean model. In response to this need of operationalising Lean, LAI produced an extensive transition roadmap in 2000 (MIT, 2000), classification schemes were provided (Papadopoulou and Özbayrak, 2005; Shah and Ward, 2003; Shah and Ward, 2007) and papers such as White and Prybutok (2001) identified the critical implementation elements of JIT philosophy.

Being originally envisioned for a manufacturing context, Lean has been mainly implemented on the production shop floor where wastes were more tangible, thereby easier to remove. At the beginning, firms start by experimenting LM with pilot projects on the shop floor and then it is extended to the remaining corporate processes in order to create an integrated management system as advocated by the proponents of lean production.

In this case, the challenge is the shift of perspective from process-level to company-level in order to avoid an excessive focus on localised optima that do not lead to firm-level improvements. Hence, the introduction of Lean requires to tackle specific process features inside the company (Pullin, 2002), but at the same time the cultural transformation must embed the entire organisation's value chain (Bhasin and Burcher, 2006). Therefore, LM is effective only by means of a holistic organisational approach (Liker, 2004) due to the change of unit of analysis from the production process to the value chain.

The value chain is a high-level model developed by Porter (1985), used to describe the process by which an input, i.e. the raw material received from suppliers, is transformed into a valuable output, i.e. the finished product, through a series of activities and then eventually sold to the customer.

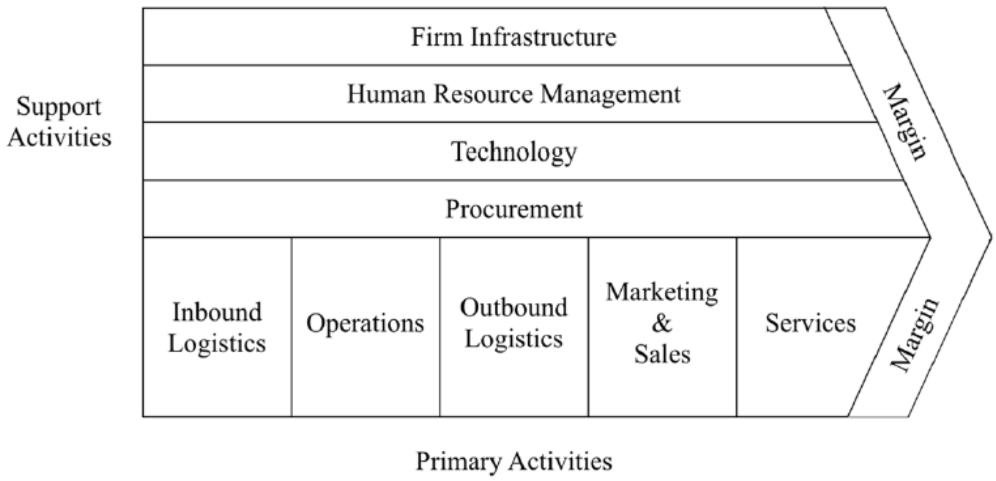

Figure 3. Value chain of an organisation (Porter, 1985)

As it is possible to observe in Figure 3, and according to Porter (1985), each organisation comprises five main primary activities and four main support activities in its value chain. The former ones contribute in adding value and creating competitive advantage, while the latter ones facilitate the efficiency of the primary activities.

This model is exploited by companies in order to understand where value is generated within the chain with the purpose of creating competitive advantage and delivering maximum value at the lowest cost. In reference to LM, the value chain model represents a valuable reference framework for the implementation of Lean practices when a company is considered as element of a bigger ecosystem that is the supply chain (SC).

However, the application of Lean principles has further extended over time by going beyond the internal boundaries of the single organisation and moving upwards and downwards in the SC. Hence, the current form of leanness has evolved from "Lean Manufacturing" to "Lean Enterprise".

Actually, the term "Lean Enterprise" was launched in Womack et al. (1990) to describe the extension of lean approach outside the internal context of the individual firm, but the Lean enterprise model was not followed by further specifications because the main priority at the time was the development of an operational roadmap for the Lean implementation (Papadopoulou and Özbayrak, 2005).

A lean enterprise can be defined as "a business organization that delivers value to its stakeholders, with little or no superfluous consumption of resources (materials, human, capital, time, physical plant equipment, information, energy)" (Helling, 2001; MIT, 2000; Richards, 1999). It is therefore a firm that, in conjunction with the continuous improvement and waste reduction, has to overcome the challenges stemming from globalisation and market competition by developing agile and responsive capabilities.

The concept of Lean enterprise takes place in a SC context where Lean practices and principles are applicable to the whole SC, from the provider to the final customer delivery, leading to what is known as Lean Supply Chain Management (SCM) (Ruiz-Benítez et al., 2018).

2.1.6 Lean benefits

Benefits related to the implementation of LM are well documented in literature and can be summarised as follows (Melton, 2005):

- Decreased lead times for customers;
- Reduced inventories for manufacturers;
- Improved knowledge management and process understanding;
- Less process waste;
- More robust processes (as measured by less errors and, therefore, less rework);
- Financial savings.

In order to evaluate the impact of LM in terms of performance, we assume business performance to be composed by two main dimensions: efficiency and effectiveness (Möller and Svahn, 2003; Möller and Rajala, 2007; Provan and Kenis, 2008). Efficiency and effectiveness can be described considering the business functioning and/or the perceived outcome (Mouzas, 2006). Efficiency measures the usage of resources when providing a set level of customer satisfaction, while effectiveness refers to the degree of satisfaction of customer's requirements (Neely et al., 2005).

Literature shows that LM positively influences mainly the efficiency side of performance of firms (Cua et al., 2001; Shah and Ward, 2003; Womack and Jones, 2003). In fact, its implementation, that encompasses all process from product design to product sale (Carvalho et al., 2011), maximizes profits through cost savings driven by waste reduction. Wastes, which result into higher cost, lead-time as well as lower quality (Fullerton et al., 2014), are minimized through the application of Lean practices. Therefore, being LM an efficiency-based approach, it is straightforward to state that it has a positive effect on all the efficiency performances of a company (Liker, 2004; Womack and Jones, 2003).

In conclusion, LM is a well-known managerial approach recognised to have a strong positive impact on firms' efficiency performances, while it has been argued that it is in a trade-off relationship with effectiveness performances. For instance, the relentless reduction of inventory exposes the company to a higher degree of vulnerability in case of disruption, thus resulting in the interruption of the continuous flow of activities. Due to the instability characterising the operating environment of companies, this theme is increasingly more relevant nowadays and it will be deepened in the subsequent paragraphs where the concept of Lean Manufacturing is analysed in conjunction with the concept of operational resilience.

2.2 Operational resilience

2.2.1 Introduction

The concept of resilience is a popular term applied in different knowledge domains such as ecological studies (Holling, 1996), psychology (Coutu, 2002), engineering (Hollnagel, 2006), and supply chain management (Sheffi and Rice, 2005). The expression experimented a significant leap in term of diffusion within the scientific literature of management research after 9/11 (Christopher and Peck, 2004) and same happened after the 2008 global financial crisis (Park et al., 2013).

The unpredictability and rapidity of change rate in the current business landscape represent a challenge for firms and supply chains. Uncertainty and environmental turbulence originate from either within the business or supply chain in question, or from the external environment. They can occur at supply-side, demand-side or internal operations including control processes (Childerhouse and Towill, 2004).

Furthermore, another critical factor to be accounted is the strong inter-dependence among businesses that amplifies the impact of unwanted consequences from sources previously considered as negligible (Trkman and McCormack, 2009). Hence. the object of analysis is not the single firm, but rather the ecosystem of interacting firms, namely the supply chain.

Examples of uncertainties and environmental turbulence are supplier bankrupts, changing customer preferences, technological shifts, new regulatory requirements, financial crises and terrorist actions.

An important tool to study the uncertainty on the demand and supply is the model developed by Lee (2002) which studies the uncertainty based on the demand- and supply-side and subsequently identifies four SC strategies (Figure 4).

The drivers of demand uncertainty are product lifecycle, average forecast error, average stockout rate, contribution margin and product variety. Instead, from the supply side

Supply Uncertainty	Demand Uncertainty: Low (Functional Products)	Demand Uncertainty: High (Innovative Products)
Low (Stable Process)	Grocery, basic apparel, food, oil and gas	Fashion apparel, computers, pop music
High (Evolving Process)	Hydro-electric power, some food produce	Telecom, high-end computers, semiconductor

Figure 4. The Uncertainty framework: examples (Lee, 2002)

perspective the drivers to consider are the level of maturity of processes and technologies, the number and the type of relationship with suppliers are the variability of the cost of raw materials. Once determined these two dimensions, the four possible SC strategies are:

- Lean SC, aimed at maximising the efficiency of total logistics cost by pursuing economies of scale, eliminating non-value adding activities, centralising management and controlling stocks;
- Risk-hedging SC, able to hedge against supply uncertainty thanks to resources and risk pooling and sharing;
- Responsive SC, based on the reactivity and flexibility necessary to cope with the changing customer needs.
- Agile SC, representing a hybrid strategy between Risk-hedging and Responsive.

In recent years, several major trends contributed in increasing the importance of supply chain risk management (SCRM), including phenomena such as globalization, outsourcing and transitioning to lean and agile operations.

Supply chain resilience is one of the core elements of SCRM and deals with risks of different nature at multiple stages of the risk management process within the SC context. The resilience perspective must also be examined since it is becoming a top priority issue for many firms as an effective way for mitigating disruptions (Chopra and Sodhi, 2014).

2.2.2 Supply chain risk management and supply chain resilience

Both SCRM and Resilience are essential to every organization, and applicable in different circumstances, but they show structural differences that are presented in this paragraph. It is, however, necessary to first introduce the concept of risk and the two main types.

Uncertainty is a condition in which there is lack of certainty about a phenomenon or its consequences (Paté-Cornell, 2012), not allowing the decision maker to make a definitive decision. Risk is the potential of unwanted negative consequence of an uncertain event or activity.

The risk is usually assessed through a two-dimensions matrix (Figure 5), developed by Norrman and Jansson (2004), that considers as dimensions the severity of the consequence of the scenario and the likelihood of the scenario to happen.

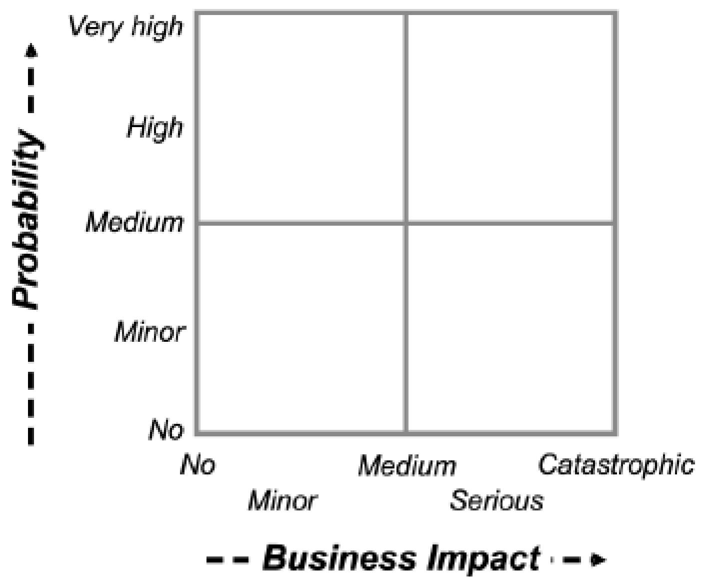

Figure 5. Risk matrix (Norrman and Jansson, 2004)

Two main categories of risk emerge: operational and disruption risk. The operational risk focuses on the single firm, while the disruption risk shifts the focus to the whole supply chain. Considering the risk matrix, the operational risk is typically related to a low business impact and low probability. On the other hand, the disruption risk is related to incidents, such natural and man-made disasters (e.g. earthquakes or economic strikes) (Tang, 2006), characterised by high business impact, but low probability.

Each category has its own drivers and mitigation strategies. In particular, Risk Management addresses the operational risk, while Resilience addresses the disruption risk. The main differences have been investigated by Park et al. (2013) and shown in Table 2.

	Risk Management	Resilience
Design principles	Preservation of status quo, that is, avoid transformative change; minimise risk of failures	Adaptation to changing conditions without permanent loss of function (e.g., changing paths, if not destinations) Acknowledgement of unknown hazards. Intentional failure may be allowed at subsystem level to reduce the possibility of permanent loss of function in larger system
Design objectives	Minimisation of probabilities of failure, albeit with rare catastrophic consequences and long recovery times	Minimisation of consequences of failure, albeit with more frequent failures and rapid recovery times
Design strategies	Armoring, strengthening, oversizing, resistance, redundancy, isolation	Diversity, adaptability, cohesion, flexibility, renewability, regrowth, innovation, transformation
Relation to sustainability	Security, longevity	Recovery, renewal, innovation
Mechanisms of coordinating response	Centralized, hierarchical decision structures coordinate efforts according to response plans	Decentralised, autonomous agents respond to local conditions
Modes of analysis	Quantitative (probability-based) and semiquantitative (scenario-based) analysis of identified hazards in context of utility theory (i.e. costs and benefits)	Possible consequence analysis of involving scenarios with unidentified causes

Table 2. Comparison of Risk and Resilience perspectives (Park et al., 2013)

In particular, considering the context of interest of supply chain, Risk Management takes the name of Supply Chain Risk Management (SCRM). Several definitions of SCRM exist in the scientific literature. For example, the one formulated by Jüttner et al. (2003) and Jüttner (2005) has become popular and widely adopted by other authors in their research (Manuj and Mentzer, 2008). SCRM is here defined as “the identification of potential sources of risk and implementation of appropriate strategies through a coordinated approach among supply chain members, to reduce supply chain vulnerability”.

An alternative definition of SCRM is proposed by Norrman & Jansson (2004) that introduces the concept of risk and uncertainty and the managerial process to deal with: “Supply Chain Risk Management is to collaborate with partners in a supply chain apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources”.

In order to manage the SC risk in a global context, Manuj and Mentzer (2008) elaborate a five-step model for global supply chain risk management. Those five steps include risk identification, risk assessment and evaluation, selection of appropriate risk management strategies, strategy implementation, and mitigation of supply chain risks

2.2.3 Limitations of traditional risk management

Previously, business environments were stable with moderated amounts of variations. Most companies developed plans to protect against recurrent, low-impact risks in their supply chains, but ignoring high-impact, low-likelihood risks. Methods such as forecasting, excess inventory, excess capacity and redundant suppliers were developed under this assumption. Within this scenario, the main challenge for managers is to handle the trade-off between risk mitigation and cost reduction, but they tend to ignore the disruption risk in case of lack of a thorough risk assessment (Kunreuther, 1976).

However, the concept of operational resilience has become popular due to the increase, both in frequency and in severity, of unexpected events in the global business context (Juttner and Maklan, 2011). The past few decades have witnessed an increasing level of globalisation and a higher rate of innovation resulting into a higher degree of complexity, connection and interdependency among firms in the SC (Blackhurst et al., 2005; Wagner and Bode, 2006; Christopher et al., 2011).

Consequently, SCs have become highly vulnerable to disruption risks that have never been accounted before. Traditional risk management approaches prove to be not effective in this new competitive scenario where unexpected incidents have significant implications on businesses. In fact, reactive approaches are costly and not successful, while proactive approaches require investments with low returns. Additionally, this type of hazard can only be observed after it has happened, thus nullifying the quantification of risks and uncertainties.

In conclusion, Risk Management approach is not sufficient to manage a highly unpredictable environment characterised by disruptive events whose causes and consequences are unknown. Businesses nowadays face the challenge of being not only efficient, but also resilient to disruptions in the SC, thus investigating about how to make firms operationally more capable of fulfilling their business targets despite the occurrence of unexpected events.

2.2.4 Different resilience perspectives

The concept of resilience has been developed through a research process lasting over a century and involving multidisciplinary interpretations on the topic. Earlier contributions on the current meaning of resilience come from at least three different fields: psychology, ecological studies (Birkie et al., 2014).

The term “resilience” was initially applied only in the materials engineering field in order to indicate the thermodynamic work required to cause elastic deformation in a solid material (Hollnagel, 2006). Then, Holling (1973) redefined resilience in the context of ecology.

Holling (1973) interpreted resilience as the characteristic of an ecosystem that allowed it to absorb shocks or changes in external or internal forcing (e.g. invasive species, habitat fragmentation and loss of biodiversity) without causing a change in its normal relationships.

Thanks to Holling’s seminal work, the term rapidly started to be used in new contexts such as psychology (Park et al., 2013). The psychological perspective on resilience studies how people react to stressful circumstances from an emotional and psychological point of view (Coutu, 2002).

2.2.5 Resilience in supply chain operations

Considering SC and operations as contexts of reference, from now on we use resilience and operational resilience as synonyms. Operational resilience has a multifaceted nature reflected into different perspectives (e.g. organisational, strategic, systems engineering and so on), as can be seen in Table 3.

Being an emerging concept within a broader supply chain risk management research stream, a large number of normative and descriptive definitions about operational resilience have been developed and summarised in Table 4.

Perspective	Literature with explicit definitions	Literature with implicit definitions	Total
Strategic	4	2	6
Organisational	10	3	13
Supply chain	7	11	18
Business continuity	7	5	12
Infrastructure	6	-	6
Engineering	2	-	2

Table 3. Literature views on operational resilience (Birkie et al., 2014)

Source	Operational resilience definition
Starr et al. (2003)	"The ability and capacity to withstand systemic discontinuities and adapt to new risk environments"
Fiksel (2003)	"The capacity of a system to tolerate disturbances while retaining its structure and function"
Hamel and Välikangas (2003)	"Resilience refers to the capacity for continuous reconstruction. It requires innovation with respect to those organisational values, processes and behaviours that systematically favour perpetuation over innovation"
Christopher and Peck (2004)	"The ability to cope with the consequences of unavoidable risk events in order to return to its original operations or move to a new, more desirable state after being disturbed"
Peck (2005)	"Resilience means to respond and recover at the same or better state of operations and thus includes system renewal"
Alberts (2011)	"Resilience provides an entity with the ability to repair, replace, patch, or otherwise reconstitute lost capability or performance (and hence effectiveness), at least in part over time, from misfortune, damage or a destabilizing perturbation in the environment"
Jüttner and Maklan (2011)	"The ability to overcome disruptions by means of flexibility, velocity, visibility and collaboration"

Pettit et al. (2013)	“The capacity of an enterprise to survive, adapt and grow in the face of change and uncertainty”
Gilly et al. (2014)	“First, a reactive capacity of the company to resist an external event; second, a more active capacity to anticipate events and thus open new development pathways”

Table 4. Definitions of operational resilience (Kamalahmadi and Mellat Parast, 2016)

Analysing the presented definitions, operational resilience is related to the ability of overcoming unexpected disruptions by restoring the initial functioning condition of the business operations.

In order to embrace as a whole the multidisciplinarity of resilience and clarify its conceptualisation, Ponomarov and Holcomb (2009) gave the following definition of operational resilience: “The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function”.

Therefore, operational resilience goes beyond the mere recovery after a disruption since it also implies anticipation and flexibility. These capabilities are necessary to ensure the fulfilment of enterprise targets and the delivery of value despite the negative impact of unanticipated circumstances (Caralli et al., 2010; Ponomarov and Holcomb, 2009)

After having clarified the meaning of resilience at the system level, it is necessary to take a further step by defining the formative elements able to provide a comprehensive representation of resilience in its entirety. In general, “the perspectives on the formative resilience elements are less consistent” (Jüttner and Maklan, 2011, p. 247) because many informative studies provide only a partial perspective of operational resilience (Sheffi, 2001; Sheffi et al., 2003). Some of the related perspectives are summarized in Table 5.

Discussed aspects	Relevant research summary
Agility, responsiveness	Christopher (2004) describes agility as one of the most powerful ways of achieving resilience in the supply chain. Agile supply networks are capable of more rapid response to changed conditions
Visibility	Increasing the visibility of demand information across the supply chain reduces the risks (Chopra and Sodhi, 2004)
Flexibility/redundancy	Christopher (2005) states that resilient processes are flexible and agile and are able to change quickly. Flexibility enables a manufacturer to respond quickly and efficiently to dynamic market changes (Swamidass and Newell, 1987). Rice and Caniato (2003) suggested a hybrid flexibility/redundancy approach for increasing supply chain resilience
Structure and knowledge	Knowledge and understanding of supply chain structures, both physical and informational, are important elements of supply chain resilience (Hong and Choi, 2002)
Reduction of uncertainty, complexity, reengineering	van der Vorst and Beulens (2002) view reduction of uncertainty as the way to improve supply chain resilience. Christopher (2000) adds reduction of complexity through business process reengineering initiatives
Collaboration	Collaborative partnerships help to manage risks effectively (Sinha et al., 2004; Lee, 2004)
Integration, operational capabilities, transparency	In describing the operational capabilities of resilient supply chains, Smith (2004) emphasized the importance of integrated environment that provides end-to-end interaction of orders, inventory, transportation and distribution to facilitate supply chain transparency

Table 5. Summary of aspects of SC resilience (Ponomarov and Holcomb, 2009)

2.3 Contingency theory

2.3.1 Introduction

The concept, appeared for the first time in 1958, was used by Woodward (1958) in order to define the link between technology and production systems and their role in shaping effective organizational structures Subsequent seminal works (Lawrence and Lorsch, 1967; Thompson, 1967) argue that a firm's performance is attributable to the match between its structure and processes with environmental conditions.

Contingency theory suggests that measures and actions for optimal results have to take into account the prevailing internal and external business environment (Sousa and Voss, 2008). Furthermore, the theory also applies for turbulent environments since it explains how proactive measures are built and how organisations adapt structures to preserve the robustness (Sousa and Voss, 2008)

The acknowledgement of contingency, with regards to the Lean implementation, demolishes the idea of "universality" envisioned by Womack et al. (1990). In fact, the mismatch between the proposed form of best practice and the specific organisational context leads to difficulties in the implementation phase (Sousa and Voss, 2001).

2.3.2 Contingent Lean Manufacturing

The contingency of Lean has been studied through different contextual variables. For example, Jayaram et al. (2010) review the key Total Quality Management (TQM) contingency studies identifying the firm size, TQM duration, unionization and industry type as factors. Considering Lean as an integrated system of managerial practices, Shah and Ward (2003) assess the unionization, plant age and plant size. Azadegan et al. (2013) also consider the operations strategy and, lastly, the industry type is accounted by Peng et al. (2008) and Powell (1995) as relevant contingent variable.

2.3.3 Contingent operational resilience

The contingency of operational resilience is a topic that has recently developed as a means against the increasing environmental uncertainty of the operating context. Thompson (1967) foresaw more than forty years ago that uncertainty may affect the effectiveness of a best practice. So, it must be considered as a full-fledged contingent factor. Nowadays, given the increasing importance of contingent factors in operations management research (Demeter and Matyusz, 2011), several supply chain risk management papers use contingency theory as the underlying one (Grötsch et al., 2013).

The concept of resilience intrinsically accounts for the contingency effect because it is the ability of a system to return to its original (or desired) state after being disturbed, thus it demands adaptability to the changing context. Hence, a resilient firm embraces change unlike a robust firm that can endure a reasonable amount of variability, but without being flexibly able to adapt to it.

In addition, the SC structural complexity and characteristics, namely density, complexity and node criticality, significantly impact the performance level after disruption (Birkie et al., 2017; Craighead et al., 2007). Given that SC complexity also consists of organisational factors including the size (Manuj and Sahin, 2011), it is reasonable to perform a contingent analysis for the resilience constituents as well.

3 RESEARCH FRAMEWORK

3.1 Research objective and question

This study pursues a deeper understanding of Lean Manufacturing (LM), one the most impactful organisational innovation in the operations management field that "will be the standard manufacturing mode of the 21th century" (Rinehart et al., 1997, p. 2). In particular, the study assesses the role played by LM in a volatile competitive landscape in terms of contribution to operational performance objectives.

The value of the research derives from the rising uncertainty of the global business context in which firms operate. Multiple events have indeed perturbed the regular flow of goods and information along the Supply Chain (SC) increasing variability and uncertainty inside organisations (Kleindorfer and Saad, 2005). Complexity has likewise increased due to emerging new trends and technological advancements. As a result, operational and financial performances have been significantly harmed (Hendricks and Singhal, 2003).

Within this context of turbulence and uncertainty, lean companies, traditionally focused on the pursuit of efficiency, cannot afford to overlook the operational resilience as a means to mitigate increasingly costlier disruptions. They are compelled to make tough choices on which direction to follow: improve performance at the expense of a higher degree of vulnerability or sacrifice the profit to increase resilience capabilities. Whether the two directions are mutually exclusive or not is nowadays a relevant question.

The purpose of the research, set in a disruptive operating context, is uncovering the role of LM and it can be explicated by means of the following research question:

RQ. What is the influence of efficiency-driven operations strategies on operational performance under disruption?

3.2 Definition of constructs

As previously introduced, the research wants to assess the suitability of efficiency-oriented strategies in a turbulent context where firms have to face the disruption risk. From a methodological point of view, this means assessing the existing relationships between constructs of interest, namely Lean Manufacturing, operational resilience and performance. LM is a manufacturing approach aimed at minimising waste and removing non-value adding activities whose suitability in the nowadays scenario is the core part of the research. Furthermore, its relationship with another manufacturing approach, resilience, is addressed. These two production paradigms are evaluated and measured against the third construct that is the performance variation upon disruption of the firm.

Lean Manufacturing is often considered as a philosophy of manufacturing with the goal of eliminating waste to achieve superior performance. However, given the objective of assessing its suitability from a quantitative perspective, LM is defined in a more operational way as follows: "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability" (Shah and Ward, 2007, p. 791). This definition shapes the concept of "Lean" as multi-dimensional managerial approach that extends across the boundaries of the single firm by involving multiple SC players.

Resilience is a concept originated from other fields such psychology and ecological studies. It has been introduced also in the SC and operations context as answer to the disruption risk (Tang, 2006). The research defines operational resilience as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function" (Ponomarov and Holcomb, 2009). This definition takes into account the main phases of an operational disruption and the associated characteristics that resilient SC and firms need to have.

With respect to performance, the research is not focused on the absolute value of the performance profile during disruption, but rather on the variation of performance due to the disruption. The decision is coherent with the shift from a risk management approach, where status quo is preserved, to a resilient approach that advocates for adaptability and flexibility towards an unavoidable change. Performance is measured at operational level with a heterogeneous set of metrics that comprehensively assess both the efficiency and effectiveness dimensions.

3.3 Theoretical frame of reference

In order to operationalise the constructs, the utilised frame of reference is the resource-based view (Barney, 1991) and, in particular, the dynamic capabilities perspective (Teece, 2007) combined with the contingency theory (Duncan, 1972). This bundled perspective explains how and why firms show competitive advantages given the prevailing highly dynamic and complex context given the prevailing environment (Ambrosini et al., 2009; Teece et al., 1997).

The RBV theory elaborates on the concept of "capability" referring to it as the firm's ability to integrate, build and reconfigure internal and external competences (Teece et al., 1997). The capability is composed of a cluster of routines that drive the exploitation of resources with the aim of gaining a sustainable competitive advantage (Peng et al., 2008). In an unpredictable and volatile environment, competitive advantage entails effectively overcoming a disruption and re-establish the pre-incident condition (Craighead et al., 2007). The dynamic capabilities perspective further advances the argument of RBV further, saying that capabilities allow firms to reconfigure, refresh, or integrate resources to meet operational and business needs in turbulent environments, namely the context of analysis of this study.

In the used approach, Lean Manufacturing and operational resilience are conceptualised as an integrated system of dynamic capabilities, such as JIT, Total Quality Management (TQM), customer involvement and partnership and Lean purchasing (Azadegan et al., 2013, Shah and Ward, 2003; Shah and Ward, 2007). These capabilities support the deployment of resources and infrastructure coherently with prevailing circumstances upon disruption (Ambulkar et al., 2015). Dynamic capabilities are then operationalised as bundles of logically interrelated practices or routines (Dabhilkar et al., 2016; Peng et al., 2008). Ketokivi and Schroeder (2004) argue that these practices are the real source of competitive advantage. In particular, the Lean practices are grouped into Lean bundles following the classification schemes by Shah and Ward (2003; 2007). On the other hand, resilience practices adopt the capability perspective of Jüttner and Maklan (2011) that define four constituents as formative elements of resilience. The procedure, also adopted by Birkie et al. (2014) and Dabhilkar et al. (2016) is better described in the subsequent chapter of Measurement model specification in the Methodology section.

Concerning the operational performance, it refers to measurable aspects of the outcomes (Wong et al., 2011; Zhang et al., 2012). In particular, the five performance objectives are quality, cost, speed, flexibility and dependability which further break down into measurable metrics. Such measurement methodology has already been applied in literature, for example by Birkie et al. (2017).

3.4 Research hypotheses

The purpose of the research, set in a disruptive operating context, is uncovering the role of LM and it can be broken down into three main sections.

Firstly, the study wants to assess whether the Lean implementation leads to a direct improvement of performance or not. In other words, the paradoxical mitigation of disruptions by means of an efficiency-oriented approach is examined. Then, the relationship between LM and performance is further explored by taking into account the operational resilience. The seeming contradiction between the two paradigms is questioned with a hypothesis of causality that, if confirmed, would secure improved operational performance and competitiveness in spite of uncertainties. Finally, the study recognises the relevance of contingency when assessing the abovementioned relationships. In particular, the analysis consists in controlling exogenous variables related to the operating context, such as the firm size and operations strategy, in order to detect any significant differences among the parameters in question.

The three sections need to be converted into explicit research hypotheses which lie on conceptual findings stemming from the scientific literature. The quantitative approach of the research then allows the empirical test and confirmation of such hypotheses. In the following sub-paragraphs each section of the research is discussed in order to provide the necessary theoretical underpinning for the formulation of the intended research hypotheses, gathered in a final table.

3.4.1 Impact of Lean on performance

The first section regards the relationship between LM and performance and it tackles a pivotal choice that companies are urged to make because of the competitive pressure and raising environmental uncertainty. Do companies need to divest the adoption of LM in order to preserve the delivery of products and services?

Such question requires the assessment of the impact of LM on operational performance, aware of the fact that the context of application of Lean has evolved since the term first appeared in Krafcik (1988). The evolution of the context is analysed with the support of a graphical representation of uncertainties affecting operations in conditions of turbulence.

Uncertainties are described in Figure X as variations that occur routinely or non-routinely (horizontal axis). Routine uncertainties commonly occur in the business, while non-routine uncertainties exceed the ordinary variations. The vertical dimension consists in the predictability of variation that discriminate uncertainties into predictable (largely known) and unpredictable (largely unknown). Predictability entails that the probability of occurrence can be estimated.

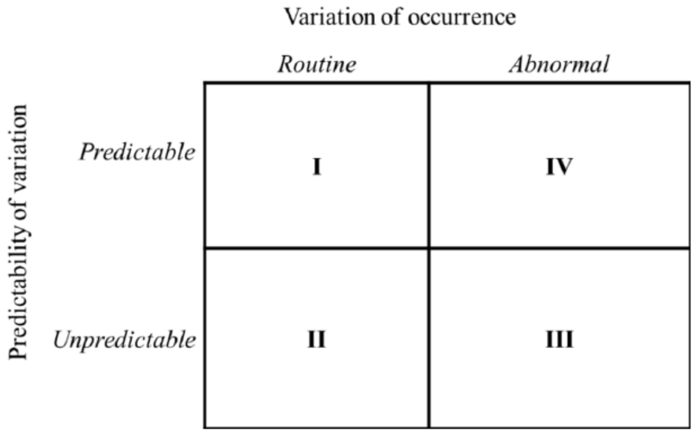

Figure 6. Characterisation of operational uncertainty as variation

The classification identifies four different scenarios represented by the four quadrants in Figure 6. Quadrant I indicates a type of uncertainty such as day-to-day and seasonal demand variation in mass production environment. Such "fairly stable" environment, with all processes assumed to be in control (Hines et al., 2004), is where LM originally developed. Examples of LM practices are Kanban and standard operating procedures, designed to pursue efficiency and productivity in conditions of stability. Following the historical evolution of the operating uncertainty, the context moved from Quadrant I to Quadrant II that includes, for example, highly customised ETO manufacturing. Here, the idea of universality of Lean depicted by Womack et al. (1990) is replaced by a pragmatic approach where LM implementation should be in line with the specificities of the context. According to Duncan (1972), Quadrant III is the reflection of a highly dynamic and complex environment, where disasters such as the 2011 Japan triple disaster occur. Within this quadrant, LM is subject to criticism because guilty of making firms vulnerable (Chopra and Sodhi, 2014). Ultimately, there is Quadrant IV, outside of the scope of the analysis, that represents uncertainties, such as work accidents, manageable with established risk management processes.

At present, the environment can hardly be assumed “stable” as in the early Quadrant I (Knemeyer et al., 2009). In fact, even minor events are able to trigger a ripple effect throughout the entire SC with unforeseeable and escalating effects (Sheffi, 2007). Therefore, the current environment is the one depicted in Quadrant III.

As a result, recent studies on Lean started to account for the new type of uncertainty within the business environment, thus redesigning tools and practices originally designed for routine and predictable variations only. For example, Costantino F. et al. (2014) develop a new inventory replenishment policy that encompasses information sharing and collaboration to increase SC resilience. Alternatively, Mohammaddust F. et al. (2014) propose a hybrid Lean and responsive methodology, able to identify the optimal SC design according to the organisations’ uncertainties and their performance goals. However, up to date the investigation of uncertainty context factors in Lean literature is still scarce (Azadegan et al., 2013).

Concerning the impact of LM on operational performance, it is imperative to account for the type of uncertainty because different uncertain environments may influence in different ways lean practices implementation and their effect on performance (Browning and Heath, 2009; Chavez et al., 2015).

The evolution of the business environment from stable to turbulent has determined a rebalancing of efficiency-related and effectiveness-related performances in terms of relative importance. Rather than continuously improving processes, one among firms’ main concerns is indeed to maintain the running of operations despite the disturbance caused by a disruption. In this regard, the scientific literature includes contrasting positions about the suitability of Lean approach in such environment. The lack of a homogeneous perspective calls even more for an empirical assessment capable of validating a hypothesis so far developed only at theoretical level.

Authors such as Christopher and Holweg (2011) have stated that efficiency-based approaches are not convenient for unstable environment where effectiveness performance is relevant. As a matter of fact, LM is perceived as a source of vulnerability (Birkie, 2016;

Chopra and Sodhi, 2014) due to the encouraged reduction of buffer availability and inventory. Hence, it becomes more difficult for the firm to recover from unexpected disruptions that lead to an interruption in the materials flow throughout the SC (Ruiz-Benítez R. et al., 2018).

Nevertheless, there are several business cases and research papers in agreement with the idea of a positive impact of Lean in presence of complex and dynamic uncertainty. For example, Toyota leveraged its flexibility to overcome the disruption of key automotive components, thus proving the pivotal role played by LM in case of disruption (e.g. Cox et al., 2011). From an academic perspective, Womack and Jones (1997) claim that LM contributes in enhancing the flexibility and responsiveness of a company. However, Bortolotti et al. (2013), while describing Just in Time (JIT) as the most impactful lean practice in performance improvement, recognise its unsuitability in case of high variability. Variability is likewise positively influenced thanks to the standardisation of working procedures that forms the baseline for Kaizen (Holweg, 2007). The theme of reduction of variability is also present in Shah and Ward (2007) that highlight the positive impact of LM under three different aspects. Supplier variability is offset thanks to partnerships with suppliers and by using an information system that builds upon the principle of regular feedback. Internal variability is reduced thanks to standard operating procedures and trained and involved employees. Finally, demand variability is countered through Lean practices such as Heijunka (Shah and Ward, 2007)

For these reasons, the research postulates a positive direct impact of Lean implementation on business performance, made explicit in the following research proposition:

H1. Lean positively influences performance loss upon disruption.

3.4.2 Relationship between Lean and resilience

If LM is a consolidated paradigm existing for more than thirty years, operational resilience is the evolution of the traditional risk management, born as the answer to the increase of environmental uncertainty. It is therefore reasonable to wonder how these two paradigms, having distinct purposes, bind to each other: how does the mix LM – operational resilience mitigate the performance degradation following a disruption?

The simultaneity of the concepts of LM and operational resilience is poorly addressed by the scientific literature, as witnessed by the low number of eligible papers (7) obtained from a structured literature review (SLR) done in early 2019. In particular, the SLR is based on two databases, namely Scopus and Web of Science, with a search string composed by the keywords “lean” and “resilience” connected by the Boolean operator “AND”. The resulting papers are shown in Table 6.

ID	Title	Authors, Year
P1	Assuring organizational resilience with lean scenario-driven exercises	Hills, 2013
P2	Disentangling resilience, agility and leanness Conceptual development and empirical analysis	Lotfi and Saghiri, 2013
P3	Finding common ground for alignment of supply chain paradigms	Azfar, 2012
P4	Lean, green and resilient practices influence on supply chain performance: interpretive structural modeling approach	Govindan et al., 2015
P5	Operational resilience and lean: in search of synergies and trade-offs	Birkie, 2016
P6	State-of-the-Art Review on Operational Resilience: Concept, Scope and Gaps	Birkie, Trucco and Kaulio, 2013
P7	Towards Lean and Resilient Production	Puchkova et al., 2015

Table 6. List of papers obtained from SLR

The relationship between LM and resilience is quite controversial in literature. In fact, academia and researchers polarise between two opposing positions, resulting in a trade-off relationship between the two paradigms.

On one side, an excessive focus on efficiency undermines the capability of the companies to sustain operations and re-attain their earlier or a better state after the occurrence of the disruption (Christopher and Peck, 2004; Woods, 2006). In particular, LM is blamed of weakening firms through a reduced flexibility and an increased vulnerability (Chopra and Sodhi, 2004; Taleb et al., 2009). Looking at the practice level, some Lean practices are in contrast with the adaptability required by the context. For example, the use of Kanban, intended to smooth variability, generates an undesired effect of rigidity.

On the other side, the possibility of creating synergistic relationships between both LM and operational resilience has been explored (Alves et al., 2012; Birkie, 2016; Purvis L. et al., 2016). In this respect, Alves et al. (2012) argue that a Lean company can leverage on its agility and learning capability in order to mitigate disruptions. In addition, Shukla et al. (2011) prove that building supply network resilience without a significant loss of efficiency is not an oxymoron. At the practice level, the adoption of one-piece flow ideally improves resilience (Liker, 2004). Moreover, Birkie (2016) demonstrates empirically that the relationship between two paradigms is “dominantly synergetic towards better performance upon disruption” (p. 202). This finding translates into an important practical implication for firms: they do not need to abandon the Lean approach for the sake of resilience. In fact, companies with high degree of diffusion of resilience and lean capabilities are more likely to obtain superior performance upon disruption.

Once identified a synergistic relationship between LM and operational resilience in the scientific literature, this work pursues further advancements towards the full comprehension of the role of LM in the disruption context. The objective is to verify if accounting for resilience helps in better explaining the positive impact of Lean on the performance loss after disruption.

In order to lay the foundations for the confirmatory analysis, theoretical evidence needs to be provided from the available scientific literature. So, the seven papers obtained from the SLR are analysed through a classification that considers the resilience constituent and the lean performance treated by the paper. The outcome of the analysis is shown in .

As it can be observed, the contribution of literature mainly addresses the flexibility constituent (row) and the efficiency performance (column). The explanation for efficiency is straightforward given the intrinsic nature of LM (Cua et al., 2001; Shah and Ward, 2003). Furthermore, common ground between flexibility and Lean can be found because both are mostly related to the operational level.

Other clusters of interest covered by literature are the combinations efficiency – visibility and efficiency – velocity. On one hand, the standardisation of information and the knowledge sharing applied by Lean companies enhance visibility and collaboration within the SC, useful to cope with unexpected events. On the other hand, lean practices are aimed at increasing efficiency, namely minimising process time, including lead time, setup time, etc., thus improving the recovery capabilities of flexibility and velocity. Since the underlying notion and motive of LM is the satisfaction of customer requirements in a flexible way, the lean implementation increases the agility of the firm to manage disruptions (Spear and Bowen, 1999). Such statement is supported by real-life experience: recollecting the previously mentioned business case of Toyota, the flexibility that enabled the mitigation of the disruption was determined by the high responsiveness of the lean-based supplier network (Cox et al., 2011).

Summing up, the analysed sources of information stress the existence of a link between LM and resilience. The conclusion draft is that company's resilience benefits from the implementation of lean practices. The research hence proposes to evaluate the effects of a mediator in the analysis.

A mediator is a variable that, as stated by Baron and Kenny (1986), "accounts for the relation between the predictor and the criterion". The observed variations in the mediator are the result of variations in the predictor, which finally cause variations in the criterion. This study assigns the role of mediator to the operational resilience because of theoretical evidence found in scientific literature. Consequently, the variations in the level of LM cause the variations in the resilience paradigm, and finally these variations reflect on the operational performance.

If variations in the levels of LM significantly account for variations in the presumed mediator, namely resilience, then there is a relationship of causality between the two paradigms. Such relationship brings along relevant managerial implications for the organisations that are forced to review their practices to withstand unexpected disruptions. Firms have to consider the implemented lean practices when improving the resilience capabilities. The dependency, therefore, highlights the importance of planning new resilience capabilities based on the "leanness" of the organisation.

In conclusion, the intended research objective is encoded in the following research proposition:

H2. Resilience significantly mediates the relationship between lean and performance loss.

3.4.3 Contingent Lean and resilience

The third and last section of the research rises from the awareness that there is no "one size fits all" in the field of operations management. The most appropriate organisational structure or decision depends on internal and external aspects of the environment, namely the contingency factors. Hence, the application of contingency theory in this research calls for an investigation into the following question: which are the factors worth considering when it comes to LM and operational resilience?

The research thus aims at testing any contingent effect determined by contextual variables, focusing, in particular, on the business size, the business sector and the operations strategy. If the first two variables are straightforward to understand, the operations strategy lies on the classification by Wortmann (1983) that revolves around the concept of Customer Order Decoupling Point (CODP). This will be explained afterwards in the phase of Data collection.

Extant literature has shown that application of lean practices is not equal to large and small firms (Matt and Rauch, 2013). Shah and Ward (2003) indeed state that "large firms are more likely to implement lean practices than their smaller counterparts" (p. 133). Regarding the business sector, lean is nowadays employed in various sectors across the world (Hallowell et al., 2009). In addition, the type of sector determines the structure of the SC that, in turn, influences the impact of disruption, according to Craighead et al. (2007). Lastly, the operations strategy is relevant for the implementation of both lean and resilience practices. Portioli and Tantardini (2008) indeed advocate the necessity of adapting lean practices, well established in a repetitive context, to a non-repetitive one. Frameworks for the configuration of lean practices are proposed accordingly (Birkie and Trucco, 2016). The structural differences between make-to-stock and make-to-order likewise prevent the immediate transfer of findings on SC integration capabilities from the former to the latter (Sahin and Robinson, 2005).

Therefore, given the reasonings above, the significance of the three factors cannot be ignored in studying the effectiveness of lean and resilience paradigms in a disruptive context. In order to address the topic, the analysis of contingency works on two distinct levels. The first level addresses the implementation of the practices, trying to verify if high degrees of leanness and resilience are specific to certain contexts of application. Then, the second level addresses the effectiveness of the practices, by introducing a moderator between the operational paradigm and the performance.

Baron and Kenny (1986) define moderator as "a qualitative or quantitative variable that affects the direction and/or strength of the relation between an independent or predictor variable and a dependent or criterion variable" (p. 1174). Business sector, business size and operations strategy are consistent with the definition and, therefore, are taken into account in the existing study as moderators of the relationship between LM and performance loss and the relationship between operational resilience and performance loss.

The third objective of the analysis seeks to validate the contingency theory through the test of the following propositions:

H3. There is significant categorical moderating effect of business sector on:

a. *The level of lean practices*
b. *The level of resilience practices*
c. *The relationship between lean and performance*
d. *The relationship between resilience and performance*

H4. There is significant categorical moderating effect of business size on:

a. *The level of lean practices*
b. *The level of resilience practices*
c. *The relationship between lean and performance*
d. *The relationship between resilience and performance*

H5. There is significant categorical moderating effect of operations strategy on:

a. *The level of lean practices*
b. *The level of resilience practices*
c. *The relationship between lean and performance*
d. *The relationship between resilience and performance*

3.5 Summary of research hypotheses

The setting of the research is an unpredictable and rapidly changing business environment in which firms face the risk of disruption at the SC level. In light of the underlying theoretical frame and literature review, the research aims at assessing the positive impact of Lean on performance, deepening the relationship between Lean and resilience and verifying the significance of contingent factors. These objectives are graphically represented by means of a research framework (Figure 7) and can be summarised in a list of research hypotheses, shown in Table 7:

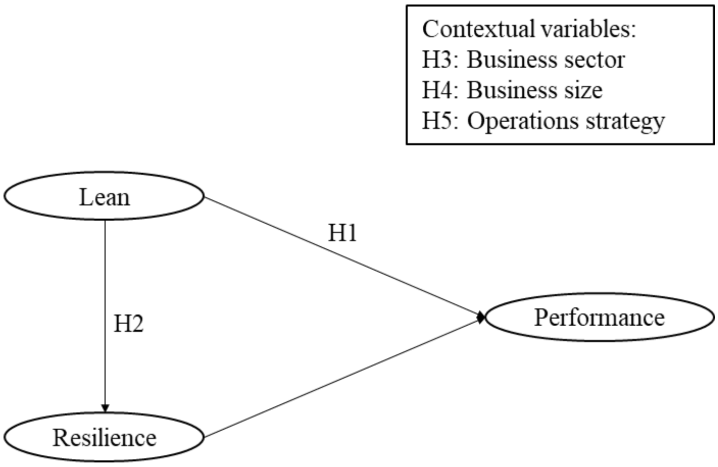

Figure 7. Research framework

ID	Research hypothesis
H1	Lean positively influences performance loss upon disruption
H2	Resilience significantly mediates the relationship between lean and performance loss.
H3	There is significant categorical moderating effect of business sector on:
	a. The level of lean practices;
	b. The level of resilience practices;
	c. The relationship between lean and performance;
	d. The relationship between resilience and performance.
H4	There is significant categorical moderating effect of business size on:
	a. The level of lean practices;
	b. The level of resilience practices;
	c. The relationship between lean and performance;

d. The relationship between resilience and performance.

H5 There is significant categorical moderating effect of operations strategy on:

a. The level of lean practices;

b. The level of resilience practices;

c. The relationship between lean and performance;

d. The relationship between resilience and performance.

Table 7. List of research hypotheses

4 RESEARCH METHODOLOGY

After having provided the background knowledge and explained value and objectives of the study, it is hence possible to start the methodological phase. Here the subsequent steps of the research are disclosed together with the presentation of the statistical model used to test the relationships among constructs.

Firstly, Structural Equation Modelling (SEM) is introduced by describing its main features, design choices and important considerations. In particular, it is here stressed how the SEM technique is configurated to the specific context of research, with regards to the definition of the variables of interest within the model and to how they relate each other. Then, the adopted procedures for data collection and coding are explained, thus describing the way the database, used to "feed" the model, was built. The database contains information about disruptive incidents occurred to firms along with the Lean Manufacturing and resilience practices adopted at that juncture. Before performing the actual analysis, it is essential to perform a preliminary analysis that addresses the goodness of the collected information. The suitability of data is expressed in terms of sufficient sample size, homogeneity of the dataset and absence of statistical bias. The framework design of the model is assessed by verifying if Lean Manufacturing and operational resilience are correctly and comprehensively represented from an empirical perspective. Finally, the statistical analysis is performed following a step-by-step procedure provided by SEM literature. In this analysis the significance of different effects is evaluated in line with the pre-set research propositions. Table 8 briefly describes the procedure followed.

	Phase	Description
1.	Model specification	Design and building of the SEM framework, i.e. definition of the measurement model and the structural model.
2.	Data collection	Gathering of information about business incidents by means of a heterogeneous set of secondary data sources.
3.	Data encoding	Encoding of collected data into numerical values according to pre-defined schemes.
4.	Data aggregation	Aggregation of item-related values into constructs based on pre-set rules.
5.	Preliminary analysis	Assessment of the goodness of the sample size and detection of statistical bias.
6.	Measurement model assessment	Verification of quality of the measurements in accordance with procedure provided by SEM literature.
7.	Structural model assessment	Running of the model and analysis of the effects among constructs of interest.
8.	Advanced analyses	

Table 8. Methodological procedure of the research

4.1 Model specification

4.1.1 What is SEM?

Structural Equation Modeling (SEM) is a class of multivariate analytical techniques that became increasingly popular among researchers in the field of statistical analysis in recent decades.

SEM is an advancement of general linear modelling procedures (Astrachan et al., 2014), such as multiple regression analysis, and it is used to assess "whether a hypothesized model is consistent with the data collected to reflect [the] theory" (Lei and Wu, 2007, p. 34). This analytical approach indeed concurrently combines factor analysis and linear regression models enabling researchers to simultaneously investigate on multi-level dependence relationships. Firstly, SEM examines the relationships among theory-based latent variables and their indicator variables with the assessment of measurement theory, "where a dependent variable becomes an independent variable in subsequent relationships within the same analysis" (Shook et al., 2004, p. 397). Then, it examines the relationships between latent variables with the assessment of structural theory (Joreskog et al., 1999).

Constructs, or latent variables, are not directly measured, while indicators, also called items or manifest variables, are the directly measured variables that contain the raw data. In order to provide a measure of the latent variable, indicators are bundled together to form a unique aggregate indicator. Then, after all the latent variables are defined, the algorithm proceeds in analysing the relationships between such variables.

4.1.2 Historical background

Statistical analysis has always been used by social science researchers to develop, explore and confirm research findings and it is continuously evolving over time.

Researchers initially used to carry out univariate and bivariate analysis for the understanding of data and validation of relationships. Then, the need for tackling more complex relationships advocated for more sophisticated multivariate data analysis methods, able to simultaneously analyse multiple variables. Moreover, such methods can assume either an exploratory or confirmatory nature. Exploratory approach means looking for patterns and relationships so far unknown, while confirmatory approach consists in validating and confirming a hypothesis based on extant literature.

The 1980's were characterised by the first-generation statistical methods (Fornell, 1982, 1987) which consist of analysis of variance, cluster analysis, exploratory and confirmatory factor analyses, logistic and multiple regressions. Then, in the 1990's second-generation methods, including the structural equation modeling (SEM) technique, have started to spread among researchers with the beginning of the computer era that facilitated the access to knowledge. Research have gradually converted to SEM methods in several disciplines such as strategic management (Shook et al., 2003), marketing (Chin et al., 2008) and psychology (MacCallum and Austin, 2000). This is because they overcome the weaknesses of first-generation methods by accounting for unobservable variables that are indirectly measured through indicator variables.

There are two main types of SEM with distinct inner logics and contexts of suitability. The first one is the covariance-based SEM (CB-SEM), developed by Karl Jöreskog in 1973, while the second is the partial least squares SEM (PLS-SEM), created in the 1960s by the econometrician Herman Wold (1966). Their differences are thoroughly explained in subsequent paragraphs when it is defined which method to apply for this study.

Despite CB-SEM being more popular in the research community, PLS-SEM has recently gained attention in a variety of disciplines including marketing (Hair et al., 2012), management information systems (Ringle et al., 2012) and operations management (Peng and Lai, 2012). As confirmation, Hair et al. (2012) states that, in the period between 1981 and 2010, 204 studies in the 30 top ranked marketing journals used PLS.

Such prominence, also observable in Figure 8, is determined by the robustness of the method, capable of handling issues such as data abnormalities and complex models (Hair et al., 2017), thus becoming an "excellent alternative" to the CB-SEM approach (Hair et al., 2017, p. xi).

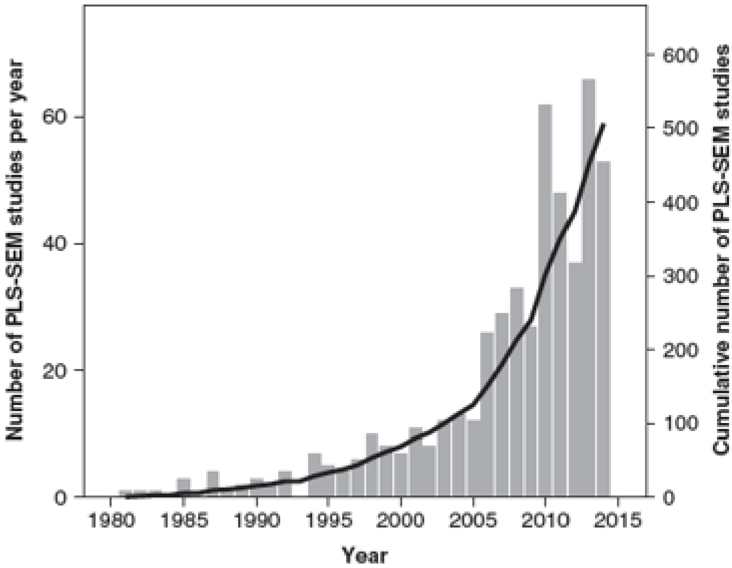

Figure 8. Number of PLS-SEM studies in Management, Marketing and MIS Quarterly (Hair et al., 2017)

4.1.3 Benefits of SEM

Researchers nowadays exploit SEM because of a more effective evaluation of measurement model and structural paths, namely the relationships between latent variables. The goodness of the method is reinforced in case of complex models containing multiple dependent variables and multi-item and multi-level constructs (Astrachan et al., 2014).

Main benefits connected with the use of SEM in the social science field are the capability of dealing with complex models and latent constructs, the possibility to analyse direct, indirect and total effects and the assessment of structural model.

Under the premise that indicator measures may not accurately represent the latent variable, SEM "provides a powerful means of simultaneously assessing the quality of measurement and examining causal relationships among constructs" (Wang and Wang, 2012, p. 1). This feature of the model is significant for the purposes of the research because it enables the evaluation of the goodness of measurement of Lean Management and operational resilience. In other words, it is possible to understand how well the operational practices, represented by the ones under the umbrella of Lean and resilience, comprehensively represent the dynamic capabilities of the firms.

The analysis carried out by SEM is deployed at different levels, namely direct, indirect and total. Direct effects consist of relationships between independent and dependent variables, indirect effects consist of relationships between independent and dependent variables, but moderated or mediated by some other variable. Total effects consist of the sum of two or more direct or indirect effects (Astrachan et al., 2014). This facilitation is of paramount importance for the thesis since it enables the assessment of contingency effects and also the mediation effect of resilience on the relationship between LM and performance.

Lastly, in contrast to regression analysis that separately evaluates each structural path of the model, SEM enables their simultaneous assessment with a simpler and more accurate approach (Astrachan et al., 2014). The logic behind the assessment of structural path differs for CB-SEM and PLS-SEM and it is then explained in a dedicated paragraph.

4.1.4 Limitations of SEM

The use of SEM techniques do not require profound statistical knowledge, thus being very accessible to most of the research community (Hair et al., 2010). However, the user-friendliness conceal its high level of sophistication that actually insight and judgement become “crucial elements of its use” (Shook et al., 2004, p. 397). Therefore, the main limitation connected with SEM techniques is understanding its suitability and correct application.

Before the estimation of parameters, it is necessary to meticulously specify the entire model. In particular, the number of indicator and latent variables, either dependent or independent, the type of measurement model and the relationships must be defined on the basis of sound theoretical foundations.

Another important limitation is related with the sample: its size must be appropriate enough to ensure a significant likelihood that the study detects an effect when there is an effect to be detected. Statistically speaking, the number of considered cases must be over a certain threshold to guarantee that the research has an acceptable statistical power. This assessment is done in the phase of preliminary analysis.

Lastly, the non-normal distribution of data may represent an important constraint for the research, but it strictly depends on the choice between CB-SEM and PLS-SEM. Therefore, it will be discussed in the comparison between the two SEM methods.

In conclusion, SEM approach offers several benefits, compared to first-generation techniques, but it poses a series of limitations that require great sensitivity from the researcher in making the correct design choices.

4.1.5 Path model

A path model is a diagram used in SEM literature to visualise the measurement and structural hypotheses, so the relationships between constructs as well as among constructs and their assigned indicators (Hair et al., 2011). An example of a path model is shown in Figure 9.

Constructs are represented in path models as circles or ovals (*Y1* to *Y4*). The indicators are represented in path models as rectangles (x1 to *x10*). Relationships are shown as single-headed arrows to indicate unidirectionality. Single-headed arrows are considered predictive relationships and, with strong theoretical support, can be interpreted as causal relationships.

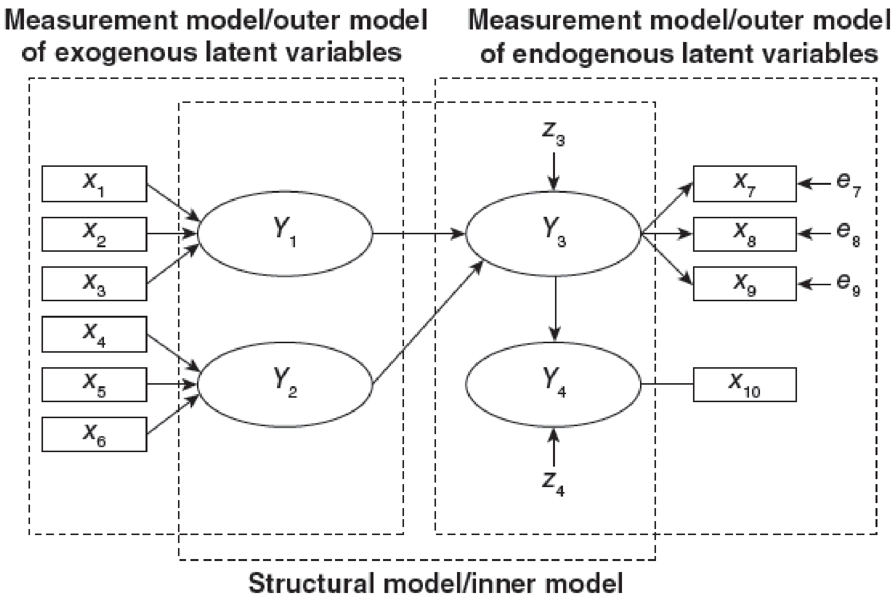

Figure 9. Example of path model (Hair et al., 2017)

A SEM path model consists of two elements. First, there is a structural model, also called inner model, that displays the relationships, or paths, between the constructs. Second, there are the measurement models, also called outer models, that display the relationships between the constructs and their specific indicator variables. Measurement models can be related to exogenous latent variables, that "explain" other variables in the model, or endogenous latent variables, that "are being explained" in the model (Diamantopoulos and Winklhofer, 2001; Jarvis et al., 2003). Reflective indicators depend on the latent variable, while formative indicators cause the latent variable (Henseler et al., 2012). The error terms (e.g., *e*7 or *e*8; Figure 9) are connected to endogenous and reflectively measured constructs, so where the relationship goes from the indicator to the dependent construct. In case of formatively measured constructs, error terms are not included. Finally, in case of single-item construct, (e.g. *Y4* in Figure 9), the direction of the relationship between indicator and construct is not relevant.

Path models are developed based on theory, meant as a set of interrelated hypotheses to be used to explain and predict outcomes. While hypotheses are individual conjectures, theories are multiple hypotheses linked together and empirically testable. In order to develop the path model, two types of theory are required: measurement theory and structural theory.

In conclusion, the model specification phase has, therefore, the objective of defining the path model of the research, through measurement theory and structural theory. In particular it is necessary to define the measurement models for the constructs of interest, namely LM, operational resilience and performance. Furthermore, structural model is obtained by converting the research propositions of the study into arrows connecting the constructs.

4.1.6 Measurement model

4.1.6.1 Concept of measurement

SEM techniques allow researchers to estimate the relationships between constructs and to evaluate the quality of measurement, so the accuracy of its representation. Measurement is "the process of assigning numbers to a variable based on a set of rules" (Hair et al., 2017, p. 6) and depends on the nature of the variable. In case of a categorical, ordinal or continuous variable, the assignment of value is straightforward, in contrast to an abstract and not directly observable variable. In this case, the measurement is not done directly, but only through a set of indicators in an indirect way. For these reasons, it is crucial to establish a solid measurement theory that defines the items that work as proxy for the latent or composite variable. Each item thus represents a distinct aspect of a larger abstract concept (latent or composite variable).

Multiple items are combined together in order to get an aggregated score of the latent variable, also called variate. A latent variable is obtained as linear combination of several item variables that are chosen based on the research problem at hand (Hair, Black, Babin, & Anderson, 2010). The process for combining the variables involves calculating a set of weights (e.g. $w1$ and $w2$), multiplying the weights for the associated data observations for the variables (e.g. $x1$ and $x2$), and summing them. The mathematical formula for this linear combination with n variables is shown as follows:

$$Latent\ value\ = w1\ \cdot\ x1\ +\ w2\ \cdot\ x2 + \ldots + wn\ \cdot\ xn$$

Equation 1. Latent value

where *x* stands for the individual variables, *w* represents the weights and the index *n* indicates the number of indicators uniquely associated to variate. The composite value is calculated for each respondent or case in the sample.

The accuracy of measurement of the latent variable is expected to increase since all the aspects are more likely to be represented and such accuracy is measured through the measurement error. The goal is, therefore, the minimisation of the measurement error.

4.1.6.2 Design choices

As already stated, SEM methods, despite the easiness of utilisation, require prudence for the statistical analysis and underpinnings coming from scientific literature. This is because only when fully defined, it is possible to perform the estimation of the parameters of the model (Lei and Wu, 2007).

With regards to the measurement of the constructs, sound specification of the measurement model is of paramount importance because its validity and reliability does have an impact on the structural model itself. The setup of the outer model involves taking decisions about:

- Multi-item or single-item scale (Diamantopoulos et al., 2012)
- Reflective or formative model (Diamantopoulos and Winklhofer, 2001; Gudergan et al., 2008)
- Hierarchical component model (Jarvis et al., 2003; Ringle et al., 2012)

4.1.6.2.1 Multi-item or single-item scale

Researchers can choose to measure a latent variable either through a single item or a multi-item, or scale, approach. Single-item guarantees simplicity in terms of ease of application, lower time effort and cost to carry out the analysis. It is also a convenient solution, according to Diamantopoulos et al., 2012), when (1) the sample size is small (N<50), (2) path coefficients (i.e. regression coefficients of the structural model) equal or lower than 0.30 are expected, (3) items of the multi-item scale are highly homogeneous (i.e., Cronbach's alpha > 0.90) and (4) the items are semantically redundant.

However, this solution comes with many risks because it undermines the predictive validity (Hair et al., 2017). Moreover, the single-item is poorly effective for handling missing information and removal of measurement error.

In conclusion, the use of single-item is a pragmatic solution in situations with a reduced sample size or feeling of "oversurveyed" (Hair et al., 2017, p. 53) for example. Single-item measures are suitable for observable characteristics such as sales and profits. Similarly, the use of sum score approach, namely the computation of the average of indicators, is discouraged because it produced bias due to the assumption that all outer weights are equal.

4.1.6.2.2 Measurement theory

Measurement theory indicates "how the latent variables (constructs) are measured" (Hair et al., 2017, p. 13). The two main streams of thought are the reflective measurement and the formative measurement.

As can be seen in Figure 10, reflective measurement is graphically displayed with directional arrows pointing from the latent variable to the items, while for formative measurement the directional arrows point from the items to the construct.

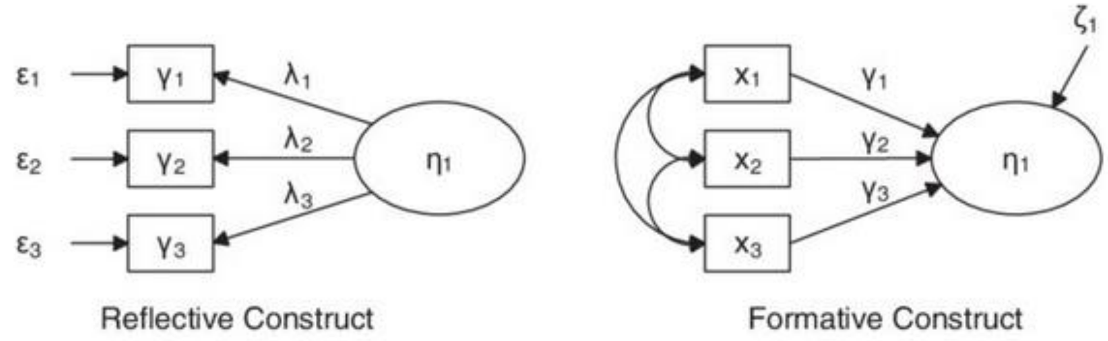

Figure 10. Representation of reflective and formative construct (Roberts et al., 2010)

Reflective measurement assumes the construct to cause the indicators, while, with regards to formative measures, the indicators are the "cause", rather than being caused by the construct. The reflective construct present an additional element that is the error term, associated to each indicator, not present in the formative construct since assumed error free (Diamantopoulos, 2011).

With regards to reflective measurement, since indicators share a causal relationship with a common construct, they are highly correlated with each other and interchangeable. Considering the direction of the relationship, a change in the construct determines a change in all indicators. A set of reflective measures is commonly called "scale".

In contrast, formative measurement models lie on the assumption that causal indicators linearly combine to form the construct. In this case, the set of measures hence takes the name of "formative index".

A substantial difference with the reflective measurement is that formative indicators are not interchangeable. Each one of them grasps a specific aspect of the construct's domain. Consequently, the number of formative items is generally higher to comprehensively cover the entire domain (Diamantopoulos and Winklhofer, 2001) and "lack of fit is to be expected" (Wilcox et al., 2008, p. 1226).

The formative construct is not a mere composite of its measures, but, as Heise (1972) argues, it is "the composite that best predicts the dependent variable in the analysis … Thus the meaning of the latent construct is as much a function of the dependent variable as it is a function of its indicators" (p. 160). The items thus contribute in determining the meaning of the construct and the omission of an indicator could potentially affect the nature of the construct itself.

The researcher struggles when trying to understand if a certain construct should be measured in a reflective or formative way. Wilcox et al. (2008) says that observing the intrinsic nature of the construct does not give any hints, but rather to look at the observables. Constructs themselves are indeed neither formative nor reflective. To facilitate the decision, Jarvis et al. (2013) provide a guideline based on four criteria, that are direction of causality, interchangeability of indicators, covariation among indicators and nomological network of indicators. However, in order to decide whether Lean Manufacturing, resilience and performance have a formative or reflective nature, the study follows the procedure by Hair et al. (2017) shown in Table 9.

Criterion	Decision	Reference
Causal priority between the indicator and the construct	• From the construct to the indicators: reflective • From the indicators to the construct: formative	Diamantopoulos and Winklhofer (2011)
Is the construct a trait explaining the indicators or rather a combination of the indicators?	• If trait: reflective • If combination: formative	Fornell and Bookstein (1982)
Do the indicators represent consequences or causes of the construct?	• If consequences: reflective • If causes: formative	Rossiter (2002)
Is it necessarily true that if the assessment of the trait changes, all items will change in a similar manner (assuming they are equally coded)?	• If yes: reflective • If no: formative	Chin (1998)
Are the items mutually interchangeable?	• If yes: reflective • If no: formative	Jarvis et al. (2003)

Table 9. Guidelines for the choice of measurement model mode (Hair et al., 2017)

4.1.6.2.3 Hierarchical component model

In case of complex models, using a single layer of constructs may not be sufficient to adequately represent a construct. In this respect, higher-order models, called hierarchical component models (HCMs), have been developed. HCMs define a construct at two or more distinct levels of abstraction as higher-order construct. Indicators form the lower-order components (LOCs) (i.e. first-order) that, in turn, form the higher-order components (HOCs) (i.e. second-order) and so on. Both components can be either reflective or formative, thus resulting in four different versions of higher-order constructs (Figure 11).

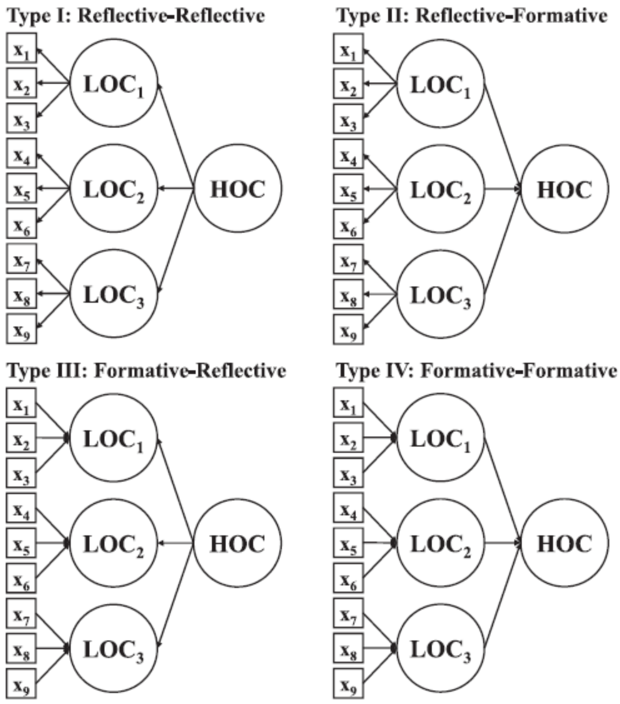

Figure 11. Types of higher-order constructs (Sarstedt et al., 2019)
Note: LOC=lower-order component; HOC=higher-order component

The choice of using HCM in a path model is determined by three main reasons. First of all, it reduces the number of relationships, thus making the model "more parsimonious and easier to grasp" (Hair et al., 2017), as also argued by Witzels et al. (2009). Secondly, it helps facing the issue of multicollinearity among constructs, thus solving the problem of discriminant validity, namely of discriminating the effect on the criterion variable of two or more predictor variables. Lastly, it fits well in case of formative indicators with issues of multicollinearity.

Sarstedt et al., (2019) state that the use of HCMs implies three main consequences. It first requires strong theoretical evidences from literature and the assessment of measurement model both at HOC and LOC level.

Secondly, in order to specify and identify HOC, it is possible to adopt the repeated indicators approach or the two-stage approach (Hair et al., 2018; Ringle et al., 2012). The former uses indicators to identify the LOCs, but the HOC as well, hence the word "repeated". The latter consists of a first stage, focused on the assessment of the measurement models of the LOCs, and a second stage that assesses the HOC through latent variable scores. The choice between the two approaches depends on which parameter bias has the priority to be minimised (Sarstedt et al., 2019). In the specific context of the analysis, the latent variables of Lean and resilience are modelled as HCMs.

The third and last implication, highlighted by Sarstedt et al. (2019) and connected with the use of HCMs, is the lack of consistency in literature when evaluating the measurement quality of higher-order constructs. In fact, there are several examples of researches that do not perform the entire procedure for the measurement model at all levels of the components. This research applies the procedure, as prescribed by Hair et al., 2017, for both the LOC and HOC levels.

4.1.6.3 Measurement model specification

The approach to model constructs (i.e., formative vs. reflective, multi-items vs. single items and single-order vs. multi-order) plays a remarkable role in the development and assessment of path models.

After having explained the main design choices related to the specification of the measurement model, now these choices are declined in the research constructs, namely Lean, resilience and performance. In particular, because the research constructs are conceptualised as HCMs in the path model, the specification is carried out on two levels (Sarstedt et al., 2019):

- The specification of the measurement model of LOCs;
- The specification of the measurement model of the higher-order construct, consisting of the relationships between the HOC and its LOCs.

The first level indicates which are the indicators and how they relate with the LOCs. Then the second level deals with LOCs and their relationship with the HOC.

Combining the SEM literature with the dynamic capabilities perspective, indicators represent the Lean or resilience practices whose implementation can be directly assessed. LOCs indicate the bundles or capabilities of the firm that allow to effectively overcome a disruption. Hence, the objective of this phase is to carefully define the structure for the measurement of the latent variables (Lean Manufacturing and operational resilience) by referring to extant literature on the two paradigms.

In other words, it wants to quantitatively assess the level of lean and resilience of a firm facing a disruption. Such level can be obtained by verifying how many lean and resilience practices have been implemented in order to prepare and recover from the disruption. In order to do that, a standard list of practices stemming from literature is needed as reference.

4.1.6.3.1 Lean manufacturing

As already explained in Literature review, Lean Manufacturing is a multi-dimensional approach built upon several management practices in an integrated system (Womack et al., 1990). Lean practices (LPs) work synergistically to achieve best quality, lowest cost, shortest lead time, best safety and high morale (Liker, 2004).

Different authors try to address the issue of LM and LPs presenting Lean as a philosophy that includes practices, tools and processes (Bhasin and Burcher, 2006). However, authors propose their own classification and list of LPs, thus indicating disagreement and the lack of a common standard regarding the LPs.

Therefore, a systematic literature review (SLR) is carried out to define a comprehensive list of LPs. The research is based on keywords referring to the article title, abstract and keywords of papers in the only Scopus database. The research is executed through the terms “lean practices” or “lean bundles”, combined through the Boolean operator “OR”. The research results into an initial number of 528 articles.

Articles are then filtered through the following criteria:

- English language only;
- Sci-mago journal rank indicator equal to Q1;

- Focus on manufacturing industry;
- Year of publication from 2000 on;
- Presence of proper and specified review or classification of LPs.

Taking into consideration the five criteria, the number of eligible journal papers, scanned through title and abstract, reduces from 528 to 81.

An analysis of all these journal papers is carried out, allowing the identification of 140 different LPs. The list of LPs, presented in Annex B, contains the number of citations per practice, the cumulative percentage per practice out of the total number of LPs and the cumulative percentage per practice in terms of citations out of the total number of citations.

From Annex B, an emerging information is that 77% of LPs are cited less than 10 times. Hence, a Pareto analysis is then performed, bases on the obtained data, to assess the relevance of the LPs (Figure 12).

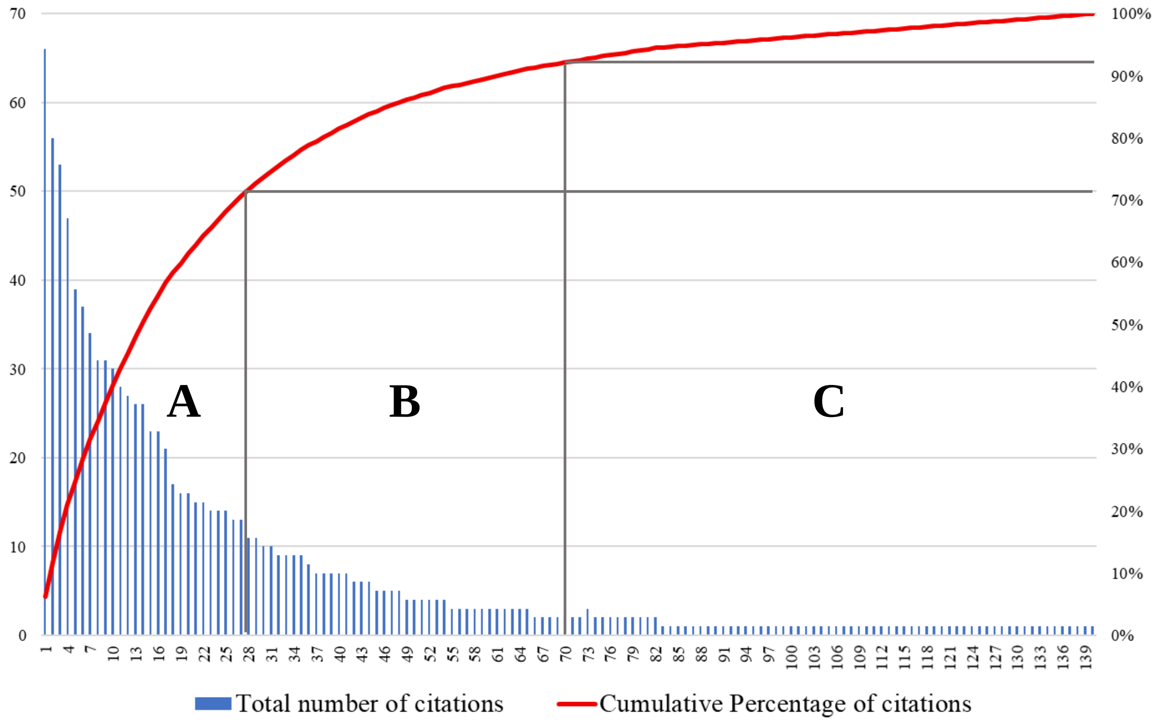

Figure 12. Pareto analysis for Lean practices

As shown in the figure, it is possible to see that the first 20% of LPs (group A) constitute around the 70% of the total citations studied, equivalent to 1054. The following group of practices between 20% and 50% (group B), corresponds to the 20% of citations with a cumulative percentage equal to 92.13%. The final group between 50% and 100% (group C) adds only a 7.87%.

Therefore, given the high concentration of citations in the first 20% of the total list of LPs, and in order to create a consistent list of LPs, it is decided to consider only the practices that present 10 or more citations in total.

A further screening is done because the list contains also wastes and bundles, while it should contain only operational and tangible practices that enable the reduction of waste. After the removal of seven non-practices, the final list of practices is finally obtained (Table 10).

Lean practice	Description
Pull system (Kanban)	Manufacturing of product only in case of order placement by the customer.
Quick changeover techniques and reduction of setup time (SMED)	Method for the minimisation of setup time.
Continuous improvement programs (Kaizen)	Kaizen events defined as continuous improvement in small steps.
Supplier involvement and development	Cooperative supplier relationships sharing design and cost improvement responsibilities.
Production smoothing (bottleneck removal, Heijunka)	Balancing of the line, levelling of variety and volume.
Cross-functional work force	Flexible and highly-skilled employees able to carry out different tasks.
Cellular manufacturing	Use of multiple cells composed by one or more dedicated machines.
Value Stream Mapping (VSM)	Investigating the flow of material through the manufacturing process.
5S	5S events are defined as the five dimensions of workplace organisation.

Work standardisation (SOPs)	Detailed descriptions of production tasks.
Error proofing (Poka-Yoke)	Fool-proof techniques seeking to eliminate judgement and discretion.
Lot size reduction	Elimination of waste related to WIP inventory.
JIT delivery	Just-in-time material shipment from the supplier.
Visual performance measures (VLPM) / Visual control	Visibility and spread of information through visual tools.
Customer involvement and partnership (feedback)	External collaboration with customer for better agility and minimisation of variability.
Statistical process control (SPC)	Method of quality control based on statistical methods.
Autonomation (Jidoka)	Use of technology for processes autonomously performed with minimum human assistance.
Employees’ involvement (suggestion schemes)	Internal relational LP that considers employees’ perspective.
Information sharing	Information made available to many actors to favour Lean implementation.
Lean management training	Communication and training for Lean cultural change.
Shop floor organisation and safety	Continuous improvement of working and safety conditions in the workplace.
Small-group problem solving	Discussion and coordination among few people to develop effective solutions.
Preventive maintenance	Maintenance regularly performed before the equipment breaks down.
Top management leadership for quality	Commitment of top managers in achieving zero defects.
Takt time definition	Definition of time needed to satisfy customer demand.

Table 10. Final list of Lean practices

The resulting panel is made by 24 LPs, with various degrees of frequency in terms of citations, but all pursuing efficiency as Lean Manufacturing. JIT and Pull systems are the practices most frequently referred, while a reduced number of suppliers and the definition of Takt Time are the least popular techniques in the reviewed literature.

Once the list of LPs is defined, it is necessary to define the Lean bundles, namely groups of inter-related and internally consistent practices, which contribute substantially to the operating performance of plants (Shah and Ward, 2003). The objective is to understand which are the Lean bundles and how LPs group into them.

The SLR previously done allowed to observe an inconsistency not only related to LPs, but for Lean bundles as well with different views proposed. Some authors classify LPs in four main groups: Just-in-Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM) and Human Resource Management (HRM) (Shah and Ward, 2003; Longoni A. et al., 2013; Hallavo et al., 2018).

JIT is an inventory management method that encompasses all the practices that schedule the arrival or replenishment of materials, goods and labour when needed in the production process (Shah and Ward, 2003). TPM can be defined as a program of periodic machine maintenance, and pre-emptive replacement of components, such as bearings, to minimise the frequency and duration of machine break-downs (Conti R., Angelis J. et al., 2006). TQM is an integrated program aimed at improving quality of process and product through several techniques, such as statistical process control and Jidoka (Conti R., Angelis J. et al., 2006). HRM is defined as the strategic approach for the effective management of people inside an organisation as means for the improvement of competitive advantage- improve its competitive advantage. Common examples of HRM practices are job rotation and enlargement, employees' involvement and cross training (Shah and Ward, 2003).

However, additional groups have been thought to be added to this classification (Belekoukias et al., 2014) and some authors do not consider HRM as a bundle (Tortorella et al., 2018).

For this research the used framework is an adaptation of Shah and Ward (2003) and Shah and Ward (2007). Shah and Ward (2003) defines in their seminal work a widely recognised classification scheme for the LPs built upon the four main bundles already mentioned. These bundles refer to manufacturing practices that are implemented within the boundaries of the firm. In order to enlarge the scope of the analysis, Shah and Ward (2007) changed the context from the single firm to the entire SC by stating that the main objective is “to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability” (p. 791). They defined three underlying constructs of Lean Manufacturing: (a) supplier related, (b) customer related and (c) internally related. The supplier-related operational constructs are supplier feedback, JIT delivery and developing suppliers, the only customer-related construct is involved customers. Among the internally related constructs, it is possible to find the four bundles defined by Shah and Ward (2003).

The adopted Lean measurement model is a hybrid scheme because it lies on the three underlying constructs, as defined by Shah and Ward (2007), but the internally-related one is broken down into the four internal bundles of Shah and Ward (2003). In lights of the above definitions of LPs and Lean bundles, the list of LPs is classified accordingly (Table 11).

Underlying construct	Operational construct	Operational measure
Internally related	JIT	Pull system (Kanban)
		Quick changeover techniques and reduction of setup time (SMED)
		Production smoothing (bottleneck removal, Heijunka)
		Cellular manufacturing
		Work standardisation (SOPs)
		Lot size reduction
		Visual performance measures (VLPM) / Visual control
		Takt time definition
	TPM	5S
		Autonomation (Jidoka)
		Information sharing
		Shop floor organisation and safety

		Preventive maintenance
	TQM	Continuous improvement programs (Kaizen)
		Value Stream Mapping (VSM)
		Error-proofing (Poka-Yoke)
		Statistical process control (SPC)
		Small group problem solving
	HRM	Cross-functional work force
		Employees' involvement (suggestion schemes)
		Lean Management training
		Top management leadership for quality
Supplier related	Supplier feedback and development	
	JIT Delivery	
Costumer related	Customer involvement and partnership	

Table 11. Lean measurement model

The work done in 2007 by Shah and Ward is, therefore, an evolution of their masterpiece published in 2003: the concepts of continuous improvement and waste reduction are extended to the nearby SC players, the customer and the supplier. Considering a SC context, firms must adopt Lean, both internally and externally, spreading Lean principles and LPs through the whole SC in order to achieve all its potential benefits (Shah and Ward, 2007).

Such extension is coherent with "Lean Enterprise", a concept developed to express the possibility of applying the Lean approach to the entire SC (Ruiz-Benítez et al., 2018). Moreover, this extension is motivated by phenomena such as globalisation and market competition that increase the contextual turbulence and uncertainty. Under this conditions firms need to develop agile and responsive capabilities to overcome these challenges. In conclusion, the classification scheme chosen to measure the Lean operational construct suits very well the research since it takes into account the nowadays disruption scenario, that is the framework of this research.

The Lean construct has been modelled as a third order construct (see Table 11) since the main concept (third level) breaks down into underlying constructs that are HOCs (second level) which further divide into operational constructs that are LOCs. Lastly, the LOCs are measured by multiple indicator variables, namely the practices.

The "leanness" of the firm is, therefore, measured at the ground level by observing which and how many Lean practices were implemented when the disruption occurred.

As argued by Sarstedt et al. (2019), the use of HCM for the measurement of the latent variable requires the assessment at each level of the construct and this study does accordingly in the subsequent phase of Model assessment.

With regards to the relationships between the indicators and the LOCs and between the LOCs and the HOCs, the research assumes the latent variables to be formative constructs at all level.

Coherently with Hair et al. (2017) (see Table 9), Lean bundles such as JIT and HRM are not interchangeable, but they provide a specific representation of the overall concept that is LM. The same reasoning is applicable at the item level where the causal relationship goes from the indicator to the LOC (Diamantopoulos and Winklhofer, 2011). It is indeed the implementation of statistical process control that makes the firm more quality-oriented, not vice versa.

In conclusion, LM is modelled as a formative-formative-formative third order construct.

4.1.6.3.2 Operational resilience

With regards to operational resilience, it has been already defined, in accordance with Ponomarov and Holcomb (2009), as "the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function".

As for LM, a standard list of practices stemming from literature is needed as reference for the definition of measurement model of operational resilience

Unlike for LM, where the vastness of literature has required a SLR to identify the most common LPs, operational resilience is a recent research stream born together with the increase of complexity and dynamism of the environment (Duncan, 1972). For this reason, “most existing frameworks are too abstract” (Dabhilkar et al., 2016, p. 949). In particular, Dabhilkar et al. (2016) and Birkie et al. (2016) frame resilience as a dynamic capability made by bundles of several practices. For the purpose of the study, the list of underlying practices by Birkie et al. (2016) is taken as reference (Table 12).

ID	Resilience practice
1	The business environment is regularly scanned for signals of possible disruption.
2	A plan for communication of incidents is established.
3	The firm promptly collects information from the incident site.
4	Scenario planning and crisis management exercises are regularly undertaken.
5	Multi-competence teams are established.
6	Relevant functions of the firm and other key factors are informed fast.
7	People with experience in handling past incidents are assigned to disruption events.
8	The firm effectively collaborates with external actors during the recovery process.
9	Demand is shifted across time, market or product.
10	Alternative suppliers are identified in the event of a possible supply disruption.
11	Responsibility for different parts of the recovery process is distributed clearly and appropriately.
12	A pre-incident systematic process for handling unforeseen supply disruptions is established.
13	Task forces make use of a systematic recovery process to solve problems.
14	Enhanced value propositions are offered to customers.
15	Managers are actively involved and support the recovery process through allocation of resources.
16	People cooperate effectively through internal coordination.
17	Long-term supplier relationships are developed.
18	The firm has long-term relation with customers.
19	Production and delivery are adjusted by balancing available resources.

Table 12. List of resilience practices (Birkie et al., 2016)

If on the side of resilience practices the literature is poor due to the scarcity of valid references, on the side of resilience bundles several classification schemes are developed by researchers. Among others, here following a short list of the main available resilience bundles.

Sheffi and Rice (2005) propose a hybrid approach to disruption consisting of redundancy, namely the stock of resources to be used "just-in-case", and flexibility that consists of "building organic capabilities that can sense threats and respond to them quickly" (p. 45). Differently, Dabhilkar et al. (2016) frame bundles along the dimensions of proactive or reactive and internal or external. Birkie et al. (2016) state that operational resilience comprise of five "core functions" (i.e. sense, build, reconfigure, re-enhance and sustain). Eventually, Jüttner and Maklan (2011) define four resilience capabilities or constituents, namely flexibility, velocity, visibility and collaboration

The ongoing analysis adopts the last framework mentioned (Jüttner and Maklan, 2011), thanks to the classification coherence with the frame of reference of the research, namely the RBV theory. Jüttner and Maklan (2011) indeed investigate at capability level, identifying four formative elements of resilience. These four constituents are based on the integration and coordination of resources in order to adapt to temporary disruptive events (Briano et al., 2009). Detailed definition of the four resilience constituents are displayed in Table 13.

Resilience constituent	Definition
Flexibility	The ease with which a supply chain can change its range number (i.e. the number of possible "options") and range heterogeneity (i.e. the degree of difference between the "options") in order to cope with a range of market changes/events while performing comparably well.
Velocity	The speed with which a supply chain can react to market changes/events.
Visibility	The extent to which actors within the supply chain have access to or share timely information about supply chain operations, other actors and management which they consider as being key or useful to their operations.
Collaboration	The level of joint decision making and working together at a tactical, operational or strategic level between two or more supply chain members. Scalable through the magnitude of relationship strength, quality and closeness.

Table 13. Resilience bundles (Jüttner and Maklan, 2011)

RBV theory is coherent also with the practice level, guaranteeing uniformity in the interpretation of operational resilience among different authors.

After having defined the resilience practices and the resilience bundles, it is necessary to define how they connect each other. In other words, it is necessary to understand to which LOC the resilience indicator refers to.

In contrast with the approach used for Lean that consisted of a literature review to identify relevant practices and bundles, the match between practices and bundles was done through the Delphi method. This method, used in a wide variety of disciplines to obtain consensus from knowledgeable experts in the field, seizes experts perceptions or judgements then refined through subsequent reviews until the convergence to an agreed position (Vázquez-Ramos et al., 2007). In particular, mini-Delphi or Estimate-Talk-Estimate (ETE) method was applied. The mini-Delphi is a simplified version of Delphi method because of face-to-face meetings in which respondents independently give their opinions, then tabulated for a subsequent discussion (Vázquez-Ramos et al., 2007). The group of experts consisted of three researchers that were asked to classify each resilience practices (Birkie et al., 2016) according to the four resilience bundles (Jüttner and Maklan, 2011).

From the analysis of the first round of responses, the researchers were well aligned except for two resilience practices that showed disagreement. The first one was "Relevant functions of the firm and other key factors are informed fast" and the second one "People cooperate effectively through internal coordination".

In the first case, it was unclear whether the information sharing was related to operating procedures, dispatched to the lower tier of firm, to follow in case of incident or rather notifications about the occurrence of the incident to the upper tier. Depending on the interpretation, the practice could be associated to the bundle "Velocity" or "Visibility". To underline the bottom-up logic of the practice, the sentence was re-worded as follows: "Key decision makers along the supply chain are informed fast".

In the second case, there was a wrong interpretation of the bundle "Collaboration" since it does not include the internal collaboration between two individuals of the same. The issue was clarified by stressing the definition on the fact that it is only an external type of collaboration.

The final allocation of the resilience practices to the bundles is showed in Table 14.

Resilience constituent	Resilience practice
Flexibility	People with experience in handling pasts incidents are assigned to disruption event.
	Demand is shifted across time, market or product.
	Alternative suppliers are identified in the event of a possible supply chain disruption.
	Enhanced value propositions are offered to customers.
	Production and delivery are adjusted by balancing available resources.
	Multi-competence teams are established.
	People cooperate effectively through internal coordination.
Velocity	Scenario planning and crisis management exercises.
	Responsibility for different parts of the recovery process is distributed clearly and appropriately.
	A pre-incident systematic recovery process to solve unforeseen incidents is established.
	Task forces make use of a systematic recovery process to solve problems.
	Plans for communication of incidents are developed prior to the incident.
Visibility	The business environment is regularly scanned for signals of possible disruptive events.
	The firm promptly collects information from the incident site.
	Key decision makers along the supply chain are informed fast.
Collaboration	The firm effectively collaborates with external actors in the recovery process.
	Managers are actively involved and support the recovery process through allocation of resources.
	Long-term supplier relationships are developed.
	Pre-incident, long-term relationships based on trust are developed with key customers.

Table 14. Resilience measurement model

The Resilience construct has been modeled as a second order construct (see Table 14) since the practices (Birkie et al., 2016) are grouped into four resilience constituents (Jüttner and Maklan, 2011) that in turn contribute in defining the level of resilience of the firm.

With regards to the type of relationships, the study assumes formative relationships at both level of measurement. Firstly, Wieland and Wallenburg (2013) view agility and robustness, two mechanisms of resilience, as formative constructs, thus confirming the formative relationship between indicators and the four LOCs. Then, velocity, visibility, collaboration and flexibility are described as formative SC constituents (Jüttner and Maklan, 2011; Ponomarov and Holcomb, 2009). Lastly, also Birkie et al. (2017) measure the operational resilience as a formative-formative second order construct.

4.1.6.3.3 Performance

Performance represent the endogenous constructs through which the effectiveness of LM and operational resilience is assessed. Indeed, the ongoing analysis is based on the significance of the paths connecting the exogenous latent variable, namely Lean and resilience, with the endogenous performance. Therefore, it is essential to measure in a comprehensive and appropriate way the performance level of the firm affected by a disruption.

As anticipated performance means here performance variation due to the disruption, thus it is relatively measured against the pre-incident condition benchmark. The measurement is coherent with the definition of competitive advantage that comes while a firm overcomes a disruption and re-establish its pre-incident condition (Craighead et al., 2007). Accordingly, the higher the level of performance, the lower the variation due to the disruption.

In the following phase of Model assessment, in particular the structural model, it will be verified whether high level of performance is determined by high level of LM or not. Hence, the objective is to understand if LM is a source of competitive advantage for the firm, together with the operational resilience, in a context of disruption.

The measurement of performance (Table 15) consists of several performance metrics, directly observable, related to different performance objectives. The list of metrics is adapted by Birkie (2016) on five performance objectives, that are cost, quality, cost, speed, flexibility and dependability (Dabhilkar et al., 2016; Slack and Lewis, 2008). It is noteworthy that most of performance metrics are operational measures since the unit of analysis of the research is the single firm affected by the disruption, not the entire holding.

Performance objective	Performance metric
Quality	Defect (scrap + rework) rate (% number of defective units / total produced)
	Customer complaints (% number of complaints / number of orders per year)
Cost	Increase in revenue
	Reduction in manufacturing unit cost
	Increase in cost of extra work force, activity or restructuring (reverse coded)
	Return on assets
	Total scrape and rework / sales
Speed	On time delivery (% of total number of deliveries)
	Reduction in delivery lead time (compared to last year average)
	Improvement in order processing speed
	Throughput time efficiency (time worked on product / manufacturing lead time)
Flexibility	Delivery volume flexibility (% number of orders with volume change satisfied / total volume change requests)
	Delivery time flexibility (% number of orders with due date change satisfied / total due date change requests due to customer)
Dependability	Accuracy of delivered quality (% orders with different quality delivered / total orders)
	Accuracy and reliability of delivered quantity (% orders with wrong quantity / total orders)

Table 15. Performance measurement model

In contrast with LM and operational resilience, the construct of performance is not measured through a multi-item scale or index. The operations performances are aggregated into a unique overall score according to a weighting scheme (Dabhilkar et al., 2016; Zhang et al., 2012), and then weighted by the severity of disruption. The procedure is further deepened in the phase of Data aggregation.

In conclusion, as for Birkie et al. (2017), performance is modeled in the path model as a single-item construct.

4.1.7 Structural model

After the specification of the measurement theory for the latent variables of the analysis, in order LM, operational resilience and performance, structural theory is needed in order to develop the path model.

Structural theory indicates "how the constructs are related to each other" (Hair et al., 2017, p. 14), so it defines the location and the sequence of the constructs based on theory and accumulated knowledge.

The earlier literature review has eventually led to the formulation of a list of research hypotheses (Table 7) to be used for drawing the relationships in the path model. In particular, *H1* and *H2* allow to postulate a direct relationship from Lean to performance and an indirect relationship passing through resilience. The research propositions *H3*, *H4*, *H5*, related to contingency effects, are not explicitly drawn because they refer to inner contextual characteristic of the sample in question.

4.1.8 Path model representation

The representation of the path model implies a sequence of reading from left to right in which the independent variables on the left precede the dependent variables on the right. In this study, Lean and resilience are the independent (exogenous) latent variables predicting performance that is the dependent (endogenous) variable.

The shape of the variable depends on the measurability of the variable, that can be either indicator or latent. Indicator variables are represented as rectangles, while latent variables are represented as circles or ovals.

The direction of arrows is relevant as well since it assumes a different connotation depending on the considered model. The arrow going from left to right in the measurement model indicates a formative relationship in which the indicator "explains" the construct, while in the structural model it relates to a causal relationship between an exogenous construct and an endogenous one.

The final path model that represents both the measurement models and the structural model is represented below (Figure 13).

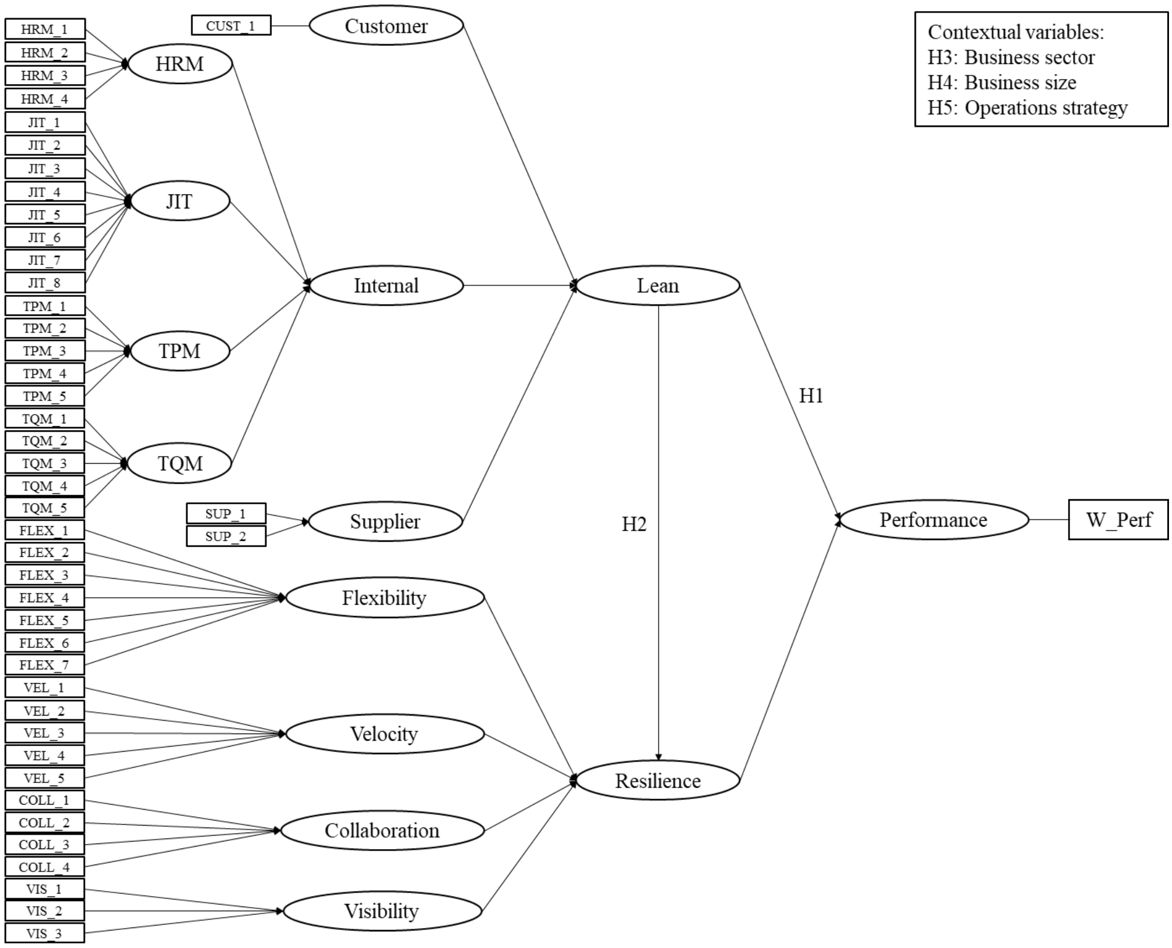

Figure 13. Research path model

4.1.9 Partial Least Square SEM

Once the path model is represented, it is necessary to define which version of SEM technique is adopted from now on between CB-SEM and PLS-SEM techniques. Such decision is relevant because it determines the following steps of Model assessment and it demands for an analysis of the research context.

4.1.9.1 CB-SEM vs. PLS-SEM

As anticipated, there are two main approaches for the estimation of structural relationships between constructs in SEM literature (Hair et al., 2010; Hair et al., 2011). The first one is the Covariance-based (CB) SEM approach, while the second one is the Partial least square (PLS) SEM approach, which was originally developed by Wold (1974, 1982).

CB-SEM and PLS-SEM mainly differentiate based on the quality of the structural models, while the measurement model is unaffected by the choice. Each approach suits a specific research context, so researchers are called to analyse the research context to ensure the correctness of the method.

While CB-SEM accurately estimate the observed covariance matrix, PLS-SEM maximizes the explained variance of endogenous constructs throughout an iterative approach (Fornell and Bookstein, 1982; Hair et al., 2014).

In particular, CB-SEM represents constructs as common factors that explain the covariation among indicators. The focus is hence the estimation of parameters that minimise the difference between the observed sample covariance matrix and the covariance matrix estimated by the model (Peng and Lai, 2012).

On the other hand, PLS-SEM creates weighted composites of indicator variables representing the constructs. An ordinary least squares (OLS) regression is then performed to minimise the error terms of the endogenous constructs, or in other terms to maximise the R^2 values (Becker et al., 2013). The focus thus is the estimation of parameters that best predict the dependent latent variables (Peng and Lai, 2012).

The composites used as proxy for endogenous constructs are unique in PLS-SEM, while there are infinite variants in CB-SEM. The latter approach is therefore unsuitable for prediction purposes because the result is not consistent (Dijkstra, 2014).

CB-SEM tends to eliminate relevant indicator variables as a result of model fit requirements (Astrachan et al., 2014). In contrast, PLS-SEM accounts for the indicator variables (Rigdon, 2012). This becomes even more relevant in case of formative constructs in which the construct is function of the indicators, so the removal of indicators would be detrimental.

PLS-SEM can manage complex models that include single-item measures and a large number of constructs, indicators and structural relationships (Hair et al., 2014). However, PLS-SEM cannot test the goodness-of-fit due to its non-parametric nature (Peng and Lai, 2012).

4.1.9.2 Context of application

CB-SEM and PLS-SEM statistically differ, aim at different objectives and have different underlying logic. Therefore, neither of the solutions is always appropriate or superior. The most correct solution is the one that fits research objectives, data characteristics and model setup. In general, the strengths of one approach are the limitations of the other one. In particular, rules of thumb for the choice between CB-SEM and PLS-SEM are indicated in Figure 14. Mainly, researchers should focus on the goal and main assumptions that distinguish the two methods (Hair et al., 2012).

Use PLS-SEM when

- The goal is predicting key target constructs or identifying key "driver" constructs.
- Formatively measured constructs are part of the structural model. Note that formative measures can also be used with CB-SEM, but doing so requires construct specification modifications (e.g., the construct must include both formative and reflective indicators to meet identification requirements).
- The structural model is complex (many constructs and many indicators).
- The sample size is small and/or the data are nonnormally distributed.
- The plan is to use latent variable scores in subsequent analyses.

Use CB-SEM when

- The goal is theory testing, theory confirmation, or the comparison of alternative theories.
- Error terms require additional specification, such as the covariation.
- The structural model has circular relationships.
- The research requires a global goodness-of-fit criterion.

Figure 14. Guidelines for choice between PLS-SEM and CB-SEM (Hair et al., 2017)

4.1.9.2.1 Goal

CB-SEM is primarily used to confirm (or reject) theories, while PLS-SEM is used mainly for the development of theories in exploratory research (Hair et al., 2017). The purpose of the approach is a consequence of the method since PLS-SEM always produces a single specific score for each composite that can thus be used to make predictions.

In case of poor knowledge about relationships between constructs or measurement characteristics of constructs, PLS-SEM is superior to CB-SEM. This is particularly true if the primary objective of applying structural modeling is prediction and explanation of target constructs (Rigdon, 2012).

4.1.9.2.2 Main assumptions

The choice between CB-SEM and PLS-SEM may also be driven by different characteristics than the research goal. In particular, the sample size, the presence of formative constructs and the non-normality distribution must be accounted.

Peng and Lai (2012) suggest the use of CB-SEM in case all the assumptions are met. However, if at least one assumption is no longer true, the use of PLS-SEM should be considered. The strength, and so popularity, of PLS-SEM is indeed its ability to handle modelling issues.

4.1.9.2.2.1 Sample size

A reduced sample size is the main reason behind the adoption of PLS-SEM approach (Peng and Lai, 2012). Despite the low number of cases under analysis, PLS-SEM is technically able to compute partial regression relationships by using separate OLS regressions.

However, researchers have taken advantage of this characteristics by improperly applying PLS-SEM with extremely small sample sizes (Hair et al., 2019). For these reasons, it is important to define the minimum acceptable sample size through power analyses (Hair et al., 2017).

4.1.9.2.2.2 Formative constructs

Diamantopoulos and Winklhofer (2001) suggest using PLS in case of formative constructs present in the research model. Although this violation does not preclude the use of CB-SEM, which generally lacks the ability to properly estimate research models with formative constructs (Peng and Lai, 2012).

4.1.9.2.2.3 Non normal data

Being a parametric test based on the maximum likelihood estimation, CB-SEM requires the populations of variables to be normally distributed even if quite robust against this violation (Chou et al., 1991). When data are non-normal, CB-SEM may lead to abnormalities, while PLS-SEM is more robust (Hair et al., 2019).

In conclusion, PLS-SEM has been selected as the most suitable approach for this study because of the following reasons. The software used as support during the analysis is *SmartPLS 3* (Ringle et al., 2015).

First of all, the goal is to verify and predict the relationship between Lean Manufacturing and performance level in a context of disruption where literature related to lean is limited. Then, the latent variables, namely LM, resilience and performance, are all formatively measured. With regards to the sample size, the dataset of the research comprises of 88 observations, so not a large sample. Eventually, the normality of variables was checked. In particular, because of the Boolean nature of the indicators, the test for normality is done at the level of higher order constructs, obtained with a sum score approach. Results of the Shapiro-Wilk test are shown in Table 16.

	Statistic	df	Sig.
Performance	0.990	88	0.749
Resilience	0.978	88	0.132
Lean	0.962	88	0.012

Table 16. Normality test for inner constructs

From Table 16 it is possible to observe that Lean has a p-value lower than the commonly accepted significance level $\alpha = 0.05$. It is, therefore, not possible to accept the null hypothesis of normal distribution.

4.1.9.3 PLS-SEM Algorithm

PLS-SEM is an OLS regression-based estimation technique that focuses on the prediction of hypothesized relationships through the maximisation of the explained variance in the dependent variable (Hair et al., 2017). Based on the PLS path model and the indicator data available, the algorithm estimates the scores of all latent variables (LV) in the model, which in turn serve for estimating the relationships of the path model.

Before running the algorithm, it is necessary to prepare the data matrix, used as input to "feed" the PLS-SEM. The data matrix contains the scores of indicator and latent variables for each observation of the sample. The study explains how the data matrix is obtained in the paragraphs of Data collection, coding and aggregation.

The basic PLS algorithm, as suggested by Lohmöller (1989) and Henseler et al. (2012), follows a two-stage approach (Figure 15).

Stage 1: Iterative estimation of the latent variable scores.

Do Loop

Step 1.1: Outer approximation of the latent variable scores.

Step 1.2: Estimation of the inner weights.

Step 1.3: Inner approximation of the latent variable scores.

Step 1.4: Estimation of the outer weights.

Until Convergence

Stage 2: Final estimation of outer weights/loadings and path coefficients through (single and multiple) ordinary least squares (OLS) regressions.

Figure 15. Basic PLS algorithm (Henseler et al., 2012)

In the first stage, the estimation of the LV scores consists of four steps, iteratively executed until convergence or maximum number of iterations has been reached.

Step 1.1: calculation of outer LV scores as weighted linear combination of the associated indicator variable scores.

Step 1.2: calculation of the inner weights indicating the strength of the relationship between the outer LV scores of the exogenous and endogenous constructs.

Step 1.3: calculation of inner LV scores as linear combinations of the adjacent outer LV scores.

Step 1.4: calculation of the outer weights resulting from the OLS regression of each inner LV score on its indicators (in formative measurement models).

In the second stage, upon the convergence of the PLS-SEM algorithm, the final outer weights from *Step 1.4* are used to calculate the final LV scores. These scores are then used for OLS regressions to determine the path coefficients.

4.1.9.4 Bootstrapping

Bootstrapping is defined by Hair et al. (2017) as "a resampling technique that draws a large number of subsamples from the original data (with replacement) and estimates models for each subsample".

PLS-SEM is a regression-based approach used to assess the path model, but, being non-parametric, it cannot make any assumptions on the distribution of residuals (Sarstedt and Mooi, 2014). Hence, the technique adopts a bootstrapping procedure that derives a distribution from the data. The purpose is the assessment of the statistical significance of model coefficients, namely path coefficients and outer weights.

In bootstrapping, subsamples are randomly drawn (with replacement) from the original set of data for the estimation of the model. Then, the single subsample is reinserted into the sample population before drawing the next observation. As a rule, the number of recommended samples, also adopted for this research, is 5000 (Hair et al., 2017). This means that 5000 path models are estimated, thus forming a bootstrap distribution that reasonably approximates an estimated coefficient's distribution.

The estimated bootstrap standard error (se^*) enables statistical hypothesis testing, in particular the Student's t test. The test verifies whether a model coefficient, e.g. path coefficient β_1, is significantly different from zero (i.e., H_0: $\beta_1 = 0$ and H_1: $\beta_1 \neq 0$) with the following formula:

$$t = \frac{\beta_1}{se^*_{\beta_1}}$$

Equation 2. Student's t test for coefficient β_1 significance

where β_1 is the path coefficient obtained from the original sample and $se^*_{\beta_1}$ is the bootstrap standard error of β_1.

If the resulting t value is above 1.96, the path coefficient is assumed to be significantly different from zero at a significance level of 5% ($\alpha = 0.05$; two-tailed test).

The same conclusion can be reached by considering the p-value, defined as the probability that a given result would occur under the null hypothesis. If the p-value is less than the chosen significance level (typically 1%, 5% or 10%), the null hypothesis is rejected at the chosen level of significance, so the coefficient is significant.

The results of the research report not only the level of significance of the relationships of interest, but they also include the bias-corrected and accelerated (BCa) bootstrap confidence intervals (Efron, 1987). Confidence interval is the range in which the model coefficient falls given a certain level of confidence and provides information about the stability of the coefficient estimate. The BCa bootstrap confidence interval, in particular, adjust for biases and skewness in the bootstrap distribution.

4.2 Data preparation

In order to run the pre-set PLS-SEM model, the software package *SmartPLS 3* needs as input the data matrix that includes values of measurable variables for each observation. With regards to the business context of disruption, variables refer to the implementation of specific lean or resilience practices and to the variation of performance metrics due to the unexpected disruption.

In this chapter, it is described the database creation, composed of several cases related to firms that had to face a disruption event. Each case is meant as the unique combination of firm and incident, thus the database is not company-based, but rather case-based.

Each case (row) consists of several information (columns) grouped in contingent information: lean-related information, resilience-related information and performance-related information.

The overall process of Data preparation goes through three sequential phases:

- Data collection
- Data encoding
- Data aggregation

4.2.1 Data collection

The phase of data collection consists in gathering quantitative and qualitative information on specific variables by applying a sound methodology. The followed procedure is the secondary data collection methodology, also applied by Birkie et al. (2017).

According to this methodology, firstly an initial list of incidents is obtained considering only those incidents fitting the risk classification by Chopra and Sodhi (2004; 2014), for example the Japan's triple disaster. Incidents are identified through news items from media such as Financial Times, Reuters and Wall Street Journal reporting SC disruption.

Then, the study identifies which are the firms involved in each incident, thus defining the cases. The final cases collected are 88, enclosed in a timeframe going from 2002 to 2018.

They may be also related to the same company facing different disruptions, such as Toyota Motor Corporation. The full list of cases is contained in Annex C.

Lastly, for each case additional information are searched on implementation of practices, contextual factors and performance level of the firm during the disruption. Overall 275 secondary data sources have been collected, spreading from annual reports, sustainability reports, case studies, incident reports, interviews, surveys, journals and research papers.

For example, performance changes have been accounted based on official reports of the quarter after the disruption. In general, the use of a heterogeneous set of information sources guarantees transparency, impartiality and no bias in the process of data collection. This topic is discussed more thoroughly in the chapter of Preliminary analysis.

It is important to state that the reference unit is the single firm or, in case of multinational with several subsidiaries, the part of the company affected by the disruption. This is also evident by the significant dominance of firm-based operational performance metrics in the measurement of the performance construct. In case of multinationals where a particular business is affected, the business unit is assumed to inherit the features of the parent firm.

4.2.2 Data encoding

Given the collected sources, data are both quantitative (e.g. survey results) and qualitative (e.g. interview transcripts). The process of encoding information varies significantly depending on the nature of the data. In case of punctual variables such as revenues and number of employees, the process of encoding is straightforward, while for textual sources, the process is more complicated.

Since the used data are mostly secondary sources and the objective is to understand whether the firm applies a specific practice or not, the majority of analysed documents are text-based. Therefore, two main issues arise: first, how to seize the qualitative information contained in a sentence and, second, how to convert a qualitative piece of information into a quantitative one to make it suitable for computer-aided analysis.

4.2.2.1 Seizing qualitative data

In order to acquire relevant information about how the firm managed the disruption, the research exploits the *NVivo* software. *NVivo* is a qualitative data analysis software that allows researchers to work with rich text-based information. It supports the coding process in a structured and organised way because it is possible to query, manage and keep track of data with ease. *NVivo* also allows to work with different file formats, including text, images, audios and dataset tabs.

NVivo introduces three important concepts that are "theme node", "case node" and "attribute".

Theme node, or simply "node", is a collection of references about a specific topic, concept or idea. In this research context, the goal of the Data encoding is to find any reference related to implemented practices or performance changes for each case study. Therefore, the node represents the single operational practice under the umbrella of LM or resilience, or performance metric.

Nodes can be organised in hierarchies, thus reflecting the relationships between HOCs, such as the Lean bundles, resilience constituents and performance objectives, and the associated LOCs, Lean and resilience practices and performance metrics respectively.

Case node, or simply "case", is the unit of observation, therefore it represents the unique combination firm – incident. Unlike the node, each case can have attributes.

Attribute is the data (demographics) known about a case. The attributes correspond to the contingent variables of the research, namely business sector, business size and operations strategy characterising the case, that is the combination firm – incident.

The coding approach is theory-driven because, in order to measure the constructs of Lean, resilience and performance, and thus it relies on a framework built from literature (see Model specification chapter). The framework identifies which practices or metrics to look for in the coding phase, allowing the definition of a node structure in *NVivo*. The coding approach is deductive because the nodes are developed prior to the examination of data.

Among the diverse coding approaches, the study adopts a coding based on queries, in particular text search queries. The text search query looks for a keyword or a combination of keywords within a case and it returns a list of references containing that combination of keywords. The researchers then manually verify the eligibility of the reference, so if it is possible to state that, for example, the firm *x* has adopted the practice *y* or suffered a decrease of the performance metric *w* in the incident *z*.

In conclusion, the final result of the coding process through the *NVivo* is a matrix that contains text-based references (i.e. sentences, quotes and official statements) of each node (Lean or resilience practice or performance metric) in a case (firm facing disruption).

4.2.2.2 Converting into quantitative data

The collection of qualitative text-based information is followed by the coding, referred as "the assignment of numbers to categories in a manner that facilitates measurement" (Hair et al., 2017, p. 9).

4.2.2.2.1 Encoding of operational practices

With regards to the Lean and resilience constructs, the *NVivo* analysis has allowed to find references that prove the implementation of a certain practice or the variation of performance during a disruption. However, it is necessary to define pre-set schemes that allow to convert the collected data into numerical values. The conversion scheme differs according to the type of variable and it is similar to the one adopted by Birkie (2016) and Birkie et al. (2017).

Considering the LM and operational resilience practices, all references in *NVivo* are encoded into binary values, which indicate whether the practice has been observed (1) or not (0).

With regards to the variations of the performance metrics, the relative changes during the disruption are encoded into three possible values: (−1) decrease in performance metric; (0) no change; or (+1) increase. The performance changes are retrieved from documents dealing with the performance implications of disruption in relation to the affected structure (e.g. group, business unit or branch level).

For both LM and resilience practices and performance variations, lack of references is accounted with the default value of zero.

4.2.2.2.2 Encoding of contextual variables

Contextual variables need to be coded as well since it is important to account for the contingency effects when evaluating the effectiveness of LM and resilience paradigms in turbulent context (Sousa and Voss, 2008). The contextual variables considered in the path model are business sector, business size and operations strategy and they are treated as categorical variables. The main characteristic of categorical variables, that makes them different from metric and ordinal variables, is the absence of intrinsic ordering of the categories.

Hence, the different sectors, operations strategies and size clusters are categories whose coding simply consists in assigning them a unique value.

4.2.2.2.2.1 Business sector

The dataset of cases consists of a representative sample of firms coming from several sectors that had to face a disruption from rom several sectors. In particular, the sectors present in the sample are automotive, electronics, industrial goods and services, chemical / pharma, leisure and personal goods, telecommunication, food and utilities and services. Information on the business sector of belonging is measured through a categorical variable that can assume values from 1 to 8 uniquely associated to each business sector.

4.2.2.2.2.2 Business size

The business size takes into account the number of employees and the revenues of the year in which the disruption occurred. Even if these two metrics relate to the entire company and not to the single firm or disrupted business part only, the effects stemming from size are supposed to replicate at lower organisational levels too. Such information is then converted from numerical value to categorical value indicating the membership of the firm to a specific size-based cluster.

As first step, in order to encode the business size, the recommendation of European union (European Union, 2003) has been utilised. In terms of workforce, if the number of employees is greater than 500, then the firm can be categorised as “Large”, otherwise as “SME”. In terms of total annual revenue, if it is higher than 50 million USD, it is categorizable as “Large” otherwise as “SME”. By applying this approach, 82 and 77 firms would result “Large” in terms of revenue and employees respectively. The result is likely connected with the higher availability of information for large firms. It is indeed more difficult to obtain rich details on incidents faced by smaller firm. Nevertheless, the result is not acceptable because the unbalance between the two clusters do not allow a fair comparison.

For this reason, instead of defining the coding scheme *ex ante*, firms are classified based on their size ex post, thus considering the variance of the sample. The *a posteriori* coding does not exploit the mean value, neither the median value, but it is rather based on a cluster analysis able to account for both employees and revenue and to handle any missing value.

Given a set of 88 cases x_1, x_2, …, x_{88} and a set of 2 objects (i.e., number of employees and total revenue) the task is to group the objects into classes so that objects within classes are more similar to one another than to members of other classes. To do that, the procedure performed with the SW package *SPSS Statistics* is structured as follows:

1. Identification of outliers through hierarchical clustering (single linkage method)
2. Removal of outliers
3. Identification of range of solutions through hierarchical clustering (Ward's method)
4. Re-inclusion of outliers

As first step a hierarchical clustering analysis is performed. Hierarchical clustering is an algorithm that clusters objects into groups in an agglomerative way (in SPSS) through a distance matrix. This study computes the distance between clusters with the squared Euclidean distance (Equation 3) because it gives more relevance to greater distances. In general, the squared Euclidean distance is the distance between the vectors associated with the pair of observations $\boldsymbol{x_i} = (x_{i1}, x_{i2}, \ldots, x_{in})$ and $\boldsymbol{x_k} = (x_{k1}, x_{k2}, \ldots, x_{kn})$:

$$D(x_i, x_k) = \sum_{j=1}^{n} (x_{ij} - x_{kj})^2$$

Equation 3. Squared Euclidean distance

In the context of analysis, the vector is the single firm whose size is described by two variables, namely the number of employees and the total revenue of the year.

With regards to the cluster method which indicates how the distance between two clusters is calculated, the research applies the single linkage method that uses as proxy of distance between the clusters c_1 and c_2 as the minimum distance between their members:

$$D(c_1, c_2) = \min_{x_1 \in c_1, x_2 \in c_2} D(x_1, x_2)$$

Equation 4. Single linkage distance

The distance is calculated for each combination of clusters and the pair of clusters with the minimum distance is merged into a single one. In this case, using the single linkage method allows to identify, and then remove, any outliers that can skew the aggregation of the firms into clusters.

The output of the first step can be visualised by the dendogram, a tree-like diagram that records the sequences of merges. In the dendogram, contained in Annex D, it is possible to detect the presence of seven outliers since they are the last ones to be aggregated into the final single cluster due to their exceptionally great size. Hence, they are removed before the fourth step of the procedure.

The clustering algorithm is then re-run, but, instead of the single linkage method, the Ward's method is applied.

$$TD_{c_1 \cup c_2} = \sum_{x \in c_1 \cup c_2} D(x, \mu_{c_1 \cup c_2})^2$$

Equation 5. Ward's method total distance

The Ward's method supposes to merge two clusters c_1 and c_2 into a single cluster $c_1 \cup c_2$ and calculates the aggregate deviation from the centroid, called total distance (TD). The next pair of clusters to be merged in the algorithm is the one with the lowest TD. The Ward's method also allows to obtain globular and fairly evenly-sized clusters.

From the dendogram in Annex E, two distinct clusters are clearly identifiable. For this reason, the business size is coded into binary variables indicating the membership of the cluster made of Large firms or the cluster made of SME firms.

4.2.2.2.2.3 Operations strategy

In accordance with the Contingency theory, it is important to account for the different production strategies when assessing the impact of LM in a disruption context (Azadegan et al., 2013; Portioli-Staudacher and Tantardini, 2012; White and Prybutok, 2001).

The research uses as reference frame the well-known classification by Wortmann (1983). With regards to manufacturing companies, the author describes the value chain as a sequence of activities, namely design, purchasing and the assembly. Such activities can be customer-driven, with information and materials flow following opposite directions, or forecast-driven, with information flow in the same direction of goods flow (Bonney et al., 1999).

The Customer order decoupling point (CODP) is the point of the value chain that separates the activities pushed by forecast from those pulled by demand. Depending on CODP positioning it is possible to identify five main operations strategies with different customisation level (Figure 16).

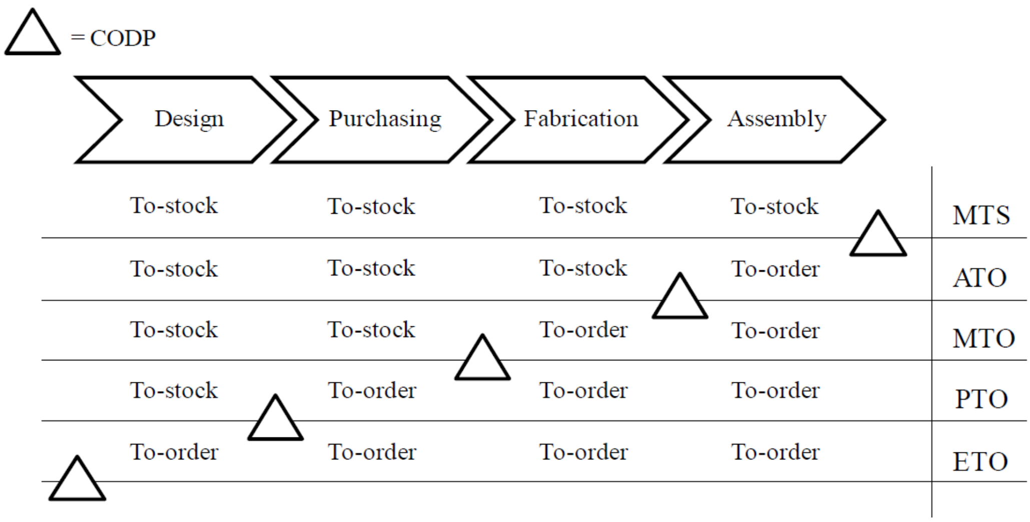

Figure 16. Operations strategy classification (Wortmann, 1983)

- *Make to stock (MTS)*: in case the lead time is higher than the time grant by the customer, companies can only adopt a MTS strategy in which the customer finds the product in stock. Producing to stock implies high inventory costs that in turn constraint the product range (Portioli-Staudacher and Tantardini, 2009).
- *Assembly to order (ATO)*: ATO companies' offering consists of fast deliveries combined with the customisation in the assembly of components produced on forecast (Muda et al., 2009). This approach is typical in the automotive sector (Markland et al., 1998).
- *Make to order (MTO)*: the processing of the material is triggered by a customer order. Long due dates allow the satisfaction of the demand without the need of anticipating the fabrication phase. The product range is wide and the customer place the order from a catalogue of pre-defined solutions.

- *Purchase to order (PTO)*: approach very similar to MTO because of wide product range and presence of catalogue containing pre-defined end items. The only difference with MTO is that also purchasing of raw materials/component is done after receiving the customer order.

- *Engineer to order (ETO)*: the customer order also affects the design of the product in terms of modifications of past designs (Wikner and Rudberg, 2005) or complete designs for new products (Cox and Blackstone, 2002; Porter et al., 1999).

In this research PTO is incorporated by MTO because of sound communalities, but also lack of information that does not allow to clearly distinguish between the two operations strategies. Consequently, the four operations strategy MTS, ATO, MTO and ETO are accounted through a categorical variable that assumes values of 1, 2, 3 and 4 respectively.

In conclusion, it is possible to describe the dataset through the several information gathered as shown in Table 17.

By business sector		By business size		By operations strategy	
Business sector	Count	Business size	Count	Operations strategy	Count
Automotive	21	Small and medium	59	MTS	26
Electronics	29	Large	29	ATO	31
Chemical / Pharma	7			MTO	20
Industrial goods and services	16			ETO	11
Leisure and personal goods	9				
Utilities and services	3				
Telecommunication	1				
Food	2				
Total	88	Total	88	Total	88

Table 17. Dataset description

In terms of business sector there are three dominant sectors (i.e., automotive, electronics and industrial goods and services), but the coverage of different sector is good. With regards to the business size, the two clusters are not perfectly balanced, but they are both well populated. Lastly, the four types of operations strategy distribute well among the 88 cases.

4.2.3 Data aggregation

Before assessing the path model by running the PLS-SEM algorithm in *SmartPLS 3*, it is necessary to understand how the scores at indicator level contribute in defining the scores at the construct level. This is because the significance of structural relationship is evaluated at the level of higher order construct.

With regards to LM and resilience bundles, the LV score is obtained as linear combination of the associated indicator LV scores weighted by the outer weights. The computational process is better explained in the paragraph PLS Algorithm. Unlike Birkie (2016) and Birkie et al. (2017) that adopt an item parcelling approach based on the computation of the average value, this study avails of the definition of latent value (Equation 1). Following the structure of the path model (Figure 13), the construct score is given by the weighted sum of the associated indicator scores also considering the outer weights.

With regards to the performance variation after a disruption, the construct is obtained through a sum score approach. This approach merges several indicators, related to the different performance metrics, into a single overall construct. In particular, the construct score is obtained by summing the indicator scores, thus corresponding to a linear combination with all outer weights equal to 1.

The sum score approach results into a single indicator for the performance construct in the path model and it also considers the severity of disruption. Disruptions differ from each other in terms of magnitude and it is indeed not possible to compare the worsening of delivery lead time due to an earthquake (type III scenario) with the one caused by the installation of a new ERP system (type I scenario).

There are three types of disruption scenario (Birkie, 2016):

- *Type I*: routine and fairly "predictable" incidents solvable without much noticeable degradation of operations. Short delays, greater than expected demand, damage of only a few of the product / input range, information exchange problems and short delays in logistics and internal operations belong to this category.

- *Type II*: events affecting the operability of facilities with limited damage to a few facilities among multiple (location) capabilities. This disruption scenario includes destruction of utility assets, damage to multiple products or inputs, few sourcing bases affected, little predictability and extended delays.

- *Type III*: most severe events which destruct company's assets or key components suppliers, affect multiple suppliers, competitors or customers, or damage people's health and well-being. They are highly unpredictable with a deep impact on multiple tiers of the SC.

The disruption scenario is modelled as a multiplicative coefficient, that can assume values of 1, 2 and 3 according to scenario type I, II and III respectively. Such coefficient amplifies the variation of the performance along with the increase of the severity of the disruption.

Eventually, the construct score of performance variation is adjusted with a constant value of +45 in order to ensure a positive range [0, 90]. The formula for the computation of performance for each case *i* is shown below (Equation 6):

$$Performance_i = \sum_j x_{ij} * Severity_i + 45$$

Equation 6. Performance formula

where x_{ij} represents the change of performance metric *j* for the case *i*.

With regards to contingent variables, they are not aggregated since they consist of a single item which indicates category belonging.

4.3 Preliminary analysis

At this point of the study, based on the research propositions and literature review, the path model has been created (Figure 13). Both the measurement models of latent constructs and the structural relationships are hence defined. Moreover, data is collected and coded, and the multiple schemes for its aggregation are defined.

However, prior to the Model assessment, it is necessary to perform a preliminary analysis, as indicated in the chapter of Research methodology (Table 8). In this phase, data is checked relatively to the goodness of sample size and the presence of statistical bias.

4.3.1 Statistical bias

Bias in statistics is any type of error or distortion that is found with the use of statistical analyses (Piedmont, 2014). Presence of bias negatively affects the reliability and validity of research.

Reliability refers to the level of consistency of the measurement by a specific method. If the same result can be consistently achieved by using the same methods under the same circumstances, the measurement is considered reliable. Concerning this research, reliability must be considered throughout the data collection process. In particular, the procedure followed for data collection has been applied consistently throughout the entire dataset.

Validity refers to the level of accuracy of the measurement by a specific method. High validity of research means that the obtained results correspond to real properties, characteristics, and variations in the physical or social world. Concerning this research, validity refers to ability of properly measuring the latent variables of LM, resilience and performance. If the three constructs are correctly measured, then any possible relationship can be considered valid, thus confirming the initial research propositions.

The concepts are related by the fact that if a measurement is valid, it is also reliable. However, the inverse relationship is not always true.

4.3.1.1 Common method bias

In order to assess the consistency in the data collection process, the preliminary analysis considers the method variance, explained as “the variance attributable to the measurement method rather than to the construct of interest" (Bagozzi and Yi, 1991, p. 426). Qualitative researches, such as the one conducted to analyse secondary sources of information, require researchers to pay attention to the adopted method because it might result into Common Method Bias (CMB), one of the main sources of measurement error (Podsakoff et al., 2013). The measurement error in turn provides an explanation for the observed relationship between constructs different from the hypothesized one.

Podsakoff et al. (2013) state that CMB can be caused by a common source or rater, a common item context, a common measurement context or by the characteristics of the items themselves. Potential sources of CMB are the use of same respondent / source for measuring the predictor and criterion variables, the item complexity and/or ambiguity and time and location of measurement.

The principle used to control method variance is "to identify what the measures of the predictor and criterion variables have in common and eliminate or minimize it through the design of the study" (Podsakoff et al., 2013, p. 887). Therefore, in order to develop a methodology that ensures the reliability of results, three procedural remedies are adopted within the data collection process. Firstly, the unit of reference of the research, namely the "case", is broken down into its two components "firm" and "incident". This means that firm-related information (i.e. LM and resilience practices, and contextual variables) is collected mainly through official company reports, while incident-related information (i.e. performance variations) through incident reports without any crossing. Secondly, a time lag between the measurement of the predictor and criterion variables is introduced. The data collection process has initially searched for performance-related information for all the 88 cases, then resilience- and finally lean-related information. Lastly, the measurement model of the constructs are rigorously designed through the definition of practices and relationships between practices. Example of rigour is the applied mini-Delphi method that has led to the re-wording of a practice, thus removing a potential source of bias in the phase of coding.

After having introduced the procedural remedies adopted before the collection of data, some statistical remedies are performed after the collection process. It is important to say that these procedures do not solve method bias, but they only detect it. Tehseen et al. (2017) suggest performing the Harman's single-factor test and the correlation matrix procedure. Another adopted procedure is the computation of the Variance inflation factor (VIF) among constructs (Kock, 2015).

The Harman's single-factor test is a post hoc procedure that checks whether a single factor is accountable for variance in the data (i.e. more than 50% of variance explained) (Chang et al., 2010). However, it cannot be computed for dichotomous or Boolean variables, namely the indicator variables of the research.

The correlation matrix procedure, instead, assesses the level of correlation between constructs and it is built exploiting the latent variable scores from 5000 bootstrapping samples. Correlation is analysed through the Pearson's correlation coefficient (Table 18) and the Spearman's rank correlation coefficient (Table 19). Both coefficients are shown to analyse the linear and monotonic relationship due to the non-normality of Lean construct (Table 16).

		1.	2.	3.
1.	Lean			
2.	Performance	.360***		
3.	Resilience	.059	.345***	

***. Correlation is significant at the 0.01 level (2-tailed).

Table 18. Correlation matrix (construct level) - Pearson's coefficient

		1.	2.	3.
1.	Lean			
2.	Performance	.373***		
3.	Resilience	.067	.325***	

***. Correlation is significant at the 0.01 level (2-tailed).

Table 19. Correlation matrix (construct level) - Spearman's coefficient

Since all relationships have coefficient <0.9 in both cases, then it is possible to state that method bias is absent (Tehseen et al., 2017). However, the sound significance of the correlations between the exogenous constructs and the endogenous one gives hints about a potential relationship whose causality is examined in the phase of Structural Model assessment.

Another method, proposed by Kock 2015), is the computation of the Variance inflation factor (VIF), an indicator of collinearity between constructs. The VIF assessment is performed three times, each one of them with a different construct as endogenous construct.

Inner construct	(a)	(b)	(c)
Lean	-	1.004	1.075
Performance	1.105	-	1.104
Resilience	1.067	1.004	-

Table 20. VIF assessment (construct level)

According to Kock (2015), if there is no value higher than 3.3, then the dataset is devoid of CMB. As it is possible to see in *Table 20*, the condition is fulfilled for all the cases (a), (b) and (c).

4.3.1.2 Observed heterogeneity

An important aspect that several researchers fail at considering when applying the PLS-SEM is the heterogeneity of the dataset. The implicit assumption is that the used sample stems from a homogeneous population (Hair et al., 2017), but actually the observed cases relate to companies with different characteristics. Not taking into account the heterogeneity generates misleading results, thus threatening the validity of PLS-SEM results (Becker et al., 2013; Hair et al., 2012). Observations should be classified into groups and the PLS-SEM results evaluated separately for each group.

Heterogeneity can be observed through contextual variables that, in this research context, are business sector, business size and operations strategy. In accordance with the CT, already explained in a dedicated paragraph in Literature review, it is necessary to consider also these variables to control the contingent effects (Sousa and Voss, 2008).

In conclusion, the effects of contextual variables are formulated into the research propositions *H3*, *H4*, *H5* because of theoretical evidence from literature and in order to avoid biased PLS-SEM results.

4.3.2 Sample size

One of the main reasons behind the utilisation of PLS-SEM is that it relaxes the constraint of sample size of CB-SEM (Hair et al., 2012; Peng and Lai, 2012). PLS-SEM indeed represents a good methodological alternative for theory-testing when the assumptions of CB-SEM, including large sample size, are violated (Hair et al., 2017). Jöreskog and Wold (1982) and Wold (1982) define it as “soft modelling” because it does not require the “hard” distributional assumptions of maximum likelihood of CB-SEM.

However, PLS-SEM has been subject to scepticism and critics (Rönkkö et al., 2016) mainly because of a wrong application, especially with regards to the assumption of reduced sample size. Several researchers have indeed abused the model since it has been used despite a too small sample size (Goodhue et al., 2012).

The sample is a representative portion of the entire population reflecting its similarities and differences. From a technical perspective, the size must be large enough to guarantee sufficient statistical power.

Statistical power is the capability of seizing a significant relationship when it is in fact significant in the population. On the one hand, low statistical power means not revealing a significant effect of the population (thus committing a Type II error). On the other hand, greater statistical power means that PLS-SEM is more likely to identify relationships as significant when they are indeed present in the population (Sarstedt and Mooi, 2014).

Statistical power and sample size are encompassed by the statistical power analysis which argues that the four inferential variables, namely sample size, significance criterion, population effect size and statistical power, are connected (Cohen 1992; Wong, 2013). In the context of research, sample size can be interpreted as function of the other three variables. Hence, given a certain level of statistical power, it is possible to understand what is the sample size required for that level of power.

Based on this principle, the sample size of the research (88) is evaluated by means of three different methods of increasing complexity to understand if the corresponding statistical power is acceptable or not.

Firstly, the 10 times rule (Barclay et al., 1995) is verified. It is a rule of thumb stating that sample size should be equal to the larger of:

- 10 times the largest number of formative indicators used to measure a single construct (i.e. the largest measurement equation or LME);
- 10 times the largest number of structural paths directed at a particular construct in the structural model (i.e. the largest structural equation or LSE).

Observing the path model (Figure 13), the LME is 8, related to the 8 formative indicators forming the Lean bundle of JIT. With regards to LSE, the 2 exogenous variables of Lean and resilience are directed at the endogenous variable of Performance. Therefore, the minimum sample size requirement is 80 and it is satisfied.

However, the 10 times rule may be too simplistic because it does not consider additional parameters, thus resulting in hypothesis tests with low power (Peng and Lai, 2012).

Alternatively, Wong (2013) proposes a method used in marketing researches to identify the minimum sample size. Sample size can be driven by the significance level, the statistical power, the minimum R^2 in the model and the maximum number of arrows pointing at a latent variable (Hair et al,. 2017). Assuming significance level equal to 5%, statistical power of 80% and R^2 values of at least 0.25, the choice of the sample size only depends on the number of arrows (Table 21).

Minimum sample size required	Maximum # of arrows pointing at a latent variable in the model
52	2
59	3
65	4
70	5
75	6
80	7
84	8
88	9
91	10

Table 21. Sample size recommendation (Wong, 2013)

As it can be noted, a number of arrows equal to 8 implies a minimum sample size of 84. The requirement is satisfied also in this case.

The third and last method is developed by Cohen (1992). It is the most complete method since it considers all the four inferential variables with the only assumption of statistical power equal to 80%. Table 22 suggests the sample size given a set configuration of number of arrows, minimum R^2 and significance level α.

Maximum Number of Arrows Pointing at a Construct (Number of Independent Variables)	Significance Level											
	10%				5%				1%			
	Minimum R^2				Minimum R^2				Minimum R^2			
	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75	0.10	0.25	0.50	0.75
2	72	26	11	7	90	33	14	8	130	47	19	10
3	83	30	13	8	103	37	16	9	145	53	22	12
4	92	34	15	9	113	41	18	11	158	58	24	14
5	99	37	17	10	122	45	20	12	169	62	26	15
6	106	40	18	12	130	48	21	13	179	66	28	16
7	112	42	20	13	137	51	23	14	188	69	30	18
8	118	45	21	14	144	54	24	15	196	73	32	19
9	124	47	22	15	150	56	26	16	204	76	34	20
10	129	49	24	16	156	59	27	18	212	79	35	21

Table 22. Sample size recommendation (Cohen, 1992)

According to Table 22, given the maximum number of arrows in the path model equal to 8, a sample size of 88 allows to achieve a minimum R^2 of 0.25 at all the significance levels.

In conclusion, the sample size is high enough for the model to detect significant relationships. In addition, the procedural and statistical remedies applied for the reduction of CMB, combined with the awareness of heterogeneity of dataset, reduce the bias in the analysis, thus making the results obtained more valid and reliable. In the next phase of Model assessment, a further assessment on the validity of the methodology is done with regards to the measurement model.

4.4 Model assessment

The PLS-SEM is a variance-based SEM technique in which relationships between latent variables (LVs) are assessed. The relationships are represented through a path model which consists of a measurement model and a structural model. The measurement model, also called outer model, explains the measurement of the constructs lean, performance and resilience through observable indicators. The structural model, also called inner model, aims at identifying components of causality between such constructs.

In the Model specification phase, both models have been meticulously defined. Now, in the Model assessment phase, their specifications are validated in order to ensure validity and reliability of the results. The assessment starts with the measurement model first because the prerequisite for structural model evaluation is that measurement model is reliable and valid (Hair et al., 2017, Peng and Lai, 2012).

The assessment is conducted by applying a bootstrapping procedure that creates 5000 samples. Trough bootstrapping it is possible to estimate standard errors and the significance of parameter estimates (Chin, 1998).

As previously explained, in addition to the significance of a parameter, the bias-corrected and accelerated (BCa) bootstrap confidence interval is reported as well.

4.4.1 Measurement model

The way LVs are measured, i.e. the measurement theory, has a profound impact on the way the measurement model is assessed. In particular, the research path model conceptualises the production paradigms of LM and resilience as formative constructs. Formative measures do not necessarily covary, so assessing them based on correlation patterns may lead to negative consequences for the content validity of the measure (Hair et al., 2017)

Our path model hypothesizes LM and resilience as formative constructs which can be indirectly measured through the practices currently adopted within the firm. The level of leanness or resilience of a firm is thus determined by how many practices the firm has implemented.

The research follows the procedure from Hair et al. (2017) that consists of three sequential steps:

- Convergent validity
- Collinearity assessment
- Significance and relevance of formative indicators

Convergent validity ensures that the indicators correctly cover all the facets of the formative construct. The collinearity technique assesses the relationships between formative indicators and the contributions of indicators to constructs are assessed by examining the indicators' significance and relevance.

It is important to remember that the constructs are made by more than a single layer of indicators (see Table 11 and Table 14). Lean is indeed subdivided into three underlying constructs, in turn subdivided into operational constructs (i.e. HRM, JIT, TPM, TQM) directly connected with indicators (Shah and Ward, 2003; 2007). Same happens for the operational resilience whose antecedents are the constituents of collaboration, flexibility, velocity and visibility from Jüttner and Maklan (2011). It is, therefore, necessary to iterate the three-steps procedure for all the levels (Sarstedt et al., 2019).

4.4.1.1 Convergent validity

Convergent validity is the extent to which a formative measure is positively correlated with a reflective measure of the same construct. Since the model is not provided with reflective measures for Lean and resilience, the convergent validity cannot be tested through a redundancy analysis.

4.4.1.2 Collinearity assessment

With regards to formative indicators, "lack of fit is to be expected" (Wilcox et al., 2008, p. 1226). This means that, in contrast to reflective indicators that are interchangeable, high correlations are not expected between items.

High correlations between two formative indicators is referred as collinearity (multicollinearity in case of multiple indicators involved) and may occur for several reasons. For example, an indicator is the linear combination of the other one, so they are not semantically distinguishable. Presence of collinearity between indicators represents an issue for the PLS-SEM. The algorithm cannot properly calculate one of the two outer weights, that are the results of a multiple regression of the construct on its set of indicators.

To assess the level of collinearity, the used indicator is the Variance inflation factor (VIF) that is the reciprocal of tolerance (TOL). Being TOL the amount of variance of one formative indicator not explained by the other indicators of the same construct, the ideal value is as low as possible. An indicator's VIF level of 5 indicates that 80% of its variance is accounted for by the remaining formative indicators related to the same construct and this is not acceptable. The threshold value of VIF above which there is an issue of collinearity is 5 (Hair et al., 2017).

4.4.1.3 Significance and relevance of formative indicators

The third and last step for the assessment of formative measurement models relates with checking the significance and relevance of the outer weights of formative indicators. As anticipated before, the outer weight is the result of a multiple regression (Hair et al., 2010) between indicator scores and construct scores as independent and dependent variables respectively.

Then, the values of the outer weights are standardised so that they can be compared with each other to understand the relative contribution. In order to assess whether they contribute in forming the construct or not, the significance of the difference from the null value is tested by means of the bootstrapping procedure.

4.4.2 Structural model

Once the reliability and validity of construct measures are confirmed, the assessment of the structural model is performed to decide whether empirical data support the research propositions. This means examining the model's capability to predict one or more target constructs.

In contrast to CB-SEM that adopts a covariance-based approach, PLS-SEM estimates the parameters through a variance-based approach that maximises the explained variance of the endogenous LV.

In this regard, six steps are followed (Hair et al., 2017):

- Collinearity assessment
- Path coefficient
- Coefficient of determination (R^2)
- Effect size (f^2)
- Predictive relevance (Q^2)
- Effect size (q^2)

First step deals with examining the structural model for collinearity using tolerance value and VIF criteria as before. The reason is that the estimation of path coefficients in the second step might be biased in case of critical levels of collinearity among the independent constructs. Then, path coefficients are estimated in order to assess the significance and relevance of the structural relationships. In step three, PLS-SEM calculates the coefficient of determination (R^2) which represent "the exogenous latent variables' combined effects on the endogenous latent variable" (Hair et al., 2017, p. 198). In step four, PLS-SEM calculates the effect size (f^2) to evaluate the effect of each predictor variable on the criterion variable. The last two steps regarding the predictive relevance (Q^2) and the effect size (q^2) cannot be performed because of the absence of endogenous reflective constructs in the path model.

4.4.2.1 Collinearity assessment

To assess collinearity, the same approach for the evaluation of the formative measurement models is used. Presence of collinearity, expressed through the VIF, is checked between the exogenous LVs. Similarly to the previous assessment phase, the threshold value for the VIF is 5.

4.4.2.2 Path coefficients

Path coefficients represent the estimation of the hypothesized relationships among constructs after running the PLS-SEM algorithm. Path coefficient is calculated for each structural path through an OLS regression between an endogenous LV and the associated exogenous LV. The individual path coefficient of the path model can be interpreted as the standardized beta coefficient in an OLS regression. A variation by one unit of the exogenous LV changes the endogenous LV by the size of the path coefficient, being everything kept constant (Hair et al., 2010).

Path coefficients are assessed in terms of significance and relevance. It is relevant if the module of the path coefficient is far from 0. Very low values close to 0 are usually not significantly different from zero. The sign of the parameter instead indicates the direction of the relationship (i.e. positive or negative).

The significance of the path coefficient is determined by the standard error that is obtained through a bootstrapping procedure. The standard error allows to compute the empirical *t* value, then compared with a critical *t* value in order to assess the significance with a certain probability error (i.e. significance level).

4.4.2.3 Coefficient of determination (R^2)

The coefficient of determination (R^2) measures the predictive power of the model and it is calculated as the squared correlation between the actual and the predicted values of a specific endogenous construct. R^2 represents the amount of variance in the endogenous construct explained by all of the exogenous constructs linked to it.

The range of the coefficient of determination goes from 0 to 1, but there is no standard rule for its assessment since it depends on the research discipline and model complexity.

R^2 value tends to increase with increasing number of exogenous constructs considered by the model. Hence, to avoid the bias towards complex models, the adjusted coefficient of determination (R^2_{adj}) is introduced and formally defined as follows (Equation 7):

$$R^2_{adj} = 1 - (1 - R^2) * \frac{n - 1}{n - k - 1}$$

Equation 7. Adjusted coefficient of determination

where n is the sample size and k is the number of exogenous LVs used to predict the endogenous LV in question.

Through k and n, the R^2_{adj} value adjusts the increase of explained variance due to non-significant exogenous constructs.

4.4.2.4 Effect size (f^2)

Effect size (f^2) is an indicator complementary to R^2 that evaluates whether omitting a construct has a meaningful impact on the endogenous constructs in terms of change of R^2. The effect size can be calculated as follows (Equation 8):

$$f^2 = \frac{R^2_{included} - R^2_{excluded}}{1 - R^2_{included}}$$

Equation 8. Effect size

where $R^2_{included}$ and $R^2_{excluded}$ are the R^2 values of the endogenous construct when the exogenous construct in question is respectively included in and excluded from the model.

The research follows the guidelines by Cohen (1988) for the assessment of f^2. In particular, values of 0.02, 0.15, and 0.35, respectively, represent small, medium, and large effects (Cohen, 1988) of the exogenous construct. Effect size values lower than 0.02 indicate absence of effect.

4.5 Advanced analyses

The standard procedure of PLS-SEM generally stops with the assessment of quality of the structural model. Significance and relevance of paths and predictive power of the model are assessed, thus finding evidence for match between theorised relationships and empirical relationships.

However, there are questions still unanswered: how do model relationships change if we consider a third variable? What is the impact of contextual factors? Which bundles of practice are most significant? Which bundles have the highest priority for implementation?

It is clear that the mere assessment of the direct effects cannot provide an answer to the above questions. Therefore, the research continues the investigation on additional effects by means of the following analyses:

- Indirect effect analysis
- Importance – performance map analysis (IPMA)
- Mediation effect analysis
- Moderation effect analysis

Indirect effect and importance – performance analyses shift the focus from the construct level to the bundle level in attempt to understand which ones mostly contribute in performance improvement. Mediation and moderation analyses consider a third variable influencing the relationship between LM and performance. In particular, mediation effect involves the construct of operational resilience, while moderation effect consider the contextual variables from the environment.

4.5.1 Indirect effect analysis

While direct effects are relationships linking two constructs with a single arrow, indirect effects are sequences of two or more direct effects with at least one intervening construct involved. The two constructs are not therefore connected with a single arrow.

Indirect effect is an effect occurring between two variables not directly connected through an arrow. The idea of this analysis is to understand which sub-paths are significant after having tested for the significance of the direct effect between a production paradigm and performance. For this reason, the indirect effect analysis logically positions itself after the direct effects analysis.

For example, given a HOC with a significant impact on the endogenous, the analysis wants to understand which LOC, among the ones associated to the HOC, is the main driver of performance improvement.

The analysis is possible because the constructs of Lean and resilience are HCMs with more than one layer of latent variables. Secondly, the analysis makes sense for formative measures in which the LOCs all contribute in forming the HOC in an independent way. In case of reflective measurement, an analysis on the LOC would lead to the conclusion that all sub-constructs are significant because of their inter-changeability.

The indirect effect is calculated as the product of the path coefficient between the HOC and performance and the outer weight between the LOC and the HOC. The requirement is that both paths must be significant with an empirical t value higher than the critical t value.

4.5.2 Importance – performance map analysis

The importance – performance map (IPMA) is an extension of the analysis of direct effects since each construct is described both in terms of Importance and Performance, thus providing relevant managerial insights.

Importance is expressed through the total effect, namely the sum of direct and indirect effects in the structural model, on a specific target construct. Performance instead is expressed through the average LV score (Fornell et al., 1996; Höck et al., 2010).

It is appropriate to specify that the "Performance" dimension, measured as average LV score of the exogenous construct, is not related with the endogenous construct of performance variation upon disruption.

The LV score is then rescaled according to a range from 0 to 100 (Höck et al., 2010). This facilitates the comparison of different LV scores that are calculated on different interval scales. In this research, the performance dimension has been calculated following the approach by Fornell et al. (1996) as follows (Equation 9):

$$LV_{rescaled} = \left(\frac{\sum_{i=1}^{j} w_i * \bar{x}_i - \sum_{i=1}^{j} w_i * min[x_i]}{\sum_{i=1}^{j} w_i * max[x_i] - \sum_{i=1}^{j} w_i * min[x_i]} \right) * 100$$

Equation 9. Performance dimension (Fornell et al., 1996)

where w_i is the indicator weight associated with indicator x_i, $max[x_i]$ and $min[x_i]$ denote, respectively, the maximum and the minimum possible values for indicator x_i.

Once obtained both the dimensions, the predecessor constructs can be plotted in a map that allows to identify the most significant drivers of performance improvement and how to prioritise them. The goal is to identify those constructs with relatively high importance (i.e. strong total effect), but also relatively low performance (i.e. low average LV scores). These constructs, located in the lower right part of the map, represent potential areas of performance improvement. A minor improvement in terms of performance indeed leads to a remarkable positive impact on the target construct.

The IPMA needs two requirements to be met. First, all the indicators must be coded in the same direction, so a low value represents a negative outcome and a high value a positive outcome. Second, the outer weights must not be negative. Only if the outer weights are positive, the performance values will stay on the range from 0 to 100.

4.5.3 Mediator and moderator effect analysis

After proving the significance of relationships between constructs of the path model, further research is required for a better assessment of the model relationships.

In fact, an estimated cause-effect relationship may not be the “true” effect because a systematic influence from an external factor is not accounted for in the model. Including a third variable in the analysis could change the understanding of the nature of the model relationship. Such inclusion refers to the effects of mediation and moderation.

In case of mediation, the third variable intervenes on the relationship between the two related constructs first-hand. While, in case of moderation, the third variable affects the nature of the relationship, in terms of direction and strength.

Therefore, this research proposes to study the mediation effect by operational resilience and the moderation effect by contextual variables in order to better explain the relationship between lean and performance.

4.5.3.1 Mediation

Mediation occurs when a third variable accounts for the relationship between an independent and a dependent variable (Baron and Kenny, 1986). More precisely, a change in the exogenous construct causes a change in the mediator variable, which, in turn, results in a change in the endogenous construct in the PLS path model.

With regards to the above definition, this research introduces the operational resilience of a firm as the mediator of the relationship between LM and performance. The variations in the level of LM cause variations in the level of resilience that in turn reflect on performance variation.

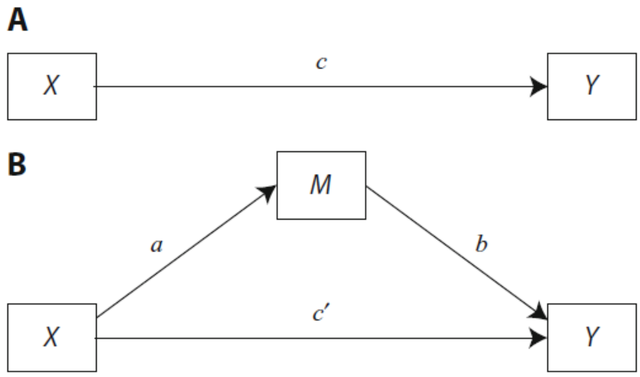

Figure 17. Illustration of direct (A) and mediation (B) effect (Preacher and Hayes, 2008)

The objective is to understand if the Lean's effect on performance is direct or actually mediated by the operational resilience. Hence, the direct and indirect effect are compared both in terms of significance and relevance. Therefore, to measure the effects of operational resilience on the relationship between LM and performance, the causal step strategy by Baron and Kenny (1986) is adopted.

Considering Figure 17, *M* can be defined mediator if:

Step 1: X significantly accounts for variability in *M*;

Step 2: X significantly accounts for variability in *Y*;

Step 3: M significantly accounts for variability in *Y* when controlling for *X*;

Step 4: the effect of *X* on *Y* decreases substantially when *M* is entered simultaneously with *X* as a predictor of *Y*.

In terms of paths, the above criteria require "*a*, *b*, and *c* to be significant and *c'* to be smaller than *c* by a nontrivial amount" (Preacher and Hayes, 2008, p. 880).

As advocated by Preacher and Hayes (2008), the research tests for the mediation effect by means of the bootstrapping procedure in *SmartPLS 3*.

4.5.3.2 Moderation

Considering the literature review of previous studies about lean implementation and development of resilience constituents, this study accounts for the contextual variables. The objective of moderation is to assess the impact of the moderator variable as it is able to change the strength or even the direction of a relationship between two constructs. The effect of business sector, business size and operations strategy is therefore examined to quantitatively validate the research propositions *H3*, *H4* and *H5*.

Moreover, moderation is also a means to account for heterogeneity in the data, as already explained in the chapter of Preliminary analysis. The analysis of the data on an aggregate level considering the sample of observables homogeneous, can easily lead to false conclusions in terms of model relationships. Negative and positive group-specific effects may even cancel each other at an aggregate level, thus suggesting the absence of a significant relationship.

The moderation analysis is split into two sub-parts, the first one focused on the constructs themselves, while the second one on the relationships beween such constructs.

In the first part, an ANOVA test is performed to understand if different categories of size, sector and operations strategy are associated to levels of resilience and Lean Management statistically different from each other. The assumptions of ANOVA test, concerning the normality of residuals and the homogeneity of variance, are first verified. Then, the significance of the difference between the mean LV scores for different levels of categorical variables is assessed.

The second part exploits the multi-group analysis (MGA) to identify significant differences in terms of path coefficient for each path of interest. The research considers only the two paths connecting the exogenous constructs of LM and resilience and the endogenous construct of performance.

MGA simultaneously moderates all the relationships of the path model, in contrast with the approach based on dummy variables that evaluates the relationships one at a time. MGA hence offers a more complete picture of the moderators' influence because the impact is examined on all model relationships.

From a statistical perspective, the null hypothesis of MGA is that path coefficients are not significantly different, so the difference between path coefficients based on different samples is 0.

With regards to the choice of the approach for MGA, the study has opted for a non-parametric approach because more consistent with the non-parametric nature of PLS-SEM. Then, among the non-parametric alternatives existing in literature such as the permutation approach by Chin and Dibbern (2010) and Dibbern and Chin (2005), Henseler et al. (2009) proposed a non-parametric MGA approach that builds on bootstrapping results.

Their PLS-MGA approach compares each bootstrap estimate of one group with all other bootstrap estimates of the same parameter in the other group. The probability is then computed by counting the number of times the bootstrap estimate of the first group is larger than those of the second group. This is the approach used and implemented in *SmartPLS 3*.

In order to minimise the computational effort by the algorithm, the MGA does not consider the entire path model inclusive of both measurement model and structural model. Only structural model is considered and the constructs are measured through the LV scores obtained in the previous analysis of direct effects.

Before doing the MGA, it has been necessary to verify if the size of the sub-samples is sufficiently large and balanced among all sub-samples. For this reason, concerning the business sector, the study considers only the three most represented categories (i.e. Automotive, Electronics, Industrial goods and services) since considering all of them would lead to error. Then, with regards to the operations strategy, ETO and MTO have been merged in order to guarantee a balance among the sub-samples. This choice can be justified considering that, according to the classification by Wortmann, (1983) both strategies have most of the activities in the value chain order-driven.

In conclusion, the MGA simultaneously analyses all the relationships in the model, but it compares only two categories for each moderator variable. For this reason, each possible combination of categories for each moderator variable is assessed.

5 FINDINGS

This chapter presents the overall findings of this research in a progressive sequence. First of all, the results related to the assessment of measurement models for the constructs are presented. Then, the causal relationships among latent variables are explored, both in terms of direct and indirect effects. Lastly, mediation effects of operational resilience and moderation effects of business sector, business size and operations strategy are shown respectively.

Each analysis serves a specific purpose by addressing one of the research propositions, previously defined. The assessment of measurement model is a preliminary, but still necessary analysis since it gives reliability and validity to the results obtained in the following analyses.

The assessment of structural model focuses on the direct effect of Lean Manufacturing (LM) on performance in a context of disruption (*H1*), further deepened by the indirect effect and importance – performance map analyses.

The mediation effect investigates on the role as mediator of operational resilience (*H2*), while the impact of contextual variables in the moderation effect analysis focuses on *H3*, *H4* and *H5*.

For the sake of brevity, the defined indicators for the measurement of the latent variables LM and resilience (Table 11 and Table 14) are renamed with a code containing the bundle to which they refer followed by a sequential number. See Annex F for more details.

5.1 Assessment of measurement model

The first step of the assessment is the computation of the variance inflation factor (VIF) in order to detect any issue of collinearity between indicators. The presence of collinearity represents a problem since it undermines the statistical significance of an independent variable, thus affecting the validity of the individual indicators. A VIF value of 5 or higher indicates a collinearity problem within formative first-order indicators (Hair et al., 2017).

Indicator	VIF
COLL_1	1.226
COLL_2	1.188
COLL_3	1.011
COLL_4	1.029
FLEX_1	1.083
FLEX_2	1.260
FLEX_3	1.110
FLEX_4	1.266
FLEX_5	1.155
FLEX_6	1.245
FLEX_7	1.250
HRM_1	1.236
HRM_2	1.246
HRM_3	1.084
HRM_4	1.120
JIT_1	1.105
JIT_2	1.394
JIT_3	1.700
JIT_4	1.332
JIT_5	1.250
JIT_6	1.866
JIT_7	1.231
JIT_8	1.648
SUPP_1	1.059
SUPP_2	1.059
TPM_1	1.446
TPM_2	1.312
TPM_3	1.071
TPM_4	1.178
TPM_5	1.070
TQM_1	1.206
TQM_2	1.070
TQM_3	1.449

TQM_4	1.163
TQM_5	1.539
VEL_1	1.425
VEL_2	1.058
VEL_3	1.229
VEL_4	1.120
VEL_5	1.238
VIS_1	1.012
VIS_2	1.053
VIS_3	1.064

Table 23. VIF results - Indicator level

As seen in Table 23, all formative indicators are way below the maximum value of 5 indicating the collinearity is not an issue for formative measurements assessment.

The next step aims at verifying the significance and relevance of formative indicators by checking the outer weights. In order to establish the significance of outer weights of formative indicators, the analysis sets a significance level equal to 10% (α = 0.1) and a probability of error equal to 1.65. Table 24 shows the results of outer weights of formative indicators.

First order construct	Indicator	Outer weight (Outer loading)	*t* Value	*p* Value	Sig.	95% BCa Confidence interval
Collaboration	COLL_1	0.567 (0.813)	1.524	0.128	NS	[-0.379, 1.034]
	COLL_2	0.622 (0.841)	1.791	0.073	*	[0.024, 1.064]
	COLL_3	0.121 (0.176)	0.465	0.642	NS	[-0.385, 0.652]
	COLL_4	-0.073 (0.073)	0.195	0.846	NS	[-0.738, 0.841]
Flexibility	FLEX_1	0.457 (0.599)	1.516	0.129	NS	[-0.218, 0.877]
	FLEX_2	-0.254 (-0.322)	1.127	0.260	NS	[-0.722, 0.143]
	FLEX_3	0.209 (0.271)	0.796	0.426	NS	[-0.287, 0.746]
	FLEX_4	0.300 (0.100)	0.986	0.324	NS	[-0.408, 0.791]
	FLEX_5	0.078 (0.090)	0.306	0.760	NS	[-0.437, 0.607]
	FLEX_6	0.259 (0.577)	0.992	0.321	NS	[-0.209, 0.749]
	FLEX_7	0.545 (0.737)	2.378	0.017	**	[0.198, 0.945]
HRM	HRM_1	0.201 (0.574)	1.729	0.084	*	[-0.027, 0.428]
	HRM_2	0.776 (0.909)	8.201	0.000	***	[0.571, 0.943]
	HRM_3	0.343 (0.534)	3.315	0.001	***	[0.135, 0.535]
	HRM_4	-0.015 (0.261)	0.134	0.893	NS	[-0.233, 0.226]
JIT	JIT_1	-0.106 (-0.132)	0.986	0.324	NS	[-0.317, 0.095]
	JIT_2	0.035 (0.312)	0.296	0.767	NS	[-0.214, 0.246]
	JIT_3	0.522 (0.790)	4.585	0.000	***	[0.317, 0.765]
	JIT_4	0.170 (0.580)	1.521	0.128	NS	[-0.045, 0.397]
	JIT_5	0.398 (0.610)	3.466	0.001	***	[0.187, 0.634]

	JIT_6	-0.061 (0.541)	0.468	0.640	NS	[-0.337, 0.177]
	JIT_7	0.283 (0.593)	2.566	0.010	**	[0.070, 0.500]
	JIT_8	0.187 (0.463)	1.537	0.124	NS	[-0.039, 0.435]
Supplier	SUPP_1	0.663 (0.806)	3.962	0.000	***	[0.264, 0.917]
	SUPP_2	0.609 (0.765)	3.696	0.000	***	[0.271, 0.911]
TPM	TPM_1	0.348 (0.699)	2.615	0.009	***	[0.076, 0.601]
	TPM_2	0.481 (0.751)	4.376	0.000	***	[0.269, 0.699]
	TPM_3	0.404 (0.596)	3.464	0.001	***	[0.183, 0.634]
	TPM_4	-0.037 (0.315)	0.334	0.739	NS	[-0.271, 0.167]
	TPM_5	0.319 (0.522)	2.700	0.007	***	[0.089, 0.554]
TQM	TQM_1	0.225 (0.590)	2.535	0.011	**	[0.061, 0.415]
	TQM_2	0.117 (0.334)	1.243	0.214	NS	[-0.059, 0.316]
	TQM_3	0.148 (0.648)	1.378	0.168	NS	[-0.052, 0.378]
	TQM_4	0.310 (0.589)	3.642	0.000	***	[0.145, 0.478]
	TQM_5	0.616 (0.893)	6.442	0.000	***	[0.412, 0.783]
Velocity	VEL_1	0.428 (0.650)	1.233	0.218	NS	[-0.149, 1.098]
	VEL_2	0.506 (0.479)	1.769	0.077	*	[0.016, 0.923]
	VEL_3	0.229 (0.550)	0.872	0.383	NS	[-0.337, 0.709]
	VEL_4	0.016 (0.315)	0.044	0.965	NS	[-0.708, 0.774]
	VEL_5	0.492 (0.709)	1.440	0.150	NS	[-0.200, 1.018]
Visibility	VIS_1	0.487 (0.557)	0.998	0.318	NS	[-0.656, 0.999]
	VIS_2	0.648 (0.757)	1.601	0.109	NS	[-0.100, 1.051]
	VIS_3	0.399 (0.596)	0.941	0.347	NS	[-0.414, 1.012]

Note: NS stands for "Not significant"

*** $p < .01$. ** $p < .05$. * $p < 0.1$.

Table 24. Outer weight assessment - Indicator level

For all indicators resulting non-significant, the procedure shown in Figure 18 is adopted in combination with the analysis of theoretical relevance since "formative indicators should never be discarded simply on the basis of statistical outcomes" (Hair et al., 2017, p. 149).

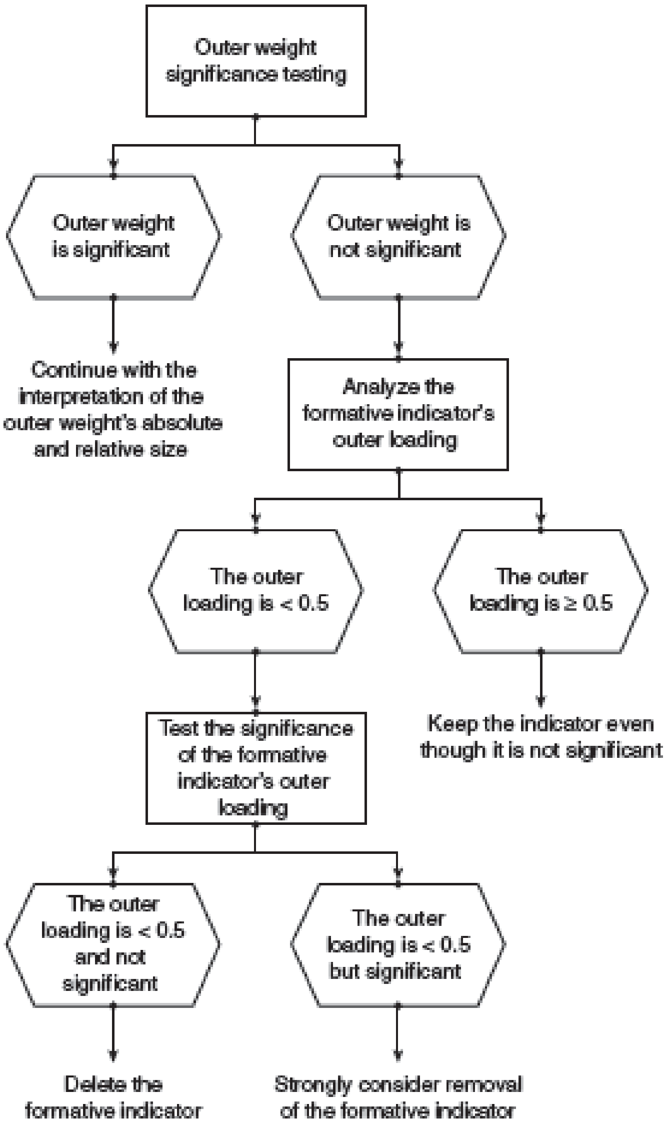

Figure 18. Retention procedure for formative indicators (Hair et al., 2017)

Eventually, six indicators are removed. *COLL_3*, *COLL_4* and *VEL_4* (i.e. "*Long-term supplier relationships are developed*", "*Pre-incident, long-term relationships based on trust are developed with key customers*" and "*Task forces make use of a systematic recovery process to solve problems*") are built upon theoretical support, but overlap with other indicators in terms of contents. *FLEX_2*, *FLEX_4* and *FLEX_5* (i.e. "*Demand is shifted across time, market or product*", "*Enhanced value propositions are offered to customers*" and "*Production and delivery are adjusted by balancing available resources*") instead, neither have a strong theory-driven conceptualisation, nor empirical support because of outer loading < 0.1 and outer weight not significant (Cenfetelli and Bassellier, 2009).

Now, following the same reasonings, it is necessary to assess the upper levels related to first-order and second-order constructs (Sarstedt et al., 2019). As shown by the tables below (i.e. Table 25, Table 26, Table 27, Table 28), there are no problems related to collinearity between constructs, nor insignificant outer weights.

First order construct	VIF
Collaboration	1.362
Flexibility	1.498
HRM	2.815
JIT	2.846
TPM	2.501
TQM	3.641
Velocity	1.442
Visibility	1.077

Table 25. VIF results - First-order construct level

Second order construct	First order construct	Outer weight	*t* Value	*p* Value	Sig.	95% BCa Confidence interval
Internal	HRM	0.298	8.481	0.000	***	[0.242, 0.379]
	JIT	0.295	10.114	0.000	***	[0.236, 0.352]
	TPM	0.254	8.793	0.000	***	[0.197, 0.311]
	TQM	0.274	8.244	0.000	***	[0.215, 0.347]
Resilience	Collaboration	0.378	10.126	0.000	***	[0.332, 0.486]
	Flexibility	0.398	12.7035	0.000	***	[0.363, 0.490]
	Velocity	0.373	11.3995	0.000	***	[0.326, 0.457]
	Visibility	0.220	3.949	0.000	***	[0.052, 0.291]

Note: NS stands for "Not significant"

*** $p < .01$. ** $p < .05$. * $p < 0.1$.

Table 26. Outer weight assessment - First-order construct level

Second order construct	VIF
Customer	1.071
Internal	1.463
Supplier	1.547

Table 27. VIF results - Second-order construct level

Third order construct	Second order construct	Outer weight	*t* Value	*p* Value	Sig.	95% BCa Confidence interval
Lean	Customer	0.257	1.933	0.053	*	[-0.152, 0.395]
	Internal	0.517	8.589	0.000	***	[0.410, 0.639]
	Supplier	0.526	9.998	0.000	***	[0.446, 0.654]

Note: NS stands for "Not significant"

*** $p < .01$. ** $p < .05$. * $p < 0.1$.

Table 28. Outer weight assessment - Second-order construct level

In conclusion, the selected indicators and bundles significantly contribute in forming the operations paradigms of Lean Management and resilience. It is, therefore, possible to proceed with the assessment of the structural model in order to understand the impact of LM on performance.

5.2 Assessment of structural model

Assessing the structural model means assessing the significance of the coefficient paths in the model. The followed procedure again searches for issues of collinearity between constructs by means of the VIF and the correlation matrix. Given the non-parametric nature of PLS-SEM and the non-normality of LM (Table 16), the correlation matrix considers the Spearman's rho coefficient r_s.

	1.	2.	3.
1. Lean			
2. Performance	.373***		
3. Resilience	.067***	.325***	

***. Correlation is significant at the 0.01 level (2-tailed).

Table 29. Correlation matrix

Inner construct	VIF
Lean	1.003
Resilience	1.003

Table 30. VIF results - Inner construct level

It is possible to see from Table 29 that there is significant correlation (*p-value* < 0.01) and r_s has "moderate" strength ($0.30 < r_s < 0.50$) according to Cohen et al. (2003). Moreover, no collinearity issues emerge from Table 30 since VIF < 5.

Then, the main parameters of the structural model, namely path coefficients, coefficient of determination and effect sizes, are shown.

Path	Path coefficient (β)	*t* Value	*p* Value	95% BCa Confidence interval
Lean → Performance	0.344	3.354	0.001	[-0.618, 0.370]
Resilience → Performance	0.311	2.025	0.043	[-0.057, 0.489]

Table 31. Path coefficients

From Table X the direct effect of Lean on performance is significant at a 1% significance level (*p*-value = 0.001). The positive sign indicates that Lean Management and performance are directly proportional.

With regards to the path Resilience → Performance, β is significant at a 5% level of significance (p-value = 0.043) and its sign is positive.

Construct	R^2	R^2 adj.	f^2
Lean	-	-	0.152
Resilience	-	-	0.124
Performance	0.226	0.208	-

Table 32. Coefficient of determination and effect sizes

In terms of performance, the model is able to explain about the 20% of endogenous variance. According to Cohen (1988), the size effects of resilience and LM are small and medium respectively (see page 102 for the evaluation guidelines).

Table 33 and Table 34 indicate the number of firms in the sample with a specific combination of Lean or resilience and performance, classified as “High” or “Low” based on the mean value of the LV scores.

		Performance	
		Low	High
Lean	Low	31	14
	High	15	28

Table 33. Frequency of Lean - performance scenarios

		Performance	
		Low	High
Resilience	Low	24	6
	High	22	36

Table 34. Frequency of resilience - performance scenarios

It is possible to see that most cases lie on the diagonal where the independent variable (i.e. LM or resilience) and the dependent variable (i.e. performance) are both High or Low, thus indicating a relationship between the exogenous and endogenous constructs.

5.3 Indirect effect analysis

After having found evidence for direct effects, indirect effects are now analysed in order to understand which are the most relevant lower order constructs.

Lower order construct	Indirect effect	*t* Value	*p* Value	Significance	95% BCa Confidence interval
Customer	0.097	1.478	0.139	NS	[-0.004, 0.282]
Internal	0.286	1.949	0.051	*	[-0.592, 0.393]
Supplier	0.044	0.601	0.548	NS	[-0.025, 0.528]
HRM	0.018	0.135	0.892	NS	[-0.177, 0.402]
JIT	0.222	1.122	0.262	NS	[-0.209, 0.523]
TPM	-0.009	0.046	0.963	NS	[-0.340, 0.226]
TQM	0.070	0.495	0.620	NS	[-0.095, 0.531]
Collaboration	0.270	2.137	0.033	**	[0.159, 0.564]
Flexibility	0.027	0.321	0.748	NS	[-0.100, 0.206]
Velocity	0.058	0.657	0.511	NS	[-0.079, 0.259]
Visibility	-0.008	0.093	0.926	NS	[-0.259, 0.099]

Note: NS stands for "Not significant"

*** $p < .01$. ** $p < .05$. * $p < 0.1$.

Table 35. Indirect effects assessment

Internal practices for Lean and Collaboration capability for resilience represent the lower-order constructs that impact on performance to a greater extent with a level of significance α of 5% and 10% respectively.

Going furtherly down into the four Internal bundles of Lean, there are no significant indirect effects on performance.

5.4 Importance – performance map analysis

The importance – performance map (IPMA) is an extension of the analysis of direct effects by including the performance of the constructs or bundles, meant as rescaled average LV score. Importance, the horizontal dimension, indicates the significance that the construct has on the target construct, namely the performance variation upon disruption, and it corresponds to the path coefficients previously analysed. Performance (not to be confused with the target construct "performance") indicates the level of implementation of the construct, operationalised as the mean of the latent variable scores obtained from running the PLS model.

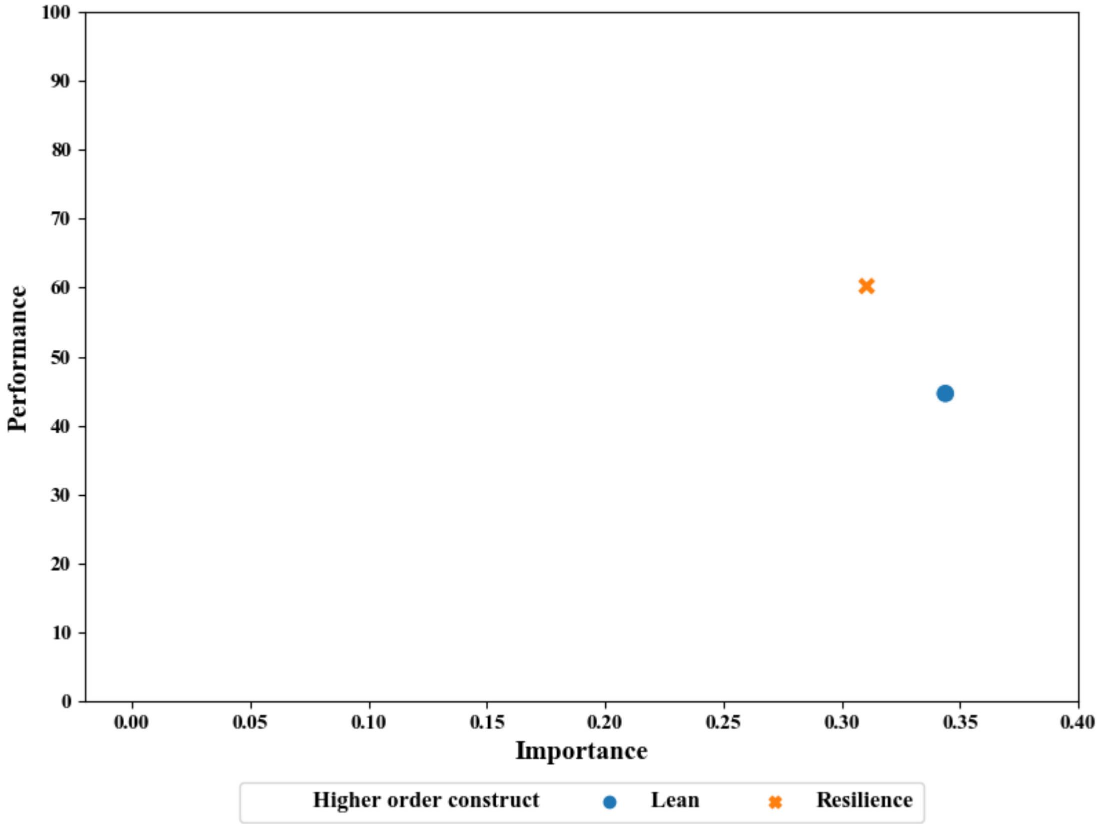

Figure 19. Importance - Performance map (construct level)

From Figure 19 it is possible to observe that Lean, in comparison with Resilience, has higher Importance, but lower Performance. This means that it is less implemented despite having higher impact on the target construct performance.

IPMA is carried out at the bundle level, thus extending the analysis of indirect effects.

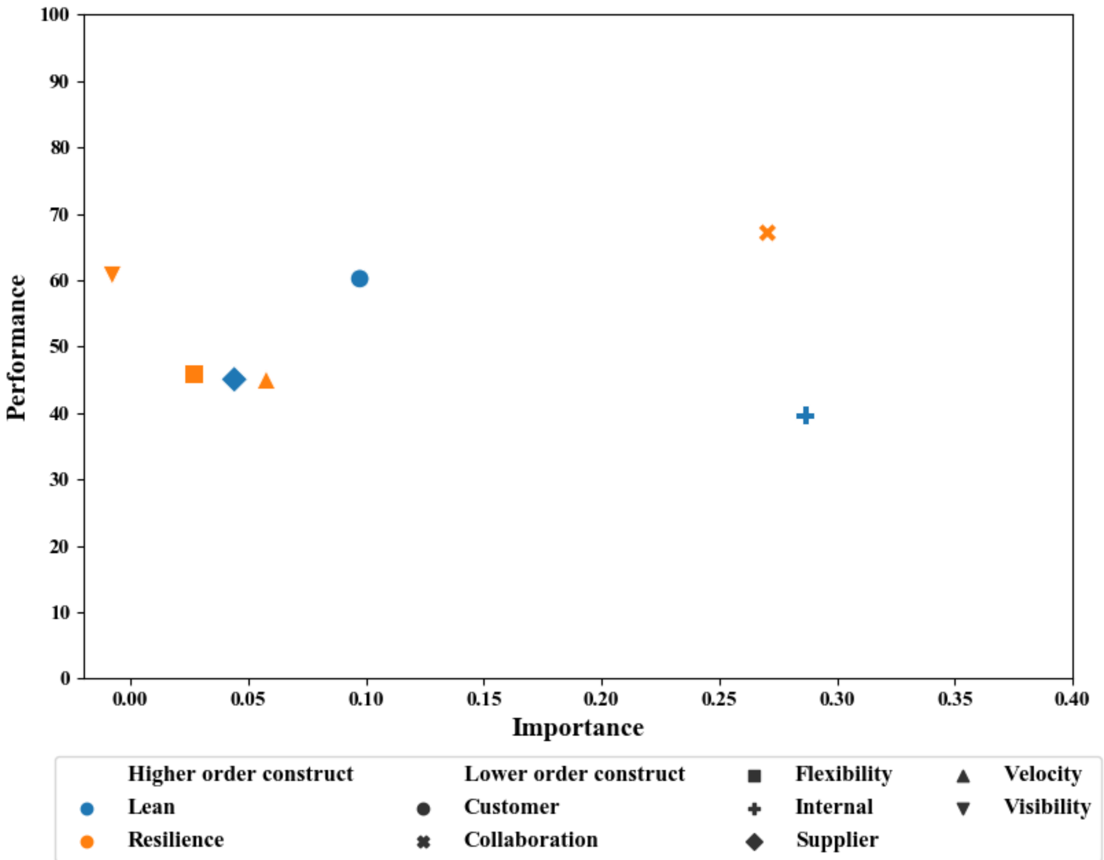

Figure 20. Importance - Performance map (bundle level)

Coherently with the indirect effect analysis, Collaboration and internal Lean practices are the most significant drivers of performance during disruption. From the map it is also possible to observe that among firms Collaboration practices are more spread than internal Lean practices.

5.5 Mediation effect

The mediation effect of operational resilience on the relationship between Lean and performance is evaluated through the procedure by Baron and Kenny (1986) (see page 106) utilised in conjunction with the bootstrapping procedure (Preacher and Hayes, 2008).

First step consists of evaluating the direct effect between the independent variable and the dependent variables, namely Lean and performance. As already assessed in Table 31, direct effect is significant given a *p-value* lower than α-level equal to 1%.

Path	Direct effect	t Value	p Value	95% BCa Confidence interval
Lean → Performance	0.344	3.354	0.001	[-0.618, 0.370]

Table 36. Step 1 of mediation effect assessment

In the second step the relationship between the independent variable and the mediator, namely Lean and performance.

Path	Direct effect	t Value	p Value	95% BCa Confidence interval
Lean → Resilience	-0.009	0.146	0.884	[-0.773, 0.382]

Table 37. Step 2 of mediation effect assessment

As can be seen from Table 37, the relationship is not significant given a *p-value* higher than a significance level of 10%. This means that the path coefficient is not significantly different from 0, thus implying no mediation effect caused by resilience on the relationship LM – performance.

5.6 Moderation effect

The analysis of the contingent effects is carried out at two different levels. Firstly, the impact on the construct is assessed through an ANOVA test that requires prior verification of assumptions (i.e. normality of residuals and homogeneity of variance or homoscedasticity). In case of non-normality, the Kruskall Wallis test is performed instead of ANOVA test. In case of heteroscedasticity, Welch's test is performed instead of ANOVA test. Secondly, the impact on the relationship (moderating effect) is assessed through a multi-group analysis (MGA).

As already explained in the chapter Advanced analyses, the levels of business sector, business size and operations strategy are respectively three (i.e. Automotive, Electronics, Industrial goods and services), two (small and medium, large) and three (MTS, ATO, MTO and ETO).

The analysis is performed for the exogenous constructs of the research framework, namely LM and resilience, thus resulting in twelve sub-analyses.

5.6.1 Lean manufacturing

5.6.1.1 Business sector

Statistic	df	Sig.
0.984	75	0.478

Table 38. Normality test - Business sector

	Levene Statistic	df1	df2	Sig.
Based on Mean	2.049	3	71	0.115
Based on Median	1.41	3	71	0.247
Based on Median and with adjusted df	1.41	3	62.542	0.248
Based on trimmed mean	2.012	3	71	0.120

Table 39. Levene's test - Business sector

With regards to the contingent effect of the business sector on the Lean construct, the assumptions are valid. Given p-value (0.478) > $\alpha = 0.05$, the null hypothesis of normality is accepted (Table 38). The null hypothesis of homogeneity of variance is also accepted because the p-value (0.115) is higher than α (Table 39).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.86	3	0.62	0.556	0.646
Within Groups	79.134	71	1.115		
Total	80.994	74			

Table 40. ANOVA test - Business sector

Finally, from the ANOVA test it is possible to argue that the mean is the same for all groups because the null hypothesis is accepted (Table 40). This means that the business sector has no effect on the implementation level of Lean, so differences in Lean are not attributable to difference in business sector.

Path	Automotive			Electronics			Industrial goods and services		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value	β_3	*t* Value	*p* Value
Lean → Performance	0.351	2.015	0.044	0.291	2.175	0.030	0.293	1.428	0.153

Table 41. Path coefficient per category - Business sector

From Table 41, it is possible to say that all the sub-samples have a significant path coefficient β, except for Industrial goods and service. However, this is the least populous sub-sample (16 cases), so, increasing the size, β_3 may become significant.

Path	Automotive vs Electronics		Automotive vs Industrial goods and services		Electronics vs Industrial goods and services	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value	$\lvert \beta_1 - \beta_3 \rvert$	*p* Value	$\lvert \beta_2 - \beta_3 \rvert$	*p* Value
Lean → Performance	0.060	0.765	0.059	0.802	0.001	0.990

Table 42. Differences between path coefficients - Business sector

In terms of moderation effect, the difference between path coefficients related to distinct business sectors is not significant in any case (Table 42). This means that the positive impact of Lean on performance does not vary according to the business sector.

5.6.1.2 Business size

Statistic	df	Sig.
0.982	88	0.268

Table 43. Normality test - Business size

	Levene Statistic	df1	df2	Sig.
Based on Mean	0.126	1	86	0.724
Based on Median	0.115	1	86	0.735
Based on Median and with adjusted df	0.115	1	84.876	0.735
Based on trimmed mean	0.112	1	86	0.739

Table 44. Levene's test - Business size

With regards to the contingent effect of the business size on the Lean construct, the preliminary assumptions related to the ANOVA test are validated, therefore the residuals are normal (Table 43) and the variances are homogeneous (Table 44).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	18.982	1	18.982	23.65	0.000
Within Groups	69.027	86	0.803		
Total	88.009	87			

Table 45. ANOVA test - Business size

The ANOVA test in Table 45 confirms a significant difference (*p-value* = 0.000) between SME firms and large firms in terms of lean implementation. In particular, large firms have higher lean implementation level than small and medium firms coherently with Shah and Ward (2003). The lean implementation level is measured as mean value of the latent variable scores for each category.

Path	Large			Small and Medium		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value
Lean → Performance	0.295	1.552	0.121	0.382	4.932	0.000

Table 46. Path coefficient per category - Business size

Considering Table 46, β_2 is significant, while β_1 not significant (*p-value* > α = 10%). A possible explanation is the reduced size of the sub-sample (29 cases involving large firms) that prevents the path Lean – performance to be significant.

Path	Large vs Small and Medium	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value
Lean → Performance	0.087	0.701

Table 47. Differences between path coefficients - Business size

From Table 47 it is possible to claim that the size of the firm does not moderate the relationship between Lean and performance. This means that being either a small or large firm does not modify the advantage given by Lean on the performance in disruption.

5.6.1.3 Operations strategy

Statistic	df	Sig.
0.981	88	0.235

Table 48. Normality test - Operations strategy

	Levene Statistic	df1	df2	Sig.
Based on Mean	8.941	2	85	0
Based on Median	6.783	2	85	0.002
Based on Median and with adjusted df	6.783	2	68.079	0.002
Based on trimmed mean	8.422	2	85	0

Table 49. Levene's test - Operations strategy

With regards to operations strategy, once verified the normality of residuals (Table 48), the Levene's test (Table 49) refuses the null hypotheses of homogeneity of variances. For this reason, Welch's test is carried out instead of ANOVA test because it is more robust against the violation of the assumption of homoscedasticity.

Statistic	df1	df2	Sig.
4.555	2	53.62	0.015

Table 50. Welch's test - Operations strategy

The resulting conclusion from Table 50 is that the level of lean implementation is influenced by the positioning of the CODP (Wortmann, 1983). This means that different levels of lean implementation do depend on different operations strategies.

Path	MTS			ATO			MTO and ETO		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value	β_2	*t* Value	*p* Value
Lean → Performance	0.344	2.333	0.020	0.441	3.485	0.000	0.221	1.798	0.072

Table 51. Path coefficient per category - Operations strategy

All path coefficients related to operations strategy-based sub-samples are significant with a common significance level α = 10% (Table 51).

Path	MTS vs ATO		MTS vs MTO and ETO		ATO vs MTO and ETO	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value	$\lvert \beta_1 - \beta_3 \rvert$	*p* Value	$\lvert \beta_2 - \beta_3 \rvert$	*p* Value
Lean → Performance	0.098	0.616	0.122	0.512	0.220	0.207

Table 52. Differences between path coefficients - Operations strategy

Nevertheless, path coefficients are not significantly different between each other, meaning that the relationship is not affected by this contingent effect (Table 52). Hence, firms belonging to different operations strategies benefit from the implementation of lean in the same way.

5.6.2 Operational resilience

5.6.2.1 Business sector

Statistic	df	Sig.
0.911	75	0.000

Table 53. Normality test - Business sector

With regards to the contingent effect of the business sector on the resilience construct, from Table 53 it is possible to state that the sample is not normally distributed, therefore the study exploits the non-parametric Kruskal Wallis test that transforms data into ranked data.

Kruskal-Wallis H	df	Asymp. Sig.
1.899	3	0.594

Table 54. Kruskal Wallis test - Business sector

Being p-value higher than $\alpha = 5\%$, the null hypothesis of equal mean ranks among sectors is accepted. This means that as for Lean, also for the implementation level of resilience, the business sector does not have a significant impact (Table 54).

Path	Automotive			Electronics			Industrial goods and services		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value	β_3	*t* Value	*p* Value
Resilience → Performance	0.413	2.618	0.009	0.092	0.543	0.587	0.091	0.324	0.746

Table 55. Path coefficient per category - Business sector

Concerning the moderation effect of business sector, β_1 is the only significant path coefficient (Table 55). It means that only for the Automotive sector it is possible to state that resilience has a positive impact on performance under disruption. This is a clear example of "observed heterogeneity", as discussed in the chapter of Preliminary analysis. Without partitioning the data, the fact that for some categories the relationship is not significant would never be discovered.

Path	Automotive vs Electronics		Automotive vs Industrial goods and services		Electronics vs Industrial goods and services	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value	$\lvert \beta_1 - \beta_3 \rvert$	*p* Value	$\lvert \beta_2 - \beta_3 \rvert$	*p* Value
Resilience → Performance	0.322	0.167	0.322	0.353	0.001	0.941

Table 56. Differences between path coefficients - Business sector

Consequently, also observing Table 56, βs are not different from each other, so the impact of resilience on performance is the same regardless of the business sector making the stratification of the analysis useless.

5.6.2.2 Business size

Statistic	df	Sig.
0.884	88	0.000

Table 57. Normality test - Business size

Kruskal-Wallis H	df	Asymp. Sig.
2.005	1	0.157

Table 58. Kruskall Wallis test - Business size

With regards to contingent effects of the business size on the resilience construct, resilience is not normally distributed (Table 57) and there are no substantial differences between the mean ranks of SME firms and large firms concerning the resilience implementation (Table 58). This means that different levels of resilience implementation level do not depend on different levels of size.

Path	Large			Small and Medium		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value
Resilience → Performance	0.142	0.759	0.448	0.356	3.150	0.002

Table 59. Path coefficient per category - Business size

In terms of relationship between resilience and performance, only the path of SMEs is significant (Table 59). However, this is likely related to an insufficient number of cases involving large firms (29) compared to the SMEs (59) that prevent to properly study the path.

Path	Large vs Small and Medium	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value
Resilience → Performance	0.214	0.323

Table 60. Differences between path coefficients - Business size

From Table 60 it is possible to see that the two path coefficients are not significantly different to imply a moderation effect by the size on the relationship between resilience and performance.

5.6.2.3 Operations strategy

Statistic	df	Sig.
0.855	88	0.000

Table 61. Normality test - Operations strategy

Kruskal-Wallis H	df	Asymp. Sig.
1.333	2	0.513

Table 62. Kruskal Wallis test - Operations strategy

Then, the results reported in Table 61 and Table 62 about normality of residuals and difference among mean ranks are the same results obtained for resilience in business sector and business size. Since the sample is not normally distributed (*p-value* < 0.05), the non-parametric test is performed. The obtained *p-value* (0.513) does not allow to reject the null hypothesis of equal mean ranks. It can be inferred that the level of resilience of a firm is not dependent on its operations strategy.

Path	MTS			ATO			MTO and ETO		
	β_1	*t* Value	*p* Value	β_2	*t* Value	*p* Value	β_2	*t* Value	*p* Value
Resilience → Performance	0.528	3.499	0.000	0.133	0.863	0.388	0.291	1.953	0.051

Table 63. Path coefficient per category - Operations strategy

With regards to the moderating effect of the operation strategy on the relationship between operational resilience and performance, all paths are meaningful except for ATO (Table 63). This means that the direct effect at aggregated level is still valid when partitioning the sample in sub-samples according to the operations strategy.

Path	MTS vs ATO		MTS vs MTO and ETO		ATO vs MTO and ETO	
	$\lvert \beta_1 - \beta_2 \rvert$	*p* Value	$\lvert \beta_1 - \beta_3 \rvert$	*p* Value	$\lvert \beta_2 - \beta_3 \rvert$	*p* Value
Resilience → Performance	0.395	0.077	0.238	0.262	0.157	0.464

Table 64. Differences between path coefficients - Operations strategy

Looking at Table 64, there is a significant difference between the paths related to MTS and ATO. However, it is not observed for the other options. Considering that MTS and ATO are the most populous sub-samples, by increasing the size of all sub-samples, the significance would extend to the other options as well. This implies that operations strategy is a contextual factor that moderates the relationship between resilience and performance.

6 DISCUSSION

This study strives to empirically examine the role of Lean Manufacturing (LM) in a context of disruption. Therefore, 14 research propositions have been formulated to be empirically tested. The research hypotheses cover:

- The direct effect of Lean on performance upon disruption (*H1*);
- The mediating effect of resilience between Lean and performance (*H2*);
- The contingent effects of business sector, business size and operations strategy on the level of Lean practices (*H3a*, *H4a*, *H5a*);
- The contingent effects of business sector, business size and operations strategy on the level of resilience practices (*H3b*, *H4b*, *H5b*);
- The moderating effects of business sector, business size and operations strategy on the relationship between Lean and performance (*H3c*, *H4c*, *H5c*);
- The moderating effects of business sector, business size and operations strategy on the relationship between resilience and performance (*H3d*, *H4d*, *H5d*).

The discussion, after a necessary initial premise to argue on the validity of the measurement model, follows the same logical sequence adopted for the formulation of the hypotheses. Firstly, the impact of LM on performance is assessed, then followed by the analysis of the relationship between LM and operational resilience. Lastly, the discussion ends by addressing the effect of contingency on the two constructs.

6.1 Impact of Lean on performance

Within a context of disruption, there are contrasting views about the impact of LM on the performance of the firm. Christopher and Holweg (2011) argue that efficiency-based approaches are not suitable for an uncertain context where turbulence is inevitable. For example, the reduction of buffer availability and inventory, distinctive feature of LM, makes the firm more vulnerable (Birkie, 2016; Chopra and Sodhi, 2014). However, there are papers and business cases (Cox et al., 2011) that support the convenience of adopting LM during disruption. It is claimed that it reduces variability (Shah and Ward, 2007) and increases responsiveness and flexibility performance (Womack and Jones, 1997), thus showing that "lean could be a suitable approach not only in stable but also in disruptive environments" (Birkie, 2016, p. 186).

The research hypothesis *H1* formulates a positive direct effect of LM on performance when a disruption occurs. The research tackles the proposition through the SEM technique, in particular by assessing the structural model.

The preliminary analysis carried out already gives hints about a significant relationship between LM and performance since the Spearman's rho coefficient r_s has significant moderate strength (Table 29).

Assessing the structural model means assessing the significance of the coefficient path β between LM and performance in the model. From Table 31 the adopted bootstrapping procedure has generated a *p-value* (0.001) lower than a significance level of 1%, thus rejecting the null hypothesis of no effect. β is equal to 0.344 and its positive sign indicates that Lean Management positively impacts on performance in a disruption context.

The main feature of the PLS-SEM algorithm is that it maximises the explained variance of endogenous constructs (Fornell and Bookstein, 1982; Hair et al., 2014). With regards to performance, the model is able to explain more than 20% of endogenous variance, almost in line with Table 22. According to Cohen (1988), the size effects of LM is medium. This means that removing the construct from the model, significantly worsens the coefficient of determination, thus indicating the relevance of the size of the effect.

Moreover, the firms in the sample characterised by low level of LM suffered from disruption in a greater extent than the ones that invested more in LM. This phenomenon can be witnessed by looking at Table 33. Here, most frequent scenarios are on the diagonal where the independent variable (i.e. LM) and the dependent variable (i.e. performance) are correlated.

In conclusion, the overall findings indicate that, in a turbulent context, embracing Lean and related practices has a remarkable positive impact in terms of performance. The mitigated variation of performance upon disruption due to Lean is coherent with papers of the literature review (Birkie, 2016; Shah and Ward, 2007).

6.2 Relationship between Lean and resilience

After the assessment of the direct impact of Lean on performance, the research wants to provide further understanding with regards to the relationship of LM with resilience, a production paradigm that allow firm to prepare, respond and recover from disruption according to Ponomarov and Holcomb (2009).

Resilience has indeed a significant impact in terms of mitigation of disruption, as corroborated by the SEM model in the analysis of direct effects: β is significant and positive (Table 31) and f^2 is small, but still significant (Table 32). This means that removing the construct does not heavily affect the coefficient of determination of the model. Then, observing Table 34, it is possible to state that, as for LM, most of analysed firms show a correspondence between resilience and performance since they lie on the diagonal. The obtained results are hence coherent with the several papers supporting the positive impact of operational resilience on performance (Ambulkar et al., 2015; Birkie et al., 2017; Dabhilkar et al., 2016).

However, despite the similarities, it is interesting to note that the strength of the relationship with the target construct performance is higher for LM than for resilience, given a higher β and a higher f^2. This means that, in case of disruption, a unitary increase of the level of leanness leads to an improvement of performance higher than the one caused by a unitary increase of the resilience level.

Another relevant difference between the two constructs is the way they contribute in improving performance, assessed through the analysis of the indirect effects. The goal is to understand which are the most relevant bundles of practices in terms of performance improvement. Observing Table 35, the internally-related practice bundle and the collaboration constituent represent the bundles that most impact on performance for Lean and resilience respectively. Therefore, the two production paradigms contribute in mitigating the performance variation in disruption through two distinct approaches: LM, being efficiency-driven, is more focused on internal processes, while resilience is more external oriented pursuing partnerships with other SC players. These results are coherent with scientific literature such as Sheffi (2007) and Jüttner and Maklan (2011) who emphasise the importance of coordination and collaboration with suppliers and customers. In addition, Bortolotti et al. (2013) state that JIT is the practice that most contributes to performance improvement, but not in case of high variability. The research, on the contrary, supports the suitability of internal practices even in case of disruption.

Moreover, by means of the Importance – Performance map analysis (IPMA), it is possible to assess the constructs Lean and resilience in terms of Importance and Performance (see Figure 19). Observing the map, Lean has higher Importance and lower Performance compared to resilience. This means that Lean is more impactful than resilience, as already noted from Table 31, but still it is not adequately exploited to face disruptions. This means that firms should consider LM as a lever to further improve performance under disruption. The analysis can then be deepened by moving to the bundle level (Figure 20). Here, it is evident that the lower-order constructs Internal and Collaboration, respectively for Lean and Resilience, represent the two most effective way for a firm to successfully overcome a disruption, coherently with the indirect effects analysis. The interesting aspect to be observed is the Performance gap between the two constructs that indicates a wide application of collaborative resilience practices. On the contrary, internal Lean practices are poorly applied in a context of disruption. That gap, therefore, represents a hidden window of opportunity for performance improvement thanks to the implementation of internally-related Lean practices.

The research, after having clarified differences and similarities between the two constructs, formulates a mediation effect as research hypothesis. In particular, the operational resilience acts as mediator of the relationship between LM and performance in disruption. The first step, as already discovered when assessing *H1*, proves a significant relationship between Lean and resilience (Table 36). The second step (Table 37) confutes the mediating effect of resilience on the relationship between LM and performance. The two constructs are not interlinked by a causality relationship, but they rather improve the performance of firm in an independent way. Therefore, findings confirm the predominance of the direct effect of Lean on performance without any indirect effect passing through operational resilience.

This result is coherent with the analyses previously conducted. The absence of mediation is indeed aligned with the low Spearman's rho coefficient (r_s = 0.067) between LM and resilience in Table 29. Furthermore, LM and resilience impact on the performance variation in two operationally distinct ways: the former acts on internal factors, while the latter one on external factors, as argued in Table 35.

However, the result is not consistent with the theoretical background used to formulate the research hypothesis of mediation. In fact, the research hypothesis stems from a SLR which eventually identified seven papers (Table 6) that provide evidence of links between LM and resilience. In particular, an efficiency-driven approach is able to enhance multiple resilience capabilities, such as flexibility, visibility and velocity (see Annex A). The standardisation of processes through standard operating procedures indeed offers room for improvement in terms of rapidity in answering to disruptions and visibility over shared information. The logic of continuous improvement and the principle of pursuit of perfection further improve the recovery capability of the firm. Therefore, the obtained result of no mediation is accepted, but, given the theoretical background, not sufficient to draw a conclusion.

Lastly, it is important to be aware that lack of significance of the mediation effect does not imply that the effect does not actually exist. It might be presence of bias in the methodology hindering the full disclosure of the mediation effect.

6.3 Contingent Lean and resilience

In the third and last part of the research the theme of "contingency" is analysed by using *SPSS* and *SmartPLS 3*. The objective is to understand whether the size, direction and significance of a structural relationship changes according to contextual variables (i.e. business size, business sector, operations strategy) or not. Literature agrees on the importance of taking into account factors such as the firm size for both LM and resilience (Birkie et al., 2017; Shah and Ward, 2003). Structural differences between repetitive and non-repetitive operations strategies are important when implementing Lean (Portioli and Tantardini, 2008), but also when developing SC integration capabilities (Sahin and Robinson, 2005). The research aims at further extending the theoretical knowledge by verifying if such statements are still valid in a disruption context.

Given two effects, three variables and two constructs, the discussion of the results first breaks down per contingent variable (i.e. business sector, business size and operations strategy) and then per construct (i.e. Lean and resilience).

6.3.1 Analysis per contingent variable

In order to give to provide an overall view of the contingency in a disruption context, the main findings are listed below:

- The path coefficients of the relationship between LM and performance are significant for all categories of each contextual variable except for the sector "Industrial goods and services" and the size "Large". This enforces the hypothesis of a positive impact of LM on performance that still holds true despite the observed heterogeneity of the sample;
- Business sector does not impact on Lean and resilience neither on the implementation level of the construct nor on the moderation level between the construct and the performance;
- Business size and operations strategy have a significant effect on the construct Lean (ANOVA analysis).

As already mentioned in the chapter Findings, there is bias in the significance of path coefficients, in turn reflected on their difference. For example, neither Lean → Performance nor Resilience → Performance are significant relationships in case of large firms or firms belonging to the Industrial goods and services sector. These findings may mistakenly lead to the conclusion that the implementation of LM or resilience does not result into any performance improvement. These phenomena can be traced back to the sample size, sufficient on an aggregate level, but still inadequate when stratified.

A significant moderating effect occurs between MTS and ATO, the two most populous sub-samples, therefore such effect is assumed to recur for all categories of operations strategy. With regards to the business size, the sample of large firms in under-represented. However, the effect is kept in light of Birkie et al. (2017) that argue that SC complexity, which includes size, has a positive moderating effect on the relationship between resilience and performance upon SC disruption.

A third finding can, therefore, be added:

- Business size and operations strategy have a significant moderating effect on the relationship between resilience and performance.

The three findings obtained from the analysis of contextual variables can be displayed through the following table (Table 65):

Construct	Contextual variable	Effect on	
		Construct	Relationship
Lean	Operations strategy	X	
	Business sector		
	Business size	X	
Resilience	Operations strategy		X
	Business sector		
	Business size		X

Note: X stands for “Significant”

Table 65. Summary of contingency on constructs

As it is possible to see, all contextual variables have an impact either on the construct or on the relationship. The only exception is represented by business sector variable, which is not influential for constructs or relationships. Consequently, it is important to account for such factors during the phases of design, monitoring etc., but also when benchmarking with other firms.

6.3.2 Analysis per construct

Moreover, an interesting pattern emerges by looking at Table 65.

On the one hand, LM is influenced at the construct level, so, for example, different operations strategies correspond to different Lean implementation levels. On the other hand, resilience is influenced at the relationship level. In other words, contingent variables moderate resilience, but are mediated by Lean (Figure 21):

Firms adopt a strategic approach for the implementation of Lean since they account for the operating context as decision-making criteria. As a result, the influence of size and operations strategy variables on performance under disruption is mediated by Lean implementation.

Nevertheless, the same cannot be told about resilience which witnesses a moderating influence of the context on the performance. Such influence is not considered in the preliminary planning phase of resilience. This behaviour might be connected to a low level of maturity of resilience since it is a recent operating paradigm, developed in response to the raising uncertainty of the competitive landscape. Consequently, resilience capabilities

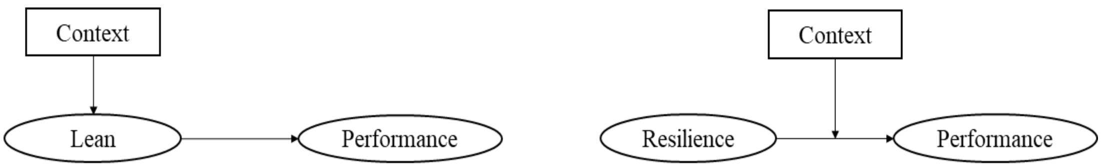

Figure 21. Contingency effect for Lean and resilience

require an equally strategic, non-contingent approach in order to create and sustain competitive advantage, according to the RBV theory. LM paradigm is instead well-known and established, but nowadays it requires a review in view of an ever-changing environment.

6.4 Final considerations

The results regarding the three macro sections of the research, namely the impact of LM on performance under disruption, the mediating effect of resilience on the relationship LM – performance and the contingent effects of contextual variables, have been assessed and then discussed against theoretical background and literature. In this way, it is possible to determine whether the research hypotheses are retained or not, thus defining the value of the research.

Considering the direct effects of the two production paradigms (i.e. Lean Manufacturing and operational resilience), both of them prove to significantly and positively impact the performance. However, the result concerning resilience is already included in the body of knowledge of operations management literature. The research, hence, merely confirms the knowledge about a relationship already widely addressed.

On the other side, the research primary objective is to provide further understanding about the role of LM within a turbulent and uncertain environment, a research stream still unexplored (*H1*). In this regard, the research confirms, on the basis of a quantitative statistical technique (i.e. SEM), that a Lean firm better offsets the variation of performance under disruption. To the best of author's knowledge, there is no precedent literature that states a positive impact of Lean Manufacturing on the performance variation due to the occurrence of a disruption. This contribution indeed represents an element of novelty that paves the way to further investigation.

Another relevant research field addressed is the Contingency theory which consists of acknowledging, and then incorporating the effects that contextual variables might have on the constructs of interest, namely Lean Manufacturing, resilience and performance. The main finding of the research is the significance of effects related to the size of the firm and its operations strategy in a disruption context (*H4*, *H5*). Accounting for such effects is impactful from both a theoretical and practical perspective. From a theoretical perspective, it is possible to assess how the impact of the production paradigm on performance changes according to the contingent variable, so heterogeneity is observed. From a practical perspective, the type of impact of the contingent variable, either on the construct or on the relationship, give interesting insights about the maturity level of the production paradigm, the way it is exploited by the firm. This part of the research is valuable since it represents an extension of existing literature that addresses also the context of disruption.

Lastly, the research focuses on the existence of a mediation relationship in which LM accounts for variation in resilience which, in turn, accounts for variation in performance. Findings indicate that the relationship is not significant, so LM and resilience act independently neglecting the formulated research hypothesis *H2*.

However, it is utterly important to understand how Lean Manufacturing combines with the resilience paradigm in order to prepare and response proactively to disruptions while minimising waste and pursuing continuous improvement.

Summary of the assessed research hypotheses and their results is shown in Table 66.

ID	Research proposition	Retained?
H1	Lean positively influences performance loss upon disruption	Yes
H2	Resilience significantly mediates the relationship between lean and performance loss.	No
H3	There is significant categorical moderating effect of business sector on:	
	e. The level of lean practices;	No
	f. The level of resilience practices;	No
	g. The relationship between lean and performance;	No
	h. The relationship between resilience and performance.	No
H4	There is significant categorical moderating effect of business size on:	
	e. The level of lean practices;	Yes
	f. The level of resilience practices;	No
	g. The relationship between lean and performance;	No
	h. The relationship between resilience and performance.	Yes
H5	There is significant categorical moderating effect of operations strategy on:	
	e. The level of lean practices;	Yes
	f. The level of resilience practices;	No
	g. The relationship between lean and performance;	No
	h. The relationship between resilience and performance.	Yes

Table 66. Summary of research hypotheses and their outcome

7 CONCLUSIONS

This chapter deals with the concluding remarks, including theoretical implications and practical/ managerial implications, then study limitations and finally propositions for future research.

The context of reference of the study is indeed characterised by phenomena such as the digital transformation, the tightening of customer requirements, the compliance with strict regulations and growing level of competition at global level. In addition, the frequency of exceptional events such as cataclysms, financial crises and incidents has increased together with their severity, posing a serious threats to the survival of businesses. Within this turbulent and complex environment, the unit of analysis, namely a Lean firm, struggles to find a compromise between the pursuit of efficiency and effectively overcoming a disruption.

Perceived as a production paradigm in contrast with the nowadays variability, the study shines new light on the role of Lean Manufacturing as a means for improving, rather than degrading, the performance.

7.1 Theoretical implications

The objective of the study is to provide a comprehensive picture about the role of efficiency within a new disruptive context that nowadays cannot be ignored anymore. In particular, the research wants to assess the impact of Lean Manufacturing on the performance variation, not simply on the performance level. This is coherent with the concept of "disruption", described as an event with serious consequences that cannot be approached with the traditional risk management techniques since it cannot be predicted. The underlying notion of the research is that change cannot be avoided, but only embraced. Therefore firms, as demonstrated by literature, need to develop the capability of "resilience": no organisation shall suffer the disruption in a passive way, but rather proactively manage it with a structured approach throughout all the phases, from early detection to long-term recovery.

The element of novelty given by the research is the explanation about how the concept of Lean fits in a scenario in which competitive advantage means not just cutting unnecessary activities and improving internal processes, but mainly guaranteeing the continuous generation and delivery of value. This intention was born from an identified scarcity of knowledge in the scientific literature about the influence of efficiency-driven operation strategies in a disruption context. Few papers indeed address the issue only at a conceptual level without providing a solid empirical validation. Therefore, the identified gaps and critical issues have been converted into a set of research hypotheses representing the starting point of the research.

Firstly, the objective is to verify if the adoption of Lean methodologies could lead to beneficial effects in terms of performance in a context of disruption. However, the research extends the investigation trying to understand how Lean interacts with the other major production paradigm, namely operational resilience. The understanding of the interplay between the two managerial approaches indeed has a significant relevance from a theoretical perspective because it is a recent research stream that advocates further studies. Lastly, the research addresses, through the theoretical lenses of Contingency theory, the importance of accounting for contextual factors. Since they proved to significantly influence the adoption of managerial paradigms and their impact on performance, it is necessary to account for them in order to a provide an unbiased and exhaustive overview of LM in disruption.

These research hypotheses are then explored through a structured research framework designed to validate them on the basis of a statistical model. In particular, the research make use of the Structural Equation Modeling (SEM) technique. SEM aims at assessing the significance of the relationship between constructs, but the measurement of such constructs is no less important.

The first theoretical contribution provided by research is not related to content, but rather to methodology. Given their intangibility, constructs such as Lean, resilience and performance cannot be directly measured, thus requiring a measurement model able to seize their nature. In this sense, the research builds up the framework for the latent constructs based on the resource-based view (RBV) theory, especially on the dynamic capabilities perspective. In accordance with the RBV theory, constructs consist of a set of "capabilities", defined as systems of interrelated routines and practices that allow to achieve competitive advantage. In particular, the research proposes the operationalisation of such capabilities based on either practices and metrics, collectable at the operational level. The measurement of constructs through capabilities, when correctly applied, ensures the validity and reliability of the discovered relationships and can be hence used for future researches.

The achieved results have important theoretical implications, among which the impact of LM on the performance in a context of disruption is undoubtedly the most significant one. The statistical model indeed argues the existence of a significant and positive path coefficient between Lean and performance, thus implying a relevant direct effect of the exogenous construct on the endogenous one. The variation of performance, as aftermath of the disruption, can be offset by applying Lean methodologies, in particular the ones related to the improvement of internal processes. The research, therefore, extends the field of application of Lean Manufacturing, traditionally characterised by low variability, to

Then, when accounting for operational resilience as mediator of the above described relationship between LM and performance, the model does not detect any significant mediation effect. This means that, despite both aiming for operational excellence, LM and resilience follow two distinct paths: the former deals with the improvement of internal processes, while resilience consists of externally oriented practices aimed at building partnerships with other SC players.

Lastly, the study highlights the importance of taking into account the context of the analysis, in particular the business size and the operations strategy. The analysis on an aggregated level represents only a starting point of the research, then required to stratify and segment in order to provide a more accurate depiction of the influence of efficiency-driven strategies in the disruption context. The model indeed uncovers a significant difference between the path coefficients of distinct categorical levels. Moreover, the type of contingent effect changes depending on the construct which it is assessed on. For Lean the contingency acts on the construct itself since different levels of Lean relate to different categories, while for resilience it moderates the relationship between resilience and performance. This phenomenon finds its explanation on the different approaches of firms when dealing with these two paradigms. Lean Manufacturing, being widely known methodology, has reached a level of maturity such that firms recognise that it cannot be universally applied, but rather adapted to the specific context. Therefore, LM is planned based on intrinsic characteristics of the firm. Instead, with regards to operational resilience, there is no evidence of such strategic approach. The level of development of resilience capabilities is constant among firms which are in turn affected by contextual factors in terms of performance. However, the moderating impact on the relationship is not controlled by firms since not consistently interiorised in the business strategy.

7.2 Practical/managerial implications

Firstly, having demonstrated the suitability of Lean Manufacturing in such context, the research fosters the implementation of Lean managerial practices even in case of disruption. The main reason is that Lean, aimed at reducing waste, drives firms to the containment and improvement of variability, a critical feature of nowadays environment. For example, demand variability can be managed through Heijunka, internal variability through the training and empowerment of operators combined with the use of standard operating procedures and the supplier variability through the creation of collaborative partnerships.

As observed through the analysis of indirect effects, the improvement is higher in case of Lean practices bundles, such as JIT, TPM, TQM and HRM, that concern the single firm. In terms of resilience, the research suggests a wider perspective which involves multiple SC layers to collaborate with. Through IPMA, it is possible to prioritise the interventions based on the Performance dimension which indicates the current level of implementation of the practice bundles. It is observed that internal Lean practices are way less implemented in comparison with collaborative practices and this is even more critical considering that they have the same significance in terms of performance improvement. Therefore, the low implementation level by firms represents an opportunity, but mostly a key priority given the tremendous untapped potential.

Another important implication is that the frameworks used in the research to assess the degree of leanness and resilience can be used by companies to assess theirs as well. The main advantages are the ease of use, since it simply consists of “flagging“ the adopted practices, and the comprehensiveness, because of the exhaustive practice list.

Lastly, the research emphasises the significance of contextual variables, in particular operations strategy and business size, which deserve managerial attention. Firms basically need to consider the contingent impacts on the implementation and effectiveness of practices when designing the systematic recovery process and when benchmarking against other firms. With special reference to resilience, the research asks for a more strategic approach that sets the resilience capabilities based on the characteristics of the firm. In this way it is possible to control its effect, rather than being controlled by it.

7.3 Study limitations and future research

By representing the research PLS model as a black box in which results are obtained from the processing of input data, it is possible to break down the analysis for the identification of weaknesses and limitations in the research.

Considering the model itself, the used framework bases the measurement of constructs on the implementation of operational practices which “form” the practice bundles. However, in addition to formative constructs, it would have been better if reflective ones had been included as well. This means considering indicators such as the maturity level or the extensiveness of implementation which allow to account for culture and other “soft” aspects that are essential component when it comes to adopting Lean and resilience methodologies. Furthermore, having both formative and reflective would allow the assess also the convergence validity of the constructs.

However, the main source of limitations is the collected data that, according to a garbage-in-garbage-out (GIGO) principle, negatively affects the quality of achieved results. The sample size, despite being acceptable at an aggregated level, is still not sufficient when the analysis is stratified and this is critical because it is necessary to account for the heterogeneity of data. Therefore, increasing the sample size, it is possible to perform analyses such as the IPMA by operations strategy, but also to deepen the analysis at the indicator level, thus understanding which practice impacts on which metrics. To conclude, so far the research has understood if Lean and resilience impact on performance in case of disruption, now the goal is to understand how they impact.

Another relevant limitation is the use of secondary data for the collection of information about the observed cases. Secondary data refers to data that has already been collected in the past by someone other than the user. Despite the low cost of acquisition, it presents flaws related to the accuracy and availability of data. In fact, information about the adoption of a specific operations practice also depends on the level of disclosure of the firm. The high number of different documents reviewed prevents the risk, but there is never the full certainty that a practice is not adopted because it is not actually adopted and not because of a lack of information. This is a potential explanation for the non-identification of the mediation effect of resilience. From literature, an effect of LM on the resilience capability of flexibility is expected, but the information is not as disclosed as for collaboration for example.

For this reason, the use of complementary research methodologies, such as the case study, is advocated in order to analyse again the mediation effect, but also the moderation effect of constructs, rather than of a categorical variable.

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ANNEXES

Annex A. SLR papers classification

Resilience constituents / Lean performances	Quality	Productivity	Efficiency	Effectiveness	Flexibility	Visibility / Transparency	Collaboration
Flexibility	P5	P3, P7	P1, P3, P4, P5, P6, P7	P4	-	-	-
Visibility	P5	P3	P3, P5, P6	-	-	-	-
Velocity	P5	-	P2, P5, P6	-	P2	-	-
Collaboration	P5	-	P5	-	-	-	-

P1, Hills (2013); P2, Lotfi and Saghiri (2013); P3, Azfar (2012); P4, Govindan et al. (2015); P5, Birkie (2016); P6, Birkie et al. (2013); P7, Puchkova et al. (2015)

Annex B. Lean practices list

Practice ID	Lean practice / tool	N. of citations	Cumulative % of citations out of total
1	Just in Time (JIT) / Continuous flow production	66	6.26
2	Pull system (Kanban)	56	11.57
3	Quick changeover techniques and reduction of setup time (SMED)	53	16.6
4	Total Productive Maintenance (TPM)	47	21.06
5	Continuous improvement programs (Kaizen)	39	24.76
6	Total quality management (TQM) / Zero defects	37	28.27
7	Supplier involvement and development	34	31.5
8	Production smoothing (Bottleneck removal, Heijunka)	31	34.44
9	Cross-functional work force	31	37.38
10	Cellular manufacturing	30	40.23
11	Value Stream Mapping (VSM)	28	42.88
12	5S	27	45.45
13	Work standardisation (SOPs)	26	47.91
14	Error proofing (Poka-Yoke)	26	50.38
15	Lot size reduction	23	52.56
16	Visual Performance Measures (VLPM) / Visual control	23	54.74
17	Customer involvement and partnership (Feedback)	21	56.74
18	Statistical Process Control (SPC)	17	58.35
19	Autonomation (Jidoka)	16	59.87
20	Employees' involvement (suggestion schemes)	16	61.39
21	Information sharing	15	62.81
22	Lean Management Training	15	64.23
23	Elimination of waste	14	65.56
24	Shop floor organisation and safety	14	66.89
25	Small-group problem solving	14	68.22
26	Low inventory	13	69.45
27	Preventive maintenance	13	70.68
28	Human Resources Management (HRM)	11	71.73
29	Top management leadership for quality	11	72.77
30	Takt time definition	10	73.72
31	Reduced number of suppliers	10	74.67
32	Long-term relationships	9	75.52
33	Teamwork	9	76.38
34	Planning and scheduling strategies	9	77.23
35	Cycle time reduction	9	78.08
36	Visual Information System	8	78.84
37	Parts standardisation	7	79.51
38	Process feedback	7	80.17
39	Mixed-model production	7	80.83
40	New process equipment / technologies	7	81.5
41	Customer requirement analysis	7	82.16
42	Design for manufacturability	6	82.73

43	Root cause analysis (5 whys)	6	83.3
44	Empowerment	6	83.87
45	Reengineered production process	5	84.35
46	Definition of mission and values of the organisation	5	84.82
47	Process capability measurements	5	85.29
48	Andon	5	85.77
49	Concurrent engineering	4	86.15
50	Supplier proximity	4	86.53
51	Value Stream Costing (VSC)	4	86.91
52	Six Sigma	4	87.29
53	Visual management of quality control (VQC)	4	87.67
54	Work order system	4	88.05
55	Competitive benchmarking	3	88.33
56	Goal oriented teams	3	88.61
57	Short lead time	3	88.9
58	Employee evaluation	3	89.18
59	Formal reward system	3	89.47
60	Work time flexibility	3	89.75
61	Group technology	3	90.04
62	Employee's autonomy	3	90.32
63	Failure Mode, Effects and Criticality Analysis (FMECA) / Failure Mode and Effect Analysis (FMEA)	3	90.61
64	Flexible resources	3	90.89
65	Overall Equipment Effectiveness (OEE)	3	91.18
66	Plan, Do, Check, Act (PDCA)	2	91.37
67	Lean Management Accounting Practices (MAP)	2	91.56
68	Focused factory production	2	91.75
69	Product customisation	2	91.94
70	Self-directed work teams	2	92.13
71	Few levels of management	2	92.31
72	Simplified purchasing process	2	92.5
73	Total cost supplier evaluation	3	92.79
74	Supplier training	2	92.98
75	First-run study	2	93.17
76	Knowledge-driven approach	2	93.36
77	Outsource non-core functions	2	93.55
78	Common database	2	93.74
79	Product modularisation	2	93.93
80	Demand stabilisation	2	94.12
81	Visibility of quality department	2	94.31
82	Flow diagrams	2	94.5
83	Safety improvement programs	1	94.59
84	High resources utilisation rate	1	94.69
85	Services to enhance value	1	94.78
86	Work delegation	1	94.88
87	Pay for performance	1	94.97
88	Simplification and strategic alignment of management accounting practices (SMAP)	1	95.07

89	New products development	1	95.16
90	Daily schedule adherence	1	95.26
91	Product postponement	1	95.35
92	Vendor managed inventory	1	95.45
93	Reduce uncertainty for suppliers	1	95.54
94	E-commerce	1	95.64
95	Enterprise resource planning	1	95.73
96	Measure supplier performance	1	95.83
97	Vendor rating and certification	1	95.92
98	CAD/CAM systems	1	96.02
99	Computer-integrated manufacturing	1	96.11
100	Economic Order Quantity (EOQ)	1	96.2
101	Regular inventory analysis	1	96.3
102	Centralised coordination of information system	1	96.39
103	Regular information update	1	96.49
104	Ability to track movement of goods in the SC	1	96.58
105	Discard obsolete information	1	96.68
106	Study demand patterns	1	96.77
107	Minimise response time to customer query	1	96.87
108	Regular customer contact programs	1	96.96
109	Equipment layout	1	97.06
110	Reverse logistics	1	97.15
111	Elimination of non-value adding tasks	1	97.25
112	Variability reduction	1	97.34
113	Keiretsu	1	97.44
114	Easy access Integrated Information System	1	97.53
115	Maximisation of customer value	1	97.63
116	Organisation by dominant flow	1	97.72
117	Computerised Maintenance Management System (CMMS)	1	97.82
118	Reliability Centered Maintenance (RCM)	1	97.91
119	Deferring decisions to the last responsible moment	1	98.01
120	Last Planner System (LPS)	1	98.1
121	Set-based design	1	98.2
122	Simultaneous product and process design	1	98.29
123	Integrated project delivery	1	98.39
124	Overlapped production	1	98.48
125	Reliable deliveries	1	98.58
126	Data check sheet	1	98.67
127	Gantt chart	1	98.77
128	Pareto chart	1	98.86
129	Run chart	1	98.96
130	Video time study	1	99.05
131	In-house technology	1	99.15
132	Demand driven production	1	99.24
133	Classification of activities	1	99.34
134	Milestones review	1	99.43
135	Supply chain integration	1	99.53

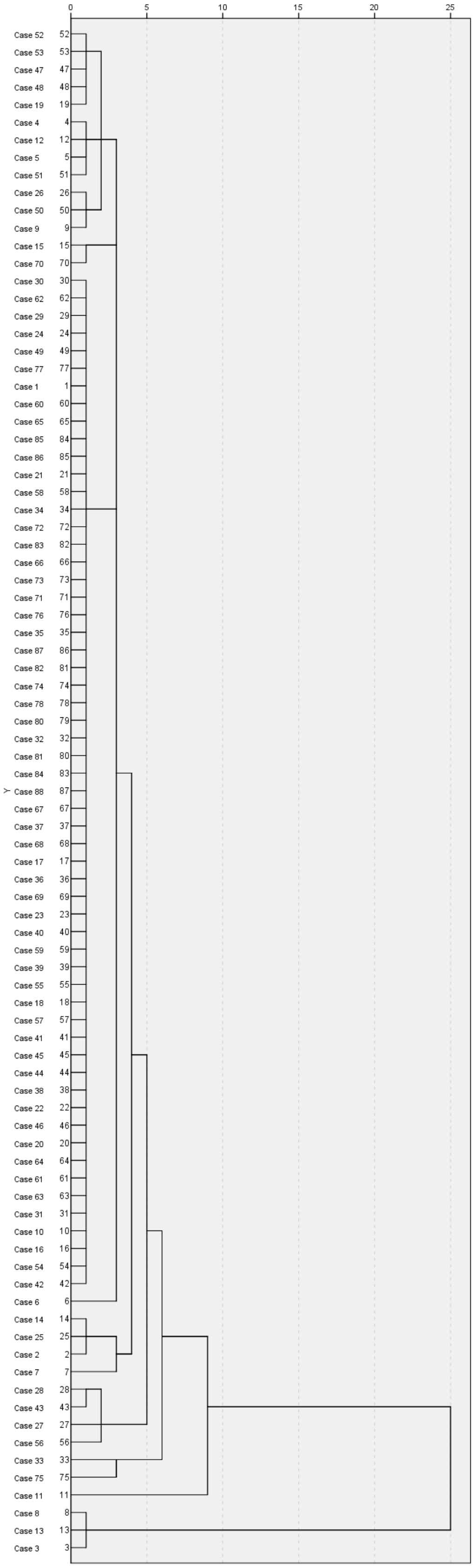
136	Virtual enterprise	1	99.62
137	Core competences management	1	99.72
138	IT-driven enterprise	1	99.81
139	Rank Order Clustering (ROC)	1	99.91
140	Single point scheduling	1	100

Annex C. Case studies list

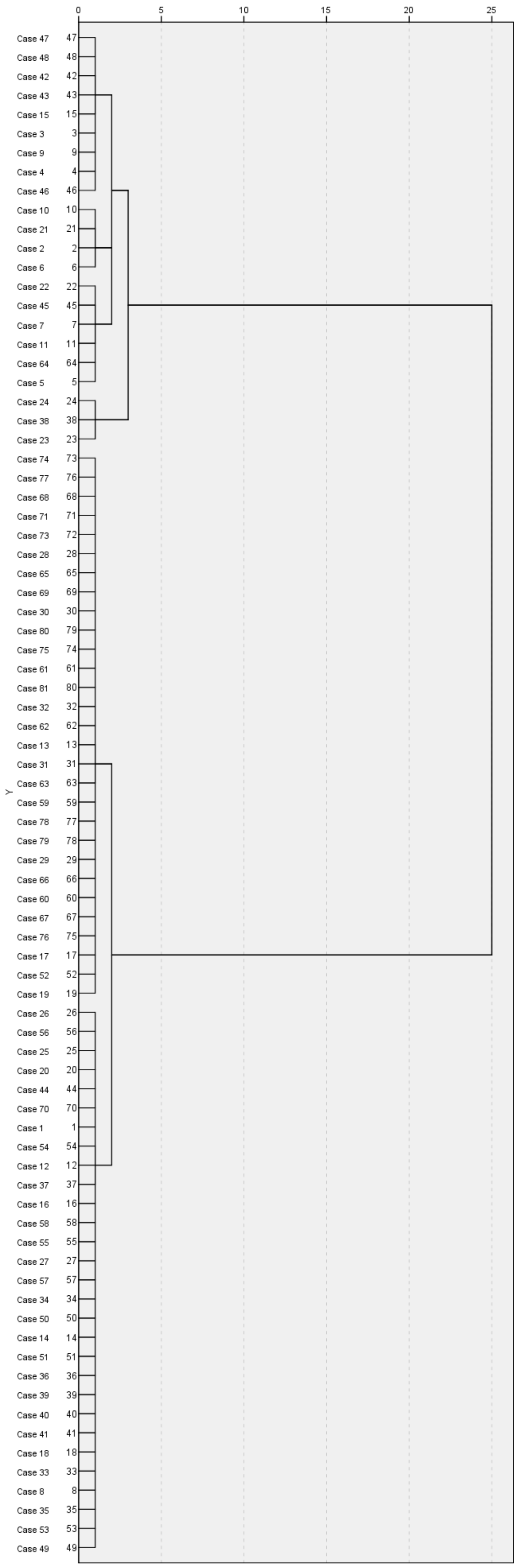
Case ID	Company name	Incident	Incident year
1	Chrysler Group LLC	Japan earthquake	2011
2	Ford Motor Company	Japan earthquake	2011
3	Toyota Motor Corporation	Japan earthquake	2011
4	Honda Motor Co.	Japan earthquake	2011
5	Groupe PSA Peugeot Citroen	Japan earthquake	2011
6	Apple Inc.	Japan earthquake	2011
7	General Motors Corporation	Japan earthquake	2011
8	Toyota Motor Corporation	Japan earthquake	2011
9	Sony Ericsson Mobile Communication	Japan earthquake	2011
10	Takata Corporation	Faulty airbag	2013
11	DHL	Japan earthquake	2011
12	Honda Motor Co.	Thai flood	2011
13	Toyota Motor Corporation	Thai flood	2011
14	Nissan Motor Co., Ltd.	Thai flood	2011
15	Procter & Gamble	Hurricane Katrina	2005
16	Dell Inc.	West coast strike	2002
17	Riken Automobile Parts Co. Ltd.	Japan earthquake	2007
18	Evonik Industries	Fire incident	2012
19	Boeing Company	Japan earthquake	2011
20	Renesas Electronics Corporation	Japan earthquake	2011
21	Freescale Semiconductor Inc.	Japan earthquake	2011
22	Mattel Inc.	Product contamination	2007
23	Genzyme Corporation	Virus contamination	2009
24	Johnson & Johnson	Quality and safety violation	2010
25	Nissan Motor Co., Ltd.	Japan earthquake	2011
26	Sony Corporation	Japan earthquake	2011
27	Panasonic Corporation	Japan earthquake	2011
28	Hitachi Ltd.	Japan earthquake	2011
29	Mitsubishi Electric Corporation	Japan earthquake	2011
30	Ericsson	Japan earthquake	2011
31	Toyota Material Handling	Wheel supply delay	2012
32	PL Fahrzeugbau GmbH	Operating system failure	2010
33	General Motors Corporation	Workforce strike	2008
34	Oriflame Cosmetics AB	New product short supply	2011
35	Cross Control	Supplier underproduction	2010
36	Flir Systems	Supplier unsuitability	2011
37	Alcro-Beckers	Microbiological growth	2011
38	Bombardier Transportation	Test equipment failure	2011
39	Scania AB	Japan earthquake	2011
40	Sandvik	Foundry oven breakdown	2011
41	Isuzu Motors Ltd.	Japan earthquake	2011
42	Suzuki Motor Corporation	Japan earthquake	2011
43	Hewlett-Packard	Japan earthquake	2011

44	Mitsubishi Motors Corporation	Thai flood	2011
45	Subaru	Japan earthquake	2011
46	Mazda Motor Corporation	Thai flood	2011
47	Fujitsu	Japan earthquake	2011
48	Fujitsu	Thai flood	2011
49	Western Digital	Thai flood	2011
50	Sony Corporation	Thai flood	2011
51	Toshiba Corporation	Thai flood	2011
52	Canon Inc.	Japan earthquake	2011
53	Canon Inc.	Thai flood	2011
54	Goodyear Tire and Rubber Company	Thai flood	2011
55	Texas Instruments Inc.	Japan earthquake	2011
56	Nestlé S.A.	Social media attack	2010
57	Kawasaki Heavy Industries, Ltd.	Japan earthquake	2011
58	ON Semiconductor	Thai flood	2011
59	Seagate Technology	Thai flood	2011
60	Sharp Corporation	Japan earthquake	2011
61	Shin Etsu Chemical Co., Ltd.	Japan earthquake	2011
62	GlaxoSmithKline plc	Japan earthquake	2011
63	Takeda Pharmaceutical Co.	Japan earthquake	2011
64	SK Hynix Inc.	Fire incident	2013
65	Sapporo Breweries Ltd.	Japan earthquake	2011
66	Fabrinet	Thai flood	2011
67	Emcore Corporation	Thai flood	2011
68	Oclaro, Inc.	Thai flood	2011
69	Mitsubishi Paper Mills Limited	Japan earthquake	2011
70	Tokyo Electric Power Company	Japan earthquake	2011
71	Lameri S.p.a.	Italy earthquake	2012
72	Leroy Merlin Italia s.r.l	Workforce strike	2018
73	HP Pelzer GmbH	Fire incident	2017
74	Entroterra S.p.a.	Fipronil scandal	2017
75	Eni S.p.a.	Electrical black-out	2013
76	Microelettrica Scientifica S.p.a.	Wrong product positioning	2014
77	Whirlpool Corporation	Turkey economic crisis	2018
78	2 ERRE S.r.l.	Customer bankruptcy	2010
79	ShenZhen Hailong Construction Products Co., Ltd.	Product quality decrease	2008
80	Tattile S.r.l.	New ERP-MRP system	2014
81	TecnoGi S.p.a.	Breakage of pipe	2016
82	B. Braun Avitum Italy S.p.a.	Italy earthquake	2012
83	Major Aerostructure Supplier	Low pace and quality issues	2010
84	Pietro Carini S.p.a.	Explosion incident	2013
85	Vodafone Italy S.p.a.	Delay of HW order	2016
86	ESA - European Space Agency	Faulty component	2012
87	Cameron Italy S.r.l.	Piston extension jam	2014
88	Mondi Frantschach	Plant IT system collapse	2017

Annex D. Hierarchical clustering (Single linkage) dendogram



Annex E. Hierarchical clustering (Ward's method) dendogram



Annex F. Conversion table for indicators

Indicator	Code
The firm effectively collaborates with external actors in the recovery process.	COLL_1
Managers are actively involved and support the recovery process through allocation of resources.	COLL_2
Long-term supplier relationships are developed.	COLL_3
Pre-incident, long-term relationships based on trust are developed with key customers.	COLL_4
People with experience in handling pasts incidents are assigned to disruption event.	FLEX_1
Demand is shifted across time, market or product.	FLEX_2
Alternative suppliers are identified in the event of a possible supply chain disruption.	FLEX_3
Enhanced value propositions are offered to customers.	FLEX_4
Production and delivery are adjusted by balancing available resources.	FLEX_5
Multi-competence teams are established.	FLEX_6
People cooperate effectively through internal coordination.	FLEX_7
Cross-functional work force	HRM_1
Employees’ involvement (suggestion schemes)	HRM_2
Lean Management training	HRM_3
Top management leadership for quality	HRM_4
Pull system (Kanban)	JIT_1
Quick changeover techniques and reduction of setup time (SMED)	JIT_2
Production smoothing (bottleneck removal, Heijunka)	JIT_3
Cellular manufacturing	JIT_4
Work standardisation (SOPs)	JIT_5
Lot size reduction	JIT_6
Visual performance measures (VLPM) / Visual control	JIT_7
Takt time definition	JIT_8
Supplier feedback and development	SUPP_1
JIT Delivery	SUPP_2
5S	TPM_1
Autonomation (Jidoka)	TPM_2
Information sharing	TPM_3
Shop floor organisation and safety	TPM_4
Preventive maintenance	TPM_5
Continuous improvement programs (Kaizen)	TQM_1
Value Stream Mapping (VSM)	TQM_2
Error-proofing (Poka-Yoke)	TQM_3
Statistical process control (SPC)	TQM_4
Small group problem solving	TQM_5
Scenario planning and crisis management exercises	VEL_1
Responsibility for different parts of the recovery process is distributed clearly and appropriately.	VEL_2
A pre-incident systematic recovery process to solve unforeseen incidents is established.	VEL_3
Task forces make use of a systematic recovery process to solve problems.	VEL_4
Plans for communication of incidents are developed prior to the incident.	VEL_5
The business environment is regularly scanned for signals of possible disruptive events.	VIS_1
The firm promptly collects information from the incident site.	VIS_2
Key decision makers along the supply chain are informed fast.	VIS_3