UNIVERSITÀ DEGLI STUDI FIRENZE

DOTTORATO DI RICERCA IN INGEGNERIA INDUSTRIALE

CICLO XXVIII

COORDINATORE Prof. Maurizio DE LUCIA

Exploring the impact that Lean Manufacturing has on flexibility in SMEs.

Settore Scientifico Disciplinare ING-IND/35

Dottorando
Dott. Lucherini Franco

____
(firma)

Tutore
Prof. Rapaccini Mario

____
(firma)

Coordinatore
Prof. De Lucia Maurizio

____
(firma)

Anni 2012/2016

Abstract

This Doctoral Thesis describes the use of Computer Simulation and Case Research to assess flexibility gains induced by the introduction of three Lean Manufacturing practices. The investigation starts from the gathering of information about the manufacturing process of a selected Small-Medium Enterprise. After this field study, Value Stream Mapping is used for visualizing flows of products and information along the production system. Then, starting from the current arrangement of the company, computer simulation is adopted to assess the flexibility improvements arising from Cellular Manufacturing, Just-in-Time, and Single Minute Exchange of Dies. Leveraging on the outcome of this evaluation, the contribution of different lean techniques is segregated through a factorial Design of Experiment. In this work the combined use of Computer Simulation and Case Research is extended to the research on Manufacturing Flexibility within Small Medium Enterprises. The knowledge on this under investigated context is enhanced collecting quantitative data. Moreover, building on the factorial Design of Experiment, a new 5-steps method is proposed with the aim to apprise the cost-benefit ratio of lean techniques for flexibility improvement. Finally, from a managerial prospective, this work provides a supporting method for the decision-making process propaedeutic to Lean Manufacturing introduction.

Keywords: Lean Manufacturing, Manufacturing Flexibility, Case-study, Simulation, SMEs, Value stream mapping.

Table of Contents

1 Introduction

The purpose of this first chapter is to introduce the reader to the PhD Research, structured as follows:

Paragraph 1 – The potential of Lean Production is shown through an introducing example.

Paragraph 2 – The context of Small Medium Enterprises is defined and described.

Paragraph 3 – An overall description of Lean Thinking is provided.

Paragraph 4 – Objectives, Research Questions, and Delimitation of the study are illustrated.

Paragraph 5 – The outline of PhD Thesis is stated.

1.1 Introducing reference examples

It is common knowledge that Lean Thinking is adopted in order to improve the quality and to decrease base costs of a company (Womack, Jones, & Ross, 1990). The potential of this methodology is presented through three examples in the following paragraphs.

1.1.1 Example #1 Value Stream Mapping for Lean transition

Seth and Gupta introduced a successful attempt to use VSM as a technique to achieve productivity improvement at supplier end for an Indian auto industry (Seth * & Gupta, 2005). The subject company of their case study is one of the principal two-wheeler automotive manufacturers (XYZ), whose main dedicated supplier, the motorcycle frames producer (ABC Ltd), acts as business partner. The recently increased marked demand made it difficult for ABC Ltd to keep the quality level under control, as their focus is to control the daily demand of XYZ. This could be mitigated by increasing the capacity of ABC Ltd. However, it could negatively affect the efficiency of both XYZ and ABC Ltd, considering the uncertainty in demand, the resulting increase of labor cost and overheads, combined with the high level of the work in progress inventory. In view of this scenario, the Value Stream Mapping is used to analyze the possible improvements on the frame manufacturing process.

Measure	**Unit**	**Current position**
Production output per man	Frames/man	13.95
Manpower	Numbers/day	129
In-process goods inventory	Frames	466
Finished goods inventory	Frames	700
Production lead-time	Days	3.215
Processing time	Minutes	15.67

Table 1 - Details of existing frame manufacturing process (Seth * & Gupta, 2005)

The target daily production is 2000 frames, including the breaks, with a tack time of 40 seconds. With this requirement in mind, the current state of frame manufacturing process at first tier (ABC Ltd) and second-tier suppliers has been evaluated to discover the potential areas for improvement. The Kanban system was proposed and applied both at the raw material inlet and at the finished product delivery. Communication improvement between XYZ and ABC Ltd leads to an overall decrement of inventories. To reduce manpower requirements and improve quality, a study was undertaken to redesign the ABC Ltd production layout with the introduction of new tools. The significant improvements achievable by the above-mentioned activities are illustrated in Table 2.

Measure	Unit	Proposed position
Production output per man	Frames/man	17.54
Manpower	Numbers/day	114
In-process inventory	Frames	90
Finished goods inventory	Frames	360
Production lead-time	Days	0.54
Processing time	Minutes	14.13

Table 2 - Details of proposed frame manufacturing process (Seth * & Gupta, 2005)

1.1.2 Example #2 Implementing Lean Manufacturing with Cellular Layout

Pattanaik and Sharma described (Pattanaik & Sharma, 2009) the implementation of a cellular layout which follows the lean principles in a small-scale industry. The manufacturing unit studied in the work is a supplier of ballistic components, established in 1978. The investigation presents the benefits achievable by the use of the cellular layout for lean manufacturing through the analysis of a fuse assembly process. The parts and machines required to assemble this component are summarized in Table 3.

Parts		Machines/operations	
P1	Disc	M1	Band saw
P2	Septum	M2	CNC machine
P3	Tag	M3	Drilling
P4	Shutter	M4	Lathe
P5	Safety cap	M5	Milling
P6	Striker pin	M6	Punching
P7	Stop detent	M7	Grinder
P8	Upper body	M8	Pressure die casting
P9	Lower body	M9	De-burring
P10	Magazine	M10	Anodizing

Table 3 - Parts and machines required to assemble fuse (Pattanaik & Sharma, 2009)

The proper machine cells have been identified by applying the hierarchical similarity-based approach (Jaccard coefficient), as shown for the first time by McAuley (McAuley, 1972). The result of the grouping is a layout composed of 3 cells: Cell #1 (M1, M2, M3, M4, M7), Cell #2 (M5, M9, M10), Cell #3 (M8, M6). The main results of the process improvement, arising from the introduction of Cellular Manufacturing and Lean Principles, consist of a capacity increase of 5.75% and an enhancement of on-time delivery. The overall improvement in production time distribution is shown in Table 4.

Activities Category	Distribution of production time	New distribution of production time
Value-adding	44.0%	54.0%
Necessary Non-value-adding	23.3%	20.5%
Non-value-adding	32.7%	25.5%

Table 4 - Distribution of production time (Pattanaik & Sharma, 2009)

1.1.3 Example #3 Appyling Lean Six Sigma in a small UK business

The achievement of these significant performance improvements was described by Andrew Thomas (Thomas, Barton, & Chuke-Okafor, 2008) in a case study on applying Lean Six Sigma (LSS) in a small UK business. The Company analyzed in the study, is a market leader in the development, manufacture and service of engineering systems for the automotive/aerospace industries. In recent years the need to become customer-oriented and flexible were the main challenges for this firm. An integrated lean six sigma approach is implemented with the aim to reduce quality issues and to increase productive capacity by ensuring high machine availability and performance. The followed process consisted of a 10-Steps methodology:

Six Sigma	**1**	Define – what is the problem? Does it exist?
	2	Measure – how is the process measured? How is it performing?
	3	Analyze – what are the most important causes of defects?
	4	Improve – how do we remove the causes of the defects?
	5	Control – how can we maintain the improvements? Application of lean
Lean	**6**	Implement 5S technique
	7	Application of Value Stream Mapping (VSM)
	8	Redesign to remove waste and improve value stream
	9	Redesign manufacturing system to achieve Single Unit Flow (SUF)
	10	Apply Total Productive Maintenance (TPM) to support manufacturing functions

Table 5 - 10-Steps methodology (Andrew, Richard, & Chiamaka, 2008)

As evidence of the possible benefits, the results of one particular LSS project undertaken in high-value product lines of the Company are listed below:

1. Reject rate reduction on the pilot line of 55%.
2. Cell Overall Equipment Effectiveness (OEE) increased from 34 to 55%.
3. A 31% increase in parts per hour from the production system.
4. Energy usage reduction of 12% per year.
5. In conjunction with the OEE performance increase, the TPM program reduced equipment downtime from 5% to 2%.

1.2 Small and medium sized enterprises

The context of this research is represented by the manufacturing SMEs. Despite the pressure coming from the financial crisis, small and medium companies still play a key role in the European economy. In the following sections an accurate definition of SMEs will be given, along with the analysis of the current economic conditions in which they are operating.

1.2.1 The characteristics of SMEs

The classification of companies (published in the Official Journal on April 30th 1996) has been operating within the European Community since January 1st 2005. According to European Community law (Commission, 2003) "small and medium-sized enterprises" are identified through three criteria:

1. Staff headcount.
2. Annual turnover.
3. Annual balance sheet.

"It is necessary to note that while it is compulsory to respect the staff headcount thresholds, an SME may choose to meet either the turnover or balance sheet ceiling. It does not need to satisfy both and may exceed one of them without losing its status" as defined in EU law.

Company category	**Employees**	**Turnover**	**Or**	**Balance sheet total**
Medium-sized	< 250	≤ € 50 m		≤ € 43 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

Table 6 - Company Categories & Thresholds

1.2.2 The importance of SMEs

In recent times the European Union has been facing recession and an escalating national debt crisis. This phenomenon affected even the best-in-class nations. Despite the challenging boundary conditions experienced recently, SMEs are nowadays recovering. SMEs in the non-financial business sector are confirming their important role across EU28 with the following statistics related to companies (Muller, Devnani, Julius, Gagliardi, & Marzocchi, 2016):

1. 23 million Companies.

2. 99.8% of all enterprises (92.8% firms with fewer than ten employees).
3. 90 million people employed.
4. 66.8% of total employment.
5. 57.4% of Gross Value Added (GVA).

This picture shows the resilience of small and medium enterprises, which are withstanding severe challenges as a result of downturn.

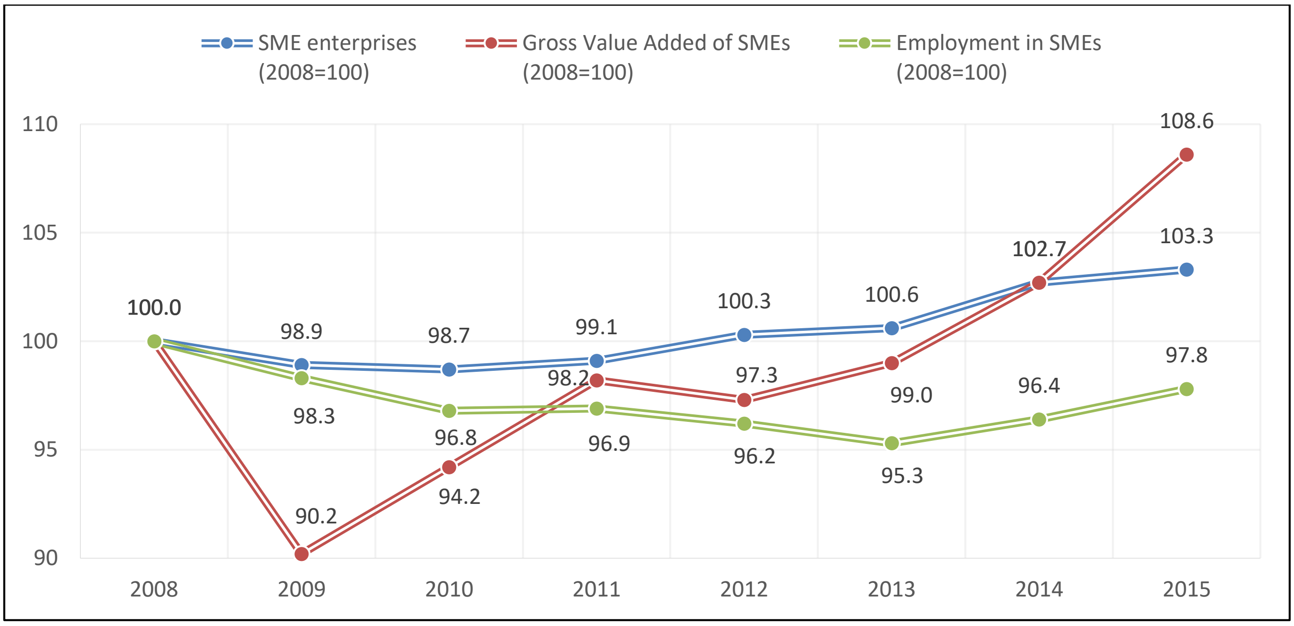

Figure 1 - Number of SMEs in the EU28, SME value added and SMEs' employment in the non-financial business (Muller et al., 2016)

This is also reflected in the key findings of the Annual report on small and medium-sized enterprises in the EU, 2015/16:

1. SME's employment growth is moderate (1.1% in 2014 and 1.5% in 2015).
2. SME's employment level remains under the 2008 (pre-crisis) level.
3. Employment growth was almost evenly spread across Europe (from 0.1% in France up to 4.8% in Malta), excluding Finland where SME's employment suffered a modest decrease (-0.3%).
4. SME's value added growth is consistent (3.8% in 2014 and 5.7% in 2015).
5. SME's value added level has exceeded the 2008 (pre-crisis) level since 2014.
6. The Overall SME's value added growth was generally positive in EU: only two States (Estonia and Greece) were underperforming in 2015 with a negative variation. Ireland, the UK and Malta were outperforming in 2015 (18.4%, 14.9% and 11.4% respectively).

7. The excellent sectors which contributed the most to the value added growth in SME value added are ‘manufacturing’, ‘wholesale/retail trade’ and ‘other’ (in the non-financial business sector across Member States).

1.2.3 The SME situation in Italy

The latest Eurostat statistics, elaborated in the Small Business Act (SBA) Fact Sheets by DG Enterprise (UE, 2012) for European Commission, describes the Italian SME as a critical sector in 2012. The number of Italian small and medium-sized companies (3,813,000) represents the largest in Europe (i.e. Germany - 2,066,000 SMEs), even if most of them have fewer than 10 employees. The percentage of micro enterprises in Italy is 94.6% (EU average: 92.2 %). Unfortunately, the effect on employment and added-value of these micro-enterprises is relatively little, due to their size. In Italy SMEs generate 3 million fewer jobs than in Germany and produce only 56% of the total added-value compared with the German counterparts. Italian SMEs are widely spread in the manufacturing sector accounting for 31% of added-value (Media EU 21%) and 25% of employment in SMEs (EU average 20%). However, the share of manufacturing SMEs engaged in high or medium-high technology is aligned with the European Union. The service industry is experiencing a worse situation. The knowledge-intensive Italian firms generate much less employment and added value compared with their European competitors (respectively 21 to 25 % and 27 to 31%). Since 2005 the trends of Italian SMEs in terms of number of enterprises, employment, and value addition have been disappointing. For this reason, the recovery from the financial crisis was much weaker than the other European companies. On all the three indicators, the Italian SME sector appears to have fallen back to 2005 levels, before the onset of the crisis. Micro-firms are the hardest hit with the slightest vigorous recovery, while large firms appear to have ridden out of the crisis fairly well up to now. A recent study, based on a sample of 1000 SMEs, and presented in the Small Business Act 2016 (Ministero dello Sviluppo Economico Direzione Generale per la Politica Industriale, 2016), describes the performances of Italian companies in relation to the Information Technology Development & Investments, Innovation Strategies and International Focus:

1. Information Technology development & Investments: despite the overall adoption of adequate IT tools in the top performing companies, these rarely use the internet for selling purpose. The main credit source derives from bank institutes, and the principle area of investment is related to production enhancement.
2. Innovation Strategy: The percentage of companies willing to invest in innovation was 96.7% in 2014 and 95.4% in 2015. Process, product and organizational innovations are the most desirable fields of improvement.

3. International Focus: most of the outperforming companies have focused in recent years on the international market. The effort in that direction is commonly related with the dimension of the firm: 35.3% of companies with 10-19 employees joined overseas opportunities in 2015, the value is 41.4% for companies with 50-249 employees.

1.3 Lean Manufacturing as strategy for Flexibility

The concept of flexibility and its extensive applicability in the industrial production are becoming more and more significant in the market. Manufacturing Flexibility (MF) consists in the capability of a system to cope with the environmental changes. Lean Manufacturing (LM) is a production philosophy whose main objective is to reduce waste, increase added value and efficiency. Womack (Womack et al., 1990) and other authors (Bortolotti, Boscari, & Danese, 2015) (Boyle & Scherrer-Rathje, 2009) (A. S. Sohal & Egglestone, 1994) (Hallgren & Olhager, 2009b) (Marodin, Saurin, Tortorella, & Denicol, 2015) assert that the chance to pursue flexibility by introducing Lean is viable. In fact, the use of lean practices also improves flexibility (Kenneth K Boyer, Leong, Ward, & Krajewski, 1997) (Swink, Narasimhan, & Kim, 2005) (Vinodh & Joy, 2012). As an instance, establishing a partnership and a continuous flow of information between a manufacturer and its suppliers is profitable (Prajogo & Olhager, 2012), especially to cope with an increasing demand. This relationship has positive effect on the performance of both parties: suppliers are real time informed about their production plan, accomplishing the possibility to detect promptly and handle criticality; manufacturer benefits the increased suppliers' inclination to absorb demand fluctuations or to more promptly change production volumes without incurring high costs or significant changes in performance outcomes (Rosenzweig & Roth, 2004). In addition to this advantage for Volume Flexibility, a close connection with suppliers also increases supplier responsiveness for product modifications that will improve firms Mix Flexibility (R. Narasimhan & Das, 1999) (Petroni & Bevilacqua, 2002), contributing to reduce cost increase usually linked to a fragmented need of sub-components. LM encourages the introduction of improved layouts (i.e. streamlines, cellular) characterized by quick changeover of equipment and smaller lot sizes (Alsmadi, Almani, & Jerisat, 2012) (Bartezzaghi & Turco, 1989). These practices improve speed, thus, they also enhance companies aptitude to quickly change the product lines, increasing flexibility in terms of product variety or range. Another important aspect is that lean practices promote multi-skilled workers who can be moved from one work center to another as required by production volume (Lee & Ebrahimpour, 1984) (Julie Yazici, 2005). Similarly, Suarez et al. (Suarez, Cusumano, & Fine, 1996) and Chang et al. (Chang, Lin, Chen, & Huang, 2005) have pointed out that training multi-skilled operators, enabling their capability to handle different products, is an important element of product mix flexibility.

This work studies the enhancement of adaptability to exogenous inputs through Lean Techniques. These concepts will be accurately discussed in the following chapters.

The references quoted in this paragraph are briefly summarized in the following table:

#	Authors	Title of Research	Topic of Research and findings
1	Womack et al., 1990	The Machine that Changed the World.	Comprehensive description of the entire Lean system. Description of its advantages over the mass production model. In the frame of this analysis Lean Manufacturing is identified as a factor for flexibility enhancement.
2	Bortolotti, Boscari & Danese, 2015	Successful lean implementation: Organizational culture and soft lean practices.	Appraisal of the effect of a positive Organizational culture in successful Lean implementations. Lean is identified as enabler for flexibility.
3	Boyle & Scherrer-Rathje, 2009	An empirical examination of the best practices to ensure manufacturing flexibility: Lean alignment.	Research on the best practices for reducing sources of uncertainty, with special regards to Lean Techniques.
4	A. S. Sohal & Egglestone, 1994	Lean production: experience among Australian organizations.	Survey on the benefits and the difficulties related to the adoption of Lean production methods in Australian manufacturing industry. The positive effect of Lean production for flexibility improvement is confirmed.
5	Hallgren & Olhager, 2009	Lean and agile manufacturing: external and internal drivers and performance outcomes.	Investigation on the Lean and agile manufacturing systems. Lean is identified as a viable strategy for flexibility.
6	Marodin, Saurin, Tortorella & Denicol, 2015	How context factors influence lean production practices in manufacturing cells.	Identification of the factors that affect the implementation of Lean practices in Manufacturing Cells. Cellular manufacturing is recognized as a means to reduce lead times, improve quality, and provide mix and volume flexibility. The same features are prioritized in Lean production.
7	Kenneth K Boyer, Leong, Ward & Krajewski, 1997	Unlocking the potential of advanced manufacturing technologies.	Survey on the performance of advanced manufacturing systems. Lean principles are associated to an increase of flexibility.
8	Swink, Narasimhan & Kim, 2005	Manufacturing practices and strategy integration: effects on cost efficiency, flexibility, and market-based performance.	The study focuses the integration of different manufacturing strategies for the improvement of cost efficiency and the enhancement of flexibility capabilities. The benefits achievable by the integration of different Lean-based practices are documented in a survey.
9	Vinodh & Joy, 2012	Structural equation modelling of lean manufacturing practices.	Review of the critical factors for the success implementation of Lean manufacturing in different industries. Flexibility is identified as a deliverable of Lean practices.
10	Prajogo & Olhager, 2012	Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration.	The significant effect of logistics integration on operations performance is appraised through a survey on 232 Australian firms. Mitigation of demand uncertainty is one of the positive effects of the partnership with suppliers.
11	Rosenzweig & Roth, 2004	Towards a theory of competitive progression: evidence from high-tech manufacturing.	Investigation about the effects of long term relationships with suppliers. Benefits in terms of quality, delivery reliability, volume flexibility, and low cost are confirmed with a survey on high-tech firms.

12	R. Narasimhan & Das, 1999	An empirical investigation of the contribution of strategic sourcing to manufacturing flexibilities and performance.	Empirical studies for achieving manufacturing flexibility goals through strategic sourcing. Partnership whit suppliers is confirmed as an option to achieve flexibility.
13	Petroni & Bevilacqua, 2002	Identifying manufacturing flexibility best practices in small and medium enterprises.	Investigation on flexibility performance of small and medium companies. Supply chain-related reorganization is one of the key strategy for mix and customization flexibility excellence.
14	Alsmadi, Almani & Jerisat, 2012	A comparative analysis of Lean practices and performance in the UK manufacturing and service sector firms.	Survey on the relations between performance and Lean adoption. Suitability of Lean practices for the production of small lots (reducing set-up time) is shown in the paper.
15	Bartezzaghi & Turco, 1989	The impact of just-in-time on production system performance: an analytical framework.	Assessment on the deliverables of the just-in-time techniques. The work highlights benefits in terms of product and mix flexibility.
16	Lee & Ebrahimpour, 1984	Just-in-time production system: some requirements for implementation.	Review on Just-in-time production system with specific focus on the prerequisites for its implementation. Multifunction workers approach is identified as an enabler of this production philosophy.
17	Julie Yazici, 2005	Influence of flexibilities on manufacturing cells for faster delivery using simulation.	The effects of cellular manufacturing on volume, mix, routing, and labor flexibilities are assessed in the paper. Multi-skilled workers shared between cells results in higher utilization, lower lead time and higher volume flexibility.
18	Suarez, Cusumano & Fine, 1996)	An Empirical Study of Manufacturing Flexibility in Printed Circuit Board Assembly.	Survey on the flexibility improvements achievable by different techniques. Multi-skilled workers approach is identified as an enabler for mix flexibility.
19	Chang, Lin, Chen & Huang, 2005	Manufacturing flexibility and manufacturing proactiveness: empirical evidence from the motherboard industry.	Develops of valid and reliable measures of manufacturing proactiveness and flexibility based on data collected from 108 motherboard manufacturers in Taiwan. Multi-skilled workforce development has positive effects on mix flexibility.

Table 7 - Summary of references

1.3.1 The importance of Lean adoption for SMEs

Nowadays SMEs are facing a critical challenge: the increased competition, due to globalization, liberalization and technological innovation. Literature (Feld, 2000) is unanimous in thinking that a leaner business model might be the proper approach to meet the market demands and to cope with this unstable situation. It is necessary for companies to be creative, innovative and able to manage changes. Womack (Womack & Jones, 2005) states that SMEs should re-shape their management, to avoid being swept away from the international scene: their best chance is the Lean Introduction.

Focusing on the Italian context, Brandolini and Bugamelli (Barandolini & Bugamelli, 2009) identify three different exogenous shocks that companies have been suffered lately:

1. Shock - The introduction of single (European) currency.
2. Shock - The market entry of Asian Manufacturers Company.
3. Shock - The quick development of new Information Technologies.

According to their analysis, it is clear that the need for Flexibility and Adaptability is one of the most important challenges of this new economic scenario. In particular, managers of SMEs are requested to upgrade production departments considering the quick market changes. The ability to detect and manage changes is an important asset for enterprises willing to compete in a scenario where "Uncertainty" is the key word. It is widely believed that the Lean Thinking is the right strategy in this environment (Bonfiglioli, 2004).

1.3.2 A need for an empirical research on Lean Thinking in SMEs

Despite Lean being extensively discussed, a review of the existing literature (Bakås, Govaert, & Van Landeghem, 2011) shows that this is rarely analyzed in a SMEs context. The evaluation, completed by searching the combination of "lean" and "SMEs" as key word groups in 5 databases is briefly summarized in Table 8 and Table 9.

Time period	Databases employed	Keywords group 1	Keywords group 2
1992 - 2011 (20 Years)	- ABI inform - Science Direct - ISI Web of Knowledge - Springer Link - Google Scholar	- Lean - Lean manufacturing - Lean production - Lean implementation	- SME - SMEs - Small and Medium-sized Enterprises

Table 8 - Details of literature research (Bakås, Govaert & Van Landeghem, 2011)

#	Authors	Methodology	Focus of research	Main findings and critical success factors
1	Achanga et al. (2006)	Literature review Cases: 10 SMEs (UK)	Critical success factors for Lean implementation in SMEs	Critical success factors: - leadership - management - finance - organizational culture - skills and expertise
2	Kumar et al. (2006)	Case: 1 SME (India), automobile accessories	Framework combining Lean Six Sigma with Lean Manufacturing	Implementation of the proposed framework shows dramatic improvement in the key metrics and substantial financial savings in the case SME. Critical success factors not addressed.

3	Jiju et al. (2005)	Survey – UK SMEs (literature review)	Strengths and weaknesses of SMEs, Six Sigma projects and lean	Companies do not have resources to implement Lean Six Sigma projects. Lean and Six Sigma not popular among SMEs. Critical success factors: - Management involvement and participation - Linking Six Sigma to customers - Linking Six Sigma to business strategy
4	Kumar et al. (2009)	Survey – UK manufacturing SMEs (64 responses of 500)	Quality improvement initiatives, Six sigma and lean	Factors critical to success of quality initiatives are equal in importance, irrespectively of the type of initiatives implemented by the firm. Critical success factors: - Management involvement and commitment - Communication - Link Quality Initiative to employee - Cultural change - Education and training
5	Wilson & Roy (2009)	Literature review Theoretical model with case	Lean procurement	The barriers faced by SMEs trying to implement a lean procurement philosophy are significant. Low volumes, small lot sizes and high frequency purchases incur significant additional distribution costs. Critical success factors not addressed.
6	Thomas et al. (2008)	Single case – UK SME	An integrated approach to lean and six sigma model	Showcases on a successful implementation of the Lean Six Sigma model in the SME case company. The lean approach developed a culture towards continuous improvement throughout the organization. Critical success factors not addressed.
7	Grewal (2008)	Single case – India SME	Value Stream Mapping	Value Stream Mapping proved useful to company Critical success factors not addressed.
8	Shah & Ward (2008)	Survey of US plans with 1757 valid responses	22 management practices from lean and six sigma	Strong support of the proposition that large plants (large companies) are more likely to possess the resources to implement lean practices than smaller plants. Critical success factors not addressed.
9	Yang & Yuyu (2010)	Survey of 100 SMEs in Wenzhou region in China	Barriers to SMEs implementation of Lean	Countermeasures to barriers to the Lean implementations in SMEs: - attention and involvement of senior managers - good communication platform - learning organizations -establishment of performance evaluation system
10	White et al. (1999)	Survey, US	Comparing 10 JIT practices in small and large firms	Larger companies more likely to implement JIT (lean) practices. Performance also dependent on manufacturer's size.

Table 9 – Reviewed papers studying LM in SMEs 1992 – 2011

(Bakås, Govaert & Van Landeghem, 2011)

The parameters presented in Table 8 have been utilized to extend the findings of literary review up to 2016. The following six papers can be added to the list of results already shown in Table 10.

#	Authors	Methodology	Focus of research	Main findings and critical success factors
1	(da Silva & Tubino, 2013)	Survey of 79 SMEs in Brazil	Strengths and Weaknesses relative to LM implementation in SMEs	Strong correlation between LM and production performances. SMEs demonstrate poor results in the management of demand.
2	(Dorota Rymaszewska, 2014)	Case studies: 2 SMEs	LM implementation challenges in SMEs	The creation of a lean culture is one of the greatest challenges for Lean implementation. Managers shall consider the adoption of lean as a long-term investment.
3	(Belhadi & Touriki, 2016)	Survey of 5 SMEs	Identification of the most suitable lean tools for SMEs	Identification of the most suitable lean tools for SMEs. Reporting of successful experiences of SMEs in implementing lean programs. Development of a basic framework for lean implementation in SMEs.
4	(Ulewicz & Kucęba, 2016)	Survey of 65 SMEs	Identifying the problems associated with implementation of the Lean concept in the SME sector	The most common problems in implementing Lean concept for SMEs are: - barrier in relations between management and employees - lack of standardization - short-term financial goals - lack of information about the effects of activities - identification of Lean with a decrease in employment
5	(Zhou, 2016)	Survey of 200 SMEs	Lean impacts on SMEs	Main Benefits of lean implementation for SMEs: - increased productivity and efficiency - increased customer satisfaction - decline in manufacturing/inventory cost Main Lean challenges - need for company culture changes - employee resistance - lack of adequate knowledge of lean tools
6	(Moeuf, Tamayo, Lamouri, Pellerin, & Lelievre, 2016)	Literature review	Strengths and weaknesses of small and medium sized enterprises regarding the implementation of LM.	The following challenges prevent the implementation of LM in SMEs: - lack of delegation - lack of resources - lack of expertise - short-term strategy - lack procedure and methods, and non-functional organization. The typical high level of interaction between leader and the field is an important factor for LM introduction in a SMEs.

Table 10 - Reviewed papers studying LM in SMEs 2012 – 2016

The limited number of journal articles, whose keywords include both “Lean Production” and “SMEs”, shows that this topic is under-researched. Similarly, Moeuf et al. in their recent paper (Moeuf et al., 2016) about strengths and weaknesses of small and medium sized enterprises analyzed 3 databases: Emerald Insight, Elsevier, Taylor & Francis. Their literature review was focused on the selection of articles dealing with LM, and considering at least one of the main SMEs' characteristics proposed by authors like Garengo (Garengo, Biazzo, & Bititci, 2005) and Torres (Torrès, 1999):

1. Local management
2. Short-term strategy
3. Lack of expertise
4. Non-functional organization
5. Limited resources
6. Lack of method and procedure

The overall result was a list of only 23 papers. The analysis on literature completed by Shah and Ward (2003) heads in the same direction (Shah & Ward, 2003): an effort to evaluate the performances of bundles of lean techniques is required. For the above-mentioned lack of empirical evidence on the implementation of lean practices, a specific academic research is not just the natural result of the guidelines available in literature, but also very appropriate. Empirical research on Lean Thinking in SMEs through case-studies could bring forth the following benefits:

1. It will have a role in the propagation of Lean Principles.
2. It will simplify Lean implementation and, consequently, increase SMEs' competitiveness, through practical examples and suggestions.

1.3.3 The Barriers to SMEs' Implementation of Lean Production

Notwithstanding the notable advantages achievable through the modernization of obsolete production systems are largely acknowledged in literature, the resistances observed in the transient phases are well documented too. According to Achanga et al. (Saad et al., 2006), Bhasin and Burcher (Bhasin & Burcher, 2006), Drew et al. (Drew, McCallum, & Roggenhofer, 2016), Emiliani and Stac (Emiliani & Stec, 2005), Padgett (Padgett, 2004), Worley and Doolen (Cassell, Worley, & Doolen, 2006), the reasons of failure can take different angles, including:

1. <u>Strategic</u>

   Lean introduction must be strictly linked with the corporate strategy. The lack of a clear vision during the lean transition and the lack of an effective communication by leaders may result in a weak sense of urgency. This, combined with an unclear understanding on the scope of lean management system, could jeopardize the success of the lean improvement.

2. Managerial

   Management plays a strong role in lean implementation, hence the need for a structured methodology and project management (cost and schedule estimation and planning) is crucial. The lack of the managerial aptitude to adapt to changing environments could lead to a failure. The blind focus on shareholders only, associated to a poor consultation with all stakeholders penalizes the company in the long run. The absence of leadership direct participation in the activities bars the sharing of commitment, and wastes important opportunities for continuous improvement.

3. Structural

   Financing is a vital factor for the success of any project, since the lack of an adequate funding is a substantial obstacle, as well as the lack of skills and expertise obtainable by a supportive human resources policy. The absence of a dedicated and fully resourced implementation team increases the chance of failure.

4. Organizational

   The availability of a supportive organizational culture is an essential base frame for the lean introduction. The failure in the establishment of a cross-functional engagement or an insufficient communication, achievable through change champions, makes the lean deploying not easy.

5. Operational

   A clear analytic measurement system must be adopted to highlight the possible improvements and recognize the benefits arising from lean introduction. The lack of such mechanism, associated with the resistance to change, is one cause of failure. In addition, the inability to sustain initial efforts and to expand improvement to other departments or to the supply chain are constrains to keep under control.

Continuing with the literature review, Yang Pingyu (Yang pingyu & Yu yu, 2010) has analyzed the barriers to the introduction of Lean Thinking through a survey of small and medium-sized enterprises. He proceeded through analyzing the survey, structured as follows:

Did you know lean production?
What did you want to achieve with implementing Lean Production?
Why did you start to implement continuous improvements?
Did you study and compare yourself with other companies before the start of the improvements?
Does the company have a strategical goal that everybody knows?
Do all workers know what they should do to support these strategical goals?
Is the work with contentious improvements well support of the board?
Is everybody committed with the lean work?
Has the work with lean production changed the way you have been working?

Table 11 - Questionaries' structure (Yang pingyu & Yu yu, 2010)

Thus, the obstacles to SMEs' implementation of LM appear distinguished in the following areas:

7. Lack of knowledge.
8. Misunderstanding of lean production.
9. The staffs' resistance to lean production.
10. Implementing lean production mechanically without any adjustments, based on the environment.

The implementation of LM does not only consist in the change of management techniques, but also in the introduction of totally different ideas. This confirms the need of case research on Lean: managers must take into account the achievable improvements and proceed to adopt this reform.

1.4 Objective, research questions and delimitations

Womack (Womack & Jones, 1996) lists three factors required to overcome the natural objections to the introduction of effective but counterintuitive Lean principles: a Crisis, an Agent of Change and a Theoretical Knowledge.

1. The "Crisis" is the triggering event which requires a quick and definitive deviation from the obsolete business practice.
2. The "Agent of Change" is responsible for the introduction of the changes needed to make a company "Lean".
3. The "Theoretical Knowledge" is the set of techniques, best practices, examples and data, whose understanding allow the Agent of Change to make the right decisions.

The financial crisis provides managers with the opportunity to leave dated organizational models wisely. These models worked successfully in the past but are no longer suitable for the current markets. In fact, a cost reduction without investment is often a must for companies, openly requested by the management. Every manager, who acts as "Agent of Change", would be glad to encourage a drastic change if the possible alternative is the bankruptcy. Considering the need for knowledge, the purpose of this work is to assess how Lean principles can enhance the MF of SMEs.

1.4.1 Objective and aim

As mentioned above, the objective of the Doctoral Research is the appraisal on the effective convenience to implement the Lean Production, for a small company willing to mitigate the effect of uncertainty with Flexibility. Computer Simulation constitutes a low-cost and high-effective method to assess the improvements achievable through Lean techniques. For that reason, the gathering of experimental evidences (i.e. production performance records, sales data and official documents) is combined with a software simulation. The procedure described in the following chapters allows the comparison between different production arrangements. Whit this regard, the measurements of flexibility and efficiency are based on some Key Performance Indicators (KPI). These are calculated combining different parameters commonly used in literature (Shah & Ward, 2003) (Lian & Van Landeghem, 2002) (Rother & Shook, 1999):

1. Work-in-process inventory

   The part of inventory that has been partially converted through the production process and is not yet finished. Minimizing the quantity of work-in-process in the manufacturing area is commonly considered a best practice.
2. Capacity

   The quantity of goods that can be produced by a plant in a fixed period through the available resources.
3. Resources Utilization

   The proportion of hours actually worked by a resource, when compared with the amount of working hours.
4. Cycle Time

   The time from the moment when the production of an item starts to when this item is ready for shipment.
5. Lead Time

   The time from the moment when the request is made by a client to when this item is delivered.
6. Change Over Time

   The period required to prepare equipment for it to change from producing the last good piece of the previous batch to the production of the first good piece of the next batch.
7. VA/NVA Time

   Value Added Time is the sum of process times that improve products. On the other hand, Non-Value Added Time is the amount of the production cycle time that is not directly used to produce goods.
8. Waiting Time

   The amount of time a product spends stored in an inventory or queue along the production process.

The aim of this study is represented by an enhancement of the operations management knowledge within SMEs context. The work has been conducted analyzing the manufacture department of an Italian semi-artisan company, whose core business is the decoration of glass items. The company is referred to as ALPHA, since a part of the disclosed information is confidential.

1.4.2 Research questions

According to Abdulmalek and Rajgopal (Abdulmalek & Rajgopal, 2007), the combined use of case-study, value stream mapping and computer simulation ensures the gathering of useful material on Lean Thinking. It also provides managers with suitable tools for assessing the benefits connected with

Lean Practices. Based on this, the study shows a similar approach to address the following research questions:

1. HOW does Lean Manufacturing enhance the production in respect to the investments?
2. HOW are Lean Manufacturing and Manufacturing Flexibility connected in the SME context?

1.4.2.1 HOW does Lean Manufacturing enhance the production in respect to the investments?

The positive effects of many lean techniques on the production systems are frequently pointed out in literature. The methods are commonly analyzed considering their general impact on manufacturing performances, often from a qualitative prospective only. On the contrary, this research focuses on 3 specific approaches (Single Minute Exchange of Dies, Just-in-Time and Cellular Manufacturing), providing quantitative data about their adoption and linking those data with the enhancement of MF. Womack and Jones (Womack & Jones, 2005) estimate minimal investments required to upgrade from a mass production system to that of a lean one, since a skilled Sensei should be able to reorganize the manufacturing plant quickly, without enduring delays. Nevertheless, the overall cost for the introduction of lean principles in SMEs deserves attention. A high-level assessment on the possible cost / benefit ratio of lean techniques will be presented. The benefits estimated by the simulation model are compared with the typical investment required to make them possible.

1.4.2.2 HOW are Lean Manufacturing and Manufacturing Flexibility connected in the SME context?

As stated in the previous paragraphs, the flexibility represents one of the main features to be pursued by companies willing to compete in the open market. The manufacturing department of ALPHA is heavily focused on testing Lean Techniques in such an unstable environment. This study assesses the flexibility gains that are specifically due to the introduction of each of these methods. In relation to this, a set of Key Performance Indicators (KPIs) is introduced for the quantitative evaluation of performance improvement. Value Stream Mapping is used along with Computer Simulation to calculate the KPIs.

1.4.3 Delimitations

This work describes the performance enhancement generated by the Lean Introduction in small companies. In particular, it focuses on the main paybacks achievable in terms of Flexibility. The research is based on a single case study within Italian SMEs. The need to compare many organizational solutions in a limited timeframe, well-suited with the PhD schedule, requires the use of computerized simulations. In fact, the initial part of data collection was totally conducted by on-field activities, while the study on improvements involves the use of dedicated software: System Modeling Corporation's Arena.

1.5 *Outline of the Thesis*

This thesis is a traditional work in its design. It is structured according to Table 12 illustrated below:

Chapter 1 Introduction	Chapter 1 provides an overview of the background and the topic description (Research Questions).
Chapter 2 Background	Chapter 2 introduces the concepts of Flexibility. In addition, the characteristics, the creation and adoption of Lean Production are presented.
Chapter 3 Research Methodology	Chapter 3 describes the research approach and the scientific methods used.
Chapter 4 Case Study: ALPHA	In chapter 4 the ALPHA case is studied; empirical evidences are associated with software simulation to answer the Research Questions.
Chapter 5 Solutions and Results	In the final section, Chapter 5, the research results are discussed and further research is suggested.
Chapter 6 References	Chapter 6 lists the references of this work.

Table 12 - Outline of the Thesis

2 Background

In the following paragraphs a brief narrative on the base concepts of the study is presented. The introduction of main notion like MF and LM, is flowed by the explanation of the set of the base techniques, metrics, and tools used for this work. Finally, the last section of this chapter contains an overview of the company, analyzed as case study.

2.1 *Introduction to literature review*

The literature review completed in this PhD Thesis has been accomplished to establish the theoretical foundation of research, as suggested by Flynn et al. (Flynn, Sakakibara, Schroeder, Bates, & Flynn, 1990). The review starts with an introductive study about the established knowledge on the keywords presented with the abstract. Then, quoted papers and books have been selected to support and justify the statements provided among the first five chapters of this document. The total 137 documents, quoted in this thesis, are papers, books, conference proceedings, reports or PhD thesis:

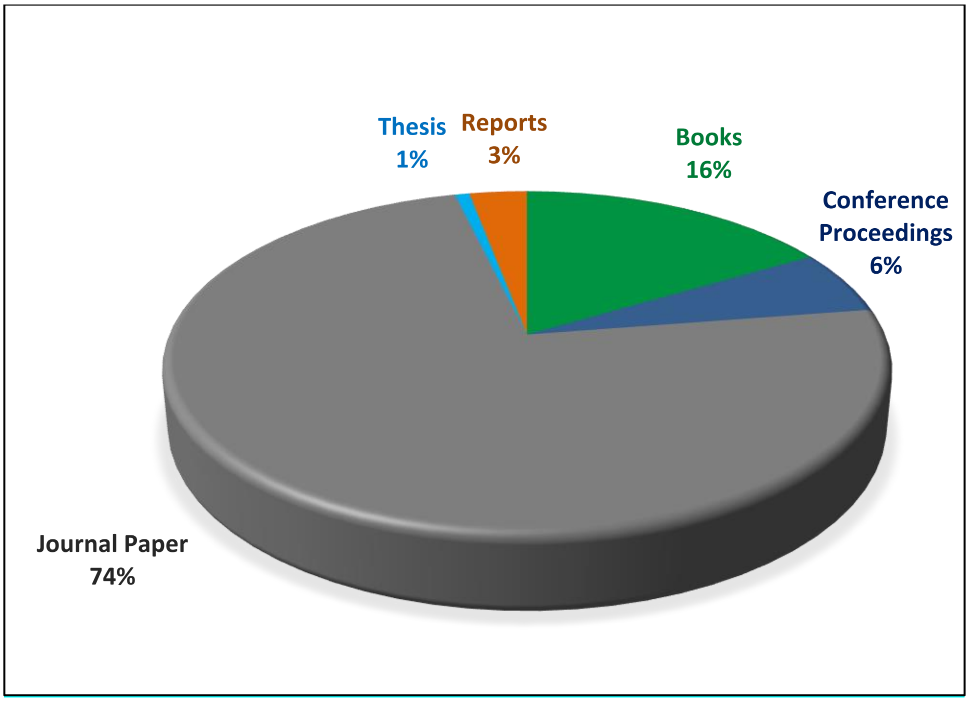

Figure 2 - References types

A statistic on the references is provided here below in Table 13:

First time quoted references (Additional quotes)

	1970-1979	1980-1989	1990-1999	2000-2009	2010-2017
Chapter 1	1	2	8	24	17
Chapter 2	1	10 (2)	17 (3)	30 (7)	7 (2)
Chapter 3	0	2	4 (1)	11	0
Chapter 4	0	0	0	0 (1)	0
Chapter 5	0	0 (2)	2 (3)	1 (8)	0 (3)
	2	14 (4)	31 (7)	66 (16)	24 (5)

Table 13 - Quoted References

Almost half of 101 papers quoted in this thesis have been published in one of the following six Journals:

1. International Journal of Operations & Production Management 11 Papers
2. International Journal of Production Research 9 Papers
3. Journal of Operations Management 7 Papers
4. Journal of Manufacturing Technology Management 6 Papers
5. International Journal of Production Economics 5 Papers

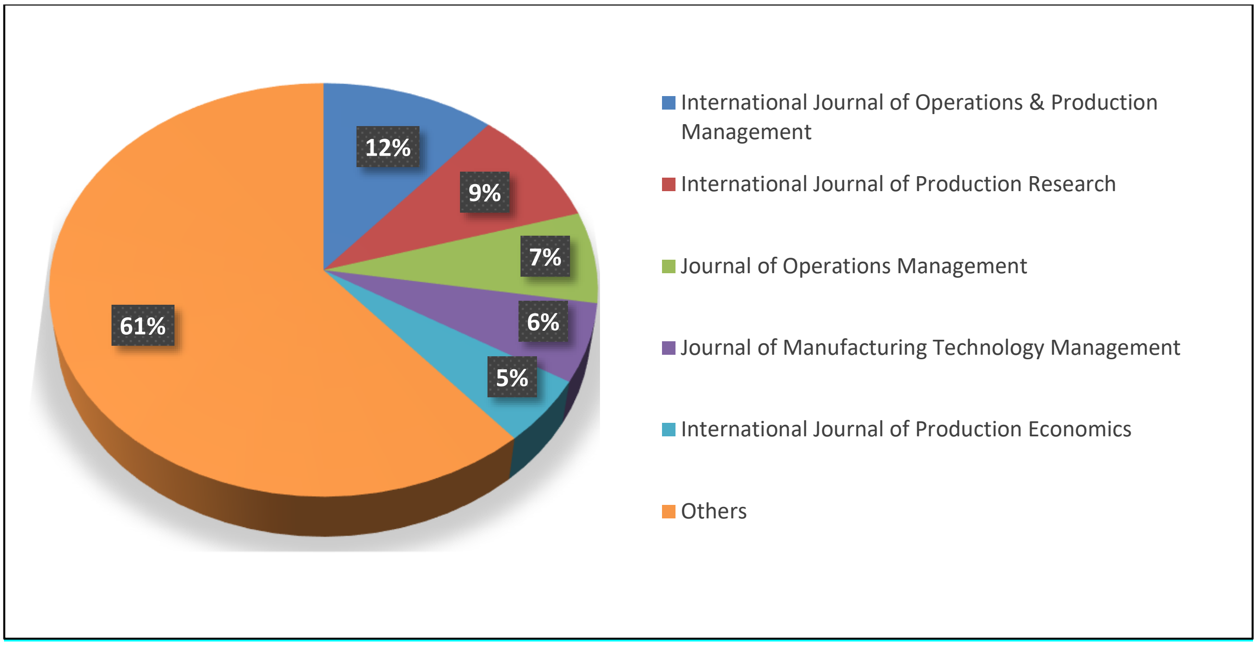

Figure 3 - Journal Papers

Each of 105 references is related to at least one of the main topics connected to the PhD investigation. The following picture shows the percentages of papers about these topics:

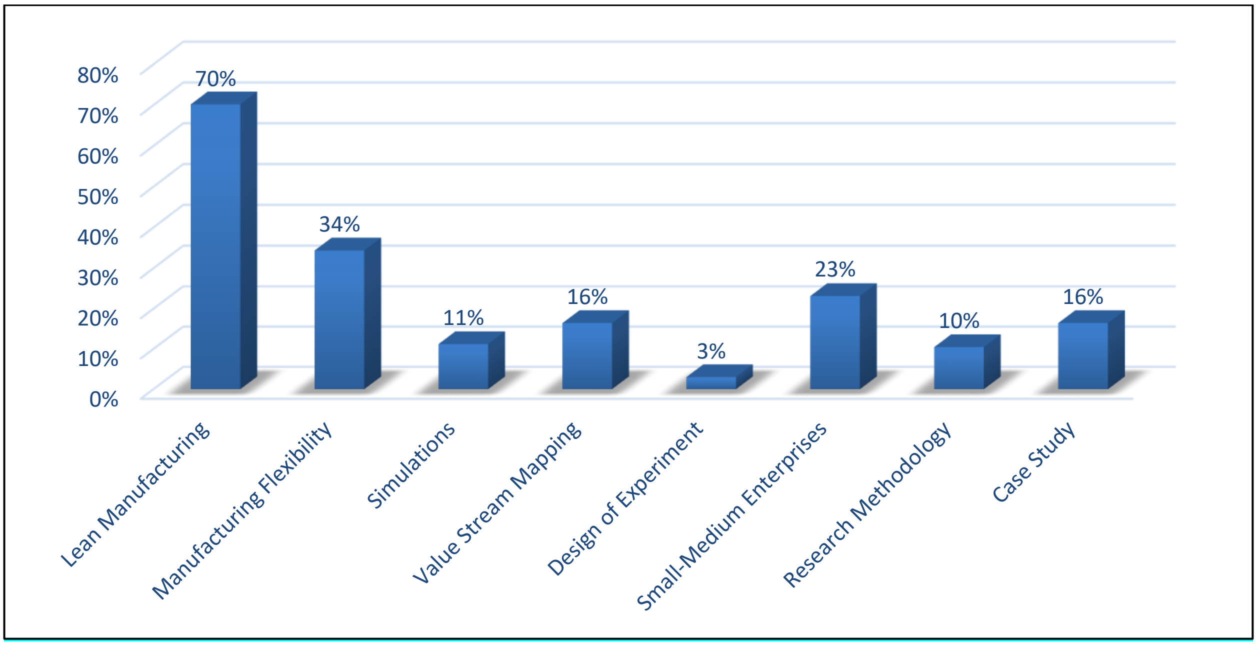

Figure 4 – Percentage of references related to topics

2.2 Manufacturing Flexibility

MF is defined in literature as the capacity of a production system to handle variable conditions (Buzacott & Mandelbaum, 1985) or uncertainty, caused by external factors (Mascarenhas, 1981). Gupta and Goyal remark that manufacturing systems should be flexible (Y. P. Gupta & Goyal, 1989) (Gupta & Goyal, 1989), as this affects the overall performances, allows customization, and reduce costs. Such critical asset affects the overall company performances, concurrently enabling customizations and cost efficiency. In accordance to this, Carpinetti, Jerome and Dorta (Carpinetti, Gerólamo, & Dorta, 2000) argue that the competitiveness of a firm depends on factors, such as cost, quality, delivery, innovation and flexibility, in adapting to changing market demands. The next two paragraphs describe the main kinds of flexibility and how these can be achieved by adopting Lean Thinking.

2.2.1 Introduction to Manufacturing Flexibility

As a result of globalization, high-quality and highly customized products are the only ones able to compete with cheap goods from the best cost countries (Gerwin, 1993). The inherent simplicity of the small companies is a strength to be used to respond promptly to the customers' needs (R. K. Singh, Garg, & Deshmukh, 2008). For this reason, one of the major objectives of an SME should be the use of flexibility (Cagliano, Blackmon, & Voss, 2001) as a strategy to provide clients with innovative products (M. Gupta & Cawthon, 1996). For empirical studies Suarez, Cusumano, and Fine (Suarez et al., 1996) suggest to focus on four "First Order" types of flexibility, which strongly impact on the competitiveness of a company:

6. Mix Flexibility.
7. New-Product Flexibility.
8. Volume Flexibility.
9. Delivery-Time Flexibility.

Other authors (i.e. Changa, Yangb, Chengc, Sheu (Chang, Yang, Cheng, & Sheu, 2003)) already referenced this approach, which will be discussed in the present work. The 4 categories are briefly presented below:

Mix flexibility can be defined as the ability to produce a widespread range of goods and options by using tools having quick changeovers. This specific kind of flexibility is commonly

considered fundamental when companies are requested to provide Customers with highly customized products.
Implications for SMEs: Semi Artisan firms are likely to act in a market requiring this adaptability, therefore the Mix Flexibility constitutes an asset for the SME segment. Mix Flexibility may also be important when the demand is not easily predictable and Competitors follow a full-line approach, providing multiple products at a competitive price.

New-product flexibility represents the responsiveness for any possible variation in a product design. This includes both the introduction of brand new products and the upgrade of existing ones. A flexible method for designing the "base products" can reduce the future investment for their upgrade and ensure better performance in providing Customers with goods aligned with current demand. The need for New-product flexibility is nowadays amplified by the increased technologic goods of the market, which implies a rapid innovation in customer requests. In this environment, where products have a short life-cycle and they consequently get replaced, firms are more and more driven to adapt product lines in order to capture a profitable market share.
Implications for SMEs: Small companies relying on the manual expertise of operators present an intrinsic predisposition on the introduction of customized new products (R. K. Singh et al., 2008). Product re-design and production process re-shape become commonly more complex with the increase of company size and, consequently, with the possible stiffening of design and production processes.

Volume flexibility is the aptitude of a firm to produce goods at different output levels cost-effectively, operating above/below the optimized capacity rate for a specific product. The possibility to change the production level with limited impacts in competitiveness is a desirable skill for every manufacturing system operating in an uncertain context. The requests for a manufacturing rate which exceed the standard capacity of the system is usually coped through the temporary outsourcing of productive units. On the contrary, in case of turn down, the base costs shall be analyzed carefully, in order to grant their covering despite the reduced income.
Implications for SMEs: the need for Volume flexibility is critical for small firms, especially in a context of reduced production volumes compared to the optimal flow. Companies belonging to the SME category cannot usually leverage on market differentiation or on large financial buffers, hence the control of their performance in relation to different demand levels is mandatory.

Delivery-time flexibility is the ability of the production system to accommodate customer's special needs in terms of products' delivery. The capability to reduce the lead time upon Customer request is typically needed in time-sensitive market segments. This kind of attitude is usually related to the latest stages of a product life cycle, when competition centers on variants such as price, delivery time and service.

Implications for SMEs: Delivery-time flexibility is an advantage where the high-quality is not considered a mandatory feature and the customer cannot wait too long to purchase the products of a specific firm. SMEs usually operate in market niches where quality and customization are the key drivers, therefore the delivery time is not considered the priority for that kind of company.

This research focuses on the Volume Flexibility (VOLF) and Mix Flexibility (MIXF) that drive most of the overall MF (Hallgren & Olhager, 2009a). The same perception is also confirmed by Metternich et al. (Metternich, Böllhoff, Seifermann, & Beck, 2013), reporting the results of a survey completed by Seidel and Von Garrel (Seidel & von Garrel, 2010) which appraises the major causes of the companies' need for flexibility. The evaluation of a sample of 1221 firms confirms that the most important reason for the companies to raise flexibility in their production system is the ability to react to a changing demand (recognized as a key factor for more than 60% of the companies). Thus, volume and mix are the principal types of flexibility since they determine the production needs. On the basis of the above research presenting the implications of flexibility for SMEs, we could also add that these 2 kinds of flexibility mostly influence the success of a small company producing customized goods and operating in a context of economic crisis. Companies which aim towards flexibility as a competitive advantage must structure their operational departments accordingly. In fact, the organizational responsiveness relies on a strong communication and cooperation between structures that, in the traditional concept of production, are rigid and divided by barriers. Unfortunately, the adoption of management systems suitable for the integration of functional units often implies a greater complexity and a higher level of cost (Abernethy & Lillis, 1995). In addition to this, investments for the acquisition and modernization of facilities are usually needed to improve the manufacturing performances. Regardless of the cultural background of a company, the financial resources constitute a key requisite for achieving an optimal level of flexibility and represents one of the main deterring factor for a SME willing to improve its effectiveness (Nemetz & Fry, 1988). Based on what is indicated above, the lean principles may be a viable option to increase the flexibility with a low investment. Boyle and Scherrer-Rathje (Boyle & Scherrer-Rathje, 2009) agree that the Lean Philosophy represents one of the most recommended way to mitigate the possible effects of uncertainty. At this regard, its wide appreciation stems from the fact that the reduction of waste, the main objective of Lean Production, contributes to reduce the negative effects of some changes (i.e. increase of base costs). The complex nature of MF requires empirical researches intended to its characterization (Vokurka & O'Leary-Kelly, 2000). The analysis of case studies provides guiding principles to select appropriate strategies for specific environments. Koste and Malhotra (Koste & Malhotra, 1999) point out the necessity to assess the benefits of different flexibility building strategies empirically. On the basis of this, the present work analyzes the impacts of Lean Introduction on the flexibility of SMEs. As previously mentioned, Flexibility is the capacity of a production system to manage variability, delivering high performances regardless to the changing environment. Since VOLF is the ability to profitably operate a manufacturing system at different production volumes (Browne, Dubois, Rathmill, Sethi, & Stecke, 1984), authors like Parker and Wirth (Parker & Wirth, 1999) state that VOLF can be evaluated as the difference between the break-even point and the maximum capacity of a company:

$$\boldsymbol{Volume\ Flexibility} = \mathbf{1} - \frac{\boldsymbol{F}}{\boldsymbol{C_{max}}}\left(\prod_{i=1}^{n}\frac{\boldsymbol{a_i}}{\boldsymbol{b_i}}\right)^{1/n}$$

$\boldsymbol{F}$	Fixed costs
$\boldsymbol{C_{max}}$	Production system capacity
$\boldsymbol{a}$	Required amount of capacity units to produce one product unit
$\boldsymbol{b}$	Contribution margin of one product unit
$\boldsymbol{n}$	Number of possible products

Considering the features of the products (variables: $\boldsymbol{a, b, n}$) constant, VOLF results in a function of fixed costs and production capacity only. On the basis of this assumption, a production system characterized by a high production capacity irrespectively to the required mix of products, and operating with low fixed costs can be considered flexible. With regard of the fixed costs, it is important for a firm to have the possibility to employ a part of the resources only when needed, so that the relevant cost can be considered variable. The resource utilization of a rigid system decreases when the production volume drops, since a part of the resources is not employed. On the contrary, in a flexible system, resources can be temporarily used for the completion of other activities during the downturn (Lee & Ebrahimpour, 1984) (Julie Yazici, 2005), and an additional capacity can be outsourced during peaks of demand; thus, a flexible system presents a stable high level of resource utilization, regardless of the fluctuation in demand. MIXF is the ability to produce different products using different materials in several ways (Browne et al., 1984). Bateman (Bateman, 1999) refers to the indicator sensitivity to change for the machines introduced by Chryssolouris and Lee (Chryssolouris & Lee, 1992) for defining a MIXF response, which is proportional to the probability of the change of products and to the duration of setup time: the Mean Sensitivity to Change.

$$MSTC = \sum_{i=1}^{n} P_i(P_i - 1)dur_i$$

P_i Probability of a certain product i occurring
dur_i Duration of setup times relevant to a product i

Considering the probabilities of products occurring constant, the only remaining parameter of the equation is related to the setup times. The direct link between a decrease in setup times and an increase in MIXF is clear. In addition to this, the possibility to extend the small lot approach to the supply chain, reducing inventories, is important for enhancing the overall MIXF of the whole system composed by manufacturer and suppliers (Mendonça Tachizawa & Giménez Thomsen, 2007) (A. Sohal, Keller, & Fouad, 1989). Bartezzaghi and Turco confirm the connection between an overall low level of inventory with a MIXF oriented approach (Bartezzaghi & Turco, 1989). Thus, a stable low work in progress inventories level can be considered as additional estimator for the MIXF level. With this regard, in the next chapters the variation of the following KPIs depending on different exogenous factors will be evaluated to measure the flexibility of different production configurations:

1. Production Capacity
2. Resources Utilization
3. Work-in-process inventory

The use of techniques to reduce the setup time will be discussed considering their intrinsic benefits on MIXF and the additional effects on KPIs.

2.2.2 Lean Manufacturing and Manufacturing Flexibility

Flexibility is considered by both researchers and managers a critical component of the manufacturing strategy and a competitive priority for organizations ((Davies & Kochhar, 2002), (Dangayach & Deshmukh, 2001), (Ketokivi, 2006). Traditional flexibility techniques commonly used in the past, such as inlet / outlet inventories and idle spare equipment, are not aligned with the current efficiency need. Boyle in his study (Boyle & Scherrer-Rathje, 2009) identifies the best practices managers use to improve MF and process performance at the same time. His research confirms that best practices for improving flexibility in manufacturing organizations, ensuring also that broader organizational goals are met, belong to LM. In addition, the overall trend for an upgrade from “Banking” strategies towards “Adaptation” approaches, by adopting lean practices, is also documented.

Flexibility strategy	Tools and practices to achieve flexibility strategy
Adaptation	Basic lean practices Six sigma quality Visual display Defect prevention One-piece flow Pull system Kanban Work cells Single-minute exchange die (SMED) Quality at source (JIDOKA) Just-in-time (JIT) supply Efficiency of motion and workplace practices Value stream mapping Total quality management (TQM) Total preventive maintenance (TPM) Kaizen (continuous improvement) Poka-yoke 5S Design for manufacturing and assembly (DFMA) Supplier management Quality function deployment (QFD) Cross-training Automation/robotics
Reduction	Long-term relationships with customers Increase customer communication Customer integration in development process Long-term relationships with suppliers Shared development products with suppliers Vertical integration through strategic alliances Strategic supplier management
Banking	Safety stock building Building inventory Increase capacity Increase workforce Increase capability of employees to conduct more than one task Working over time Safety stock building
Redefinition	New product design Modified processes Design innovation Implementation of new technologies

Table 14 - Tools and practices to achieve flexibility strategy (T. A. Boyle & Scherrer-Rathje, 2009)

2.3 Lean Manufacturing

At the end of the World War II Japan was experiencing a critical industrial condition with regards to its lack of resources (material, financial and human). As a reaction to this serious circumstance, a new manufacturing concept was conceived in the automotive industry: the "Toyota Production System" or "Lean Manufacturing".

2.3.1 Five-Step approach for Lean Introduction

Womack (Womack et al., 1990), in his most famous book, suggests a five-steps approach, aimed to ban waste and maximize the performances of a production flow. This foundational lean philosophy, focused on the Added Value activities, leads towards perfection through the following continuous process (producing more with less cost).

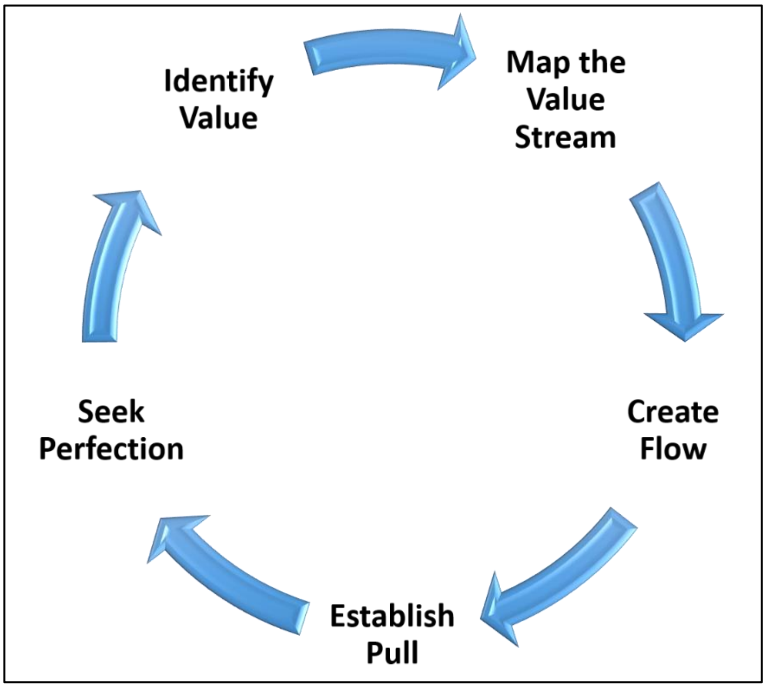

Figure 5 - Five-Steps Approach

The five-steps approach for Lean Introduction is illustrated in Figure 2 and explained below:

2.3.1.1 Identify Value

The base of any project aiming to develop the market of new products is the identification of features which create added value for customers. The worth of the product offered and its availability has to be compared with the price. The target is to define accurately the value of each specific product features through a dialogue with customers. The value is the capacity of a product/service to meet the needs of the client at a given price and at a given time. The use of resources is only justified if they create value for the final customer; otherwise this constitutes waste (Muda).

2.3.1.2 Map the value stream

The value stream can be defined as the set of activities required to convert raw materials into finished products. After the survey on the manufacture steps, it is mandatory to map clearly the activities required for the production to focus exclusively on adding. The Value Stream Mapping shows the amount of waste, dividing processing into three categories:

4. Value-creating: activities whose costs can be transferred to the client.
5. Necessary No-Value-creating: activities whose costs cannot be eliminated with the existing production systems.
6. Unnecessary No-Value-creating: activities whose costs should be deleted immediately.

2.3.1.3 Create Flow

Added Value activities have to be organized as a flow in order to ban gradually all wastes. The traditional batch production is replaced by teams focused on similar products. Each team independently controls the whole assigned process, managing any issue which may arise step-by-step across the manufacturing sequence. The continuous production flow, with the associated high efficiency, is typically achieved through radical changes.

2.3.1.4 Establish Pull

The unpredictability of the demand is qualitatively and quantitatively increasing. Therefore, the adoption of Pull logic is required to satisfy customers' expectations. The Lean thinking suggests a real-time aligning of the production stream, based on market's needs and expectations. In conclusion, the company must acquire the capability to design, plan and carry only what the customer wants, when he wants.

2.3.1.5 Seek Perfection

The adoption of Lean thinking is meant as work focused on continuous improvement towards perfection. The perfection consists in eliminating total waste of time, space and costs. The inefficiency of a production system is closely connected with the interruptions in the production workflow. In an ideal production system, each product, component, or raw material should appear in only two conditions: processing or handling.

2.3.2 Seven Wastes of Lean

Taiichi Ohno, Toyota chief engineer, identified seven different types of waste (so-called Muda) that can be considered the root of all unprofitable activity within an organization. According to Lean Thinking, everything that does not add a value is considered a form of wastage and shall be solved.

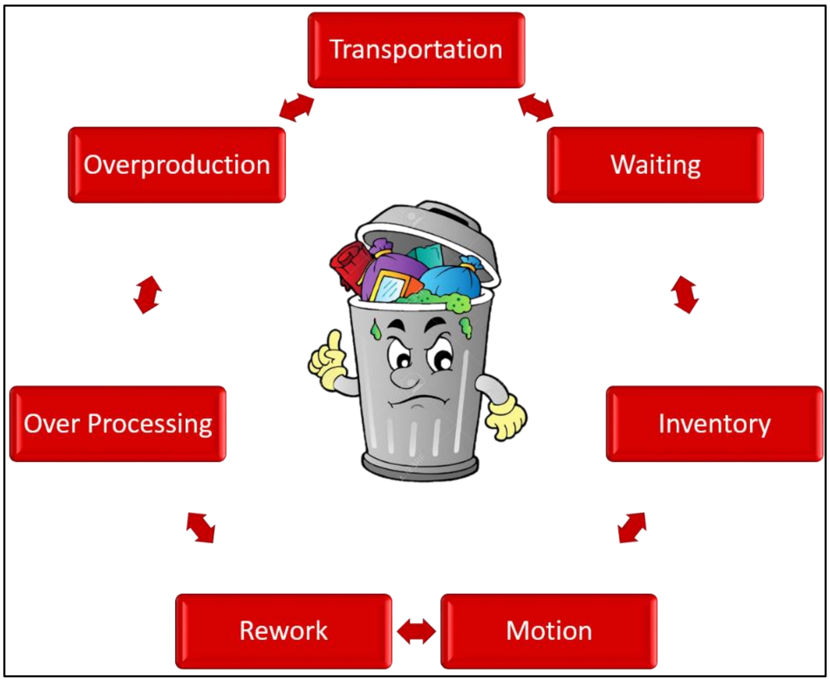

Figure 6 - Seven Wastes

The 7 kinds of waste, shown in Figure 3, are briefly described below:

2.3.2.1 Overproduction

Overproduction occurs when the production exceeds the quantitative requests. The produced goods are often more than enough to deal with downtimes, defects and absences. Such waste is typical of the traditional batch production: the quantity of parts to be produced is defined and planned according to a logic, not aligned with clients' orders. This often involves net of sales, inventory and storage of finished or semi-finished products. The stock brings to an increase of costs: the value of the unsold product, the storage of "not requested" items and the related "waste" of space. Other costs of overproduction come from the consumption of raw materials earlier than necessary, a larger workforce, more machinery, more space for the processing or for the goods' storage, and, finally, more movements and administrative expenses. Thus, the target is to produce only what is effectively needed. This goal is not easy to achieve and usually requires a general production lines rearrangement. The successful key procedures are:

1. Production Planning: it is essential to calculate the number of goods to produce the right amount per the orders received.
2. Process flexibility: all processes must be designed for maximum operational flexibility.
3. Process control and stability: the results of each process steps must be known, repetitive and stable over time.
4. Efficiency: maximum organizational efficiency must be pursued, in terms of human resource management and process management/materials.

2.3.2.2 Transportation

Each transport has a cost in terms of resources and a product may be damaged, lost or delayed. For this reason, the movement represents an avoidable cost. Usually there are two aspects to consider and tackle:

1. The reason why transport is necessary: constraints, requiring the handling, must be removed.
2. The optimization: each transport should be analyzed in terms of frequency, distance, time, required equipment and operating procedure.

The final goal is the elimination of all types of unrequired transport.

2.3.2.3 Waiting

Each product, waiting in the production cycle for times not strictly necessary to manufacture, is equivalent to fixed assets and this often leads to inefficiency. The most common causes are:

1. Synchronization errors.
2. Late arrival of materials.
3. Queue.
4. Delays due to equipment breakdowns.
5. Lack of operators.
6. Waiting for machine tooling.

These delays usually conceal various aspects:

1. Incorrect design of production lines.
2. Lack of proper training.

3. Lack of control.

In conclusion, even if the removal of all delays along the production flow can be difficult and expensive, a careful evaluation of the waiting times should be completed to set goals and establish a reviewed strategy.

2.3.2.4 Inventory

Stocks (raw materials, materials in process "WIP" or finished products) are an investment which has not produced a gain yet. Their existence generates a quantity of "trapped value" (Working Capital), function of products amount and their position in the production flow. Therefore, the appropriated solution is to reduce stocks to minimize the frozen capital. However, this difficult task often needs a corporate reorganization and it sometimes involves external actors (e.g. Suppliers).

2.3.2.5 Motion

Motion differs from Transport because it is carried out within the processing cycle. In other words, we talk about Transport when a piece is transferred from an area (work station, department and line) to another one. On the other hand, Motion is when the transfer takes place within the same processing cycle in a defined location. Also in this case the target is to minimize movements (men, machines and products) within the processing cycle: the result will be an improvement of productivity.

2.3.2.6 Rework

In the Lean philosophy, the production of a defective piece (scrap or requesting additional working, re-working, compared to the standard) is considered waste. It is not easy to identify and resolve problems which may lead to waste and defective parts, nevertheless this waste is undeniable. Extra work and rework constitute a significant part of the cost structure. Every piece must be analyzed accurately, with the aim to minimize the rate of possible intrinsic defect.

2.3.2.7 Over Processing

Using resources which are more expensive than necessary or producing any features exceeding the customers' requests, create waste. For example, employing workers with higher qualifications than required generates costs: the execution of low-skilled tasks does not require any high-skilled professionals.

2.3.3 Lean Techniques

As mentioned in the previous paragraph, the most important target of Lean Thinking is the banning of wastes. This can be pursued by adopting a set of techniques, the backbone of Lean Philosophy, which is widely discussed in literature: Monden (Monden, 1998), Feld (Feld, 2000), Nahmias (Nahmias, 2001), Marodin et all (Marodin et al., 2015), Shah & Ward (Shah & Ward, 2003), and Bortolotti et all (Bortolotti et al., 2015). Shah & Ward (Shah & Ward, 2003), in their work propose and validate 4 different bundles of lean practices, which are divided according to their main objectives:

1. Bundle #1 Just-in-Time (JIT): this bundle includes all practices related to production flow. The primary goal of JIT is the continuous banning of all forms of waste (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). Work-in-process (WIP) inventory and unnecessary delays are two key wastages. Both can be minimized by applying practices related to production flow:

WIP inventory reduction	Unnecessary delays reduction
Lot size reduction	Cellular layout
Cycle time reduction	Reengineering production processes
Quick changeover	Bottleneck removal

Table 15 - JIT Practices (Shah & Ward, 2003)

2. Bundle #2 Total Quality Management (TQM): practices linked with continuous improvement and control of products and process quality belong to the TQM bundle. This includes quality management programs and formal continuous improvement programs.

3. Bundle #3 Total Preventive Maintenance (TPM): the TPM bundle consists of practices conceived to improve equipment effectiveness through planned predictive and preventive maintenance (e.g. by using maintenance optimization).

4. Bundle #4 Human Resource Management (HRM): the most common HRM practices are job rotation, job design, job enlargement, formal training programs, cross-training programs, work teams, problems solving groups and employee involvement, as suggested by many authors (Ichniowski, Shaw, & Prennushi, 1997); (MacDuffie, 1995); (Osterman, 1994). Shah & Ward (Shah & Ward, 2003) include only two practices in the HRM bundle: self-directed work teams and flexible, cross-functional work force. These two practices can be anyway considered higher level practices, including many lower level tools.

According to the definitions provided previously, the following table shows the grouping of some of the main Lean Practices:

Lean bundles	**JIT**	**TPM**	**TQM**	**HRM**
Lot size reductions	X			
JIT/continuous flow production	X			
Pull system	X			
Cellular manufacturing	X			
Cycle time reductions	X			
Focused factory production systems	X			
Agile manufacturing strategies	X			
Quick changeover techniques	X			
Bottleneck/constraint removal	X			
Reengineered production processes	X			
Predictive or preventive maintenance		X		
Maintenance optimization		X		
Safety improvement programs		X		
Planning and scheduling strategies		X		
New process equipment or technologies		X		
Competitive benchmarking			X	
Quality management programs			X	
Total quality management			X	
Process capability measurements			X	
Formal continuous improvement program			X	
Self-directed work teams				X
Flexible, cross-functional workforce				X

Table 16 - Lean Practices bundles (Shah & Ward, 2003)

Bortolotti et al. (Bortolotti et al., 2015) propose a different categorization based on a binary approach where the Lean Tools are identified as "Hard" or "Soft". The definition of these categories is presented below:

1. Soft practice: tools related to principles, managerial concepts, people and relations.
2. Hard practice: tools adopted to improve production systems.

Six well-recognized LM practices are presented in Table 17 and described in the following paragraphs. The concept of Value Stream Mapping will also be drilled down in a dedicated section (2.3. Overview of Value Stream Mapping and Software Simulation).

LM practice	Hard/soft practice
Single Minute Exchange of Dies	Hard LM practice
Cellular Manufacturing	Hard LM practice
Kanban	Hard LM practice
Small group problem solving	Soft LM practice
JIT delivery by suppliers	Soft LM practice
Continuous Improvement	Soft LM practice

Table 17 - Hard and soft LM practices (Bortolotti et al., 2015)

2.3.3.1 Single Minute Exchange of Dies (SMED)

Dave and Sohani (Dave & Sohani, 2012) describe Single Minute Exchange of Die (SMED) as a lean production method which provides a rapid and efficient way of converting a manufacturing process from producing the current product to producing the next product. The exchange of dies is a demanding activity that, case by case, can deserve lengthy time for the machines setup. This has represented and still represents a not added value activity for companies with a production system not developed properly, from this point of view. The SMED (Single Minute Exchange of Dies) is a technique completely integrated within the LM and arises from the need to have a Quick Changeover (QCO). The setup has two key components:

1. Inside Exchange of Die: activities which can be completed only when the production line is stopped.
2. Outside Exchange of Die: activities which can be completed even if the production line is initiated.

The market pressure for flexibility and for the production of small lots entails a high frequency of setup. For this reason quick changeovers are required to cope with demand uncertainty (McIntosh, Culley, Mileham, & Owen, 2000). On the base of this and of the definitions provided in paragraph 2.1. Manufacturing Flexibility, SMED can be considered a promising tool for the enhancement of MIXF. The positive effect of SMED on Flexibility is also confirmed by Alves (Alves & Tenera, 2009) who highlights that SMED reduces the non-productive time by streamlining and standardizing the operations for exchange tools.

2.3.3.2 Cellular Manufacturing (CELLMFG)

Traditional facilities are structured in functional departments and the product usually crosses various departments generating queues at the entrance of each division. The Cellular Manufacturing (CELLMFG) represents one of the most significant improvements of Lean Thinking. Shorter product life-cycles, unpredictable demand and customized products characterize the environment where firms are operating nowadays. According to Mungwattana (Mungwattana, 2000), the following benefits can be associated with the adoption of CELLMFG:

1. Setup time is reduced
2. Lot sizes are reduced
3. Work-in-process and finished goods inventories are reduced
4. Material handling costs and time are reduced (each part processed within a single cell)
5. A reduction in flow time is obtained
6. Tool requirements are reduced
7. A reduction in space is required
8. Throughput times are reduced
9. Product quality is improved

Mungwattana considers CELLMFG a promising technique in instable scenarios thanks to its high potential in terms of process flow rate and flexibility. MIXF takes advantage of the reduced setup time and reduced lot size. VOLF will benefit, in particular, from the fact that the number of active cells can be aligned with production needs, reducing the manufacturing costs. As per this approach, the production is organized into cells, a working unit defined and delimited, typically from 3 to 12 employees, with 5 - 15 workstations. The ideal cell can produce the highest number of similar products, containing all the equipment, facilities and human resources required for the purpose. The main advantages achievable are summarized as follows:

1. Increase of productivity.
2. Decrease of lead time.
3. Increase of product quality.
4. Inventory reduction.
5. Better use of accounting activities (ABC).
6. Increase of coordination and communication.

2.3.3.3 Kanban

Kanban literally means ‘Label’ and identifies a characteristic feature of the JIT system for replenishment of consuming stocks. The label, indicating the type of material used for machining, is affixed to the related container which is refilled when requested. The real-time control that handles refilling is visual and needs no planning, due to its base on the number of cards removed from emptied containers. Different variation of this practice were developed over the years to adapt properly to various scenarios and corporates' realities (Lage Junior & Godinho Filho, 2010). Kanban leads to a considerable reduction in stocks, with an increased reactiveness in response to market changes and to planning simplification.

2.3.3.4 Small group problem solving

According to Sakakibara et all (Sakakibara, Flynn, & Schroeder, 1993) this technique consists of the use of small groups of workers, staff and management to solve production problems. This methodology encourages workers to share operative criticalities in dedicated problem-solving sessions. Boyer (Kenneth K. Boyer, 1996) identifies the use of teamwork and group problem solving as a critical component of both TQM and JIT, enabling a beneficial deployment of troubleshooting activities. Teamwork and group problem solving contribute to break down barriers and boost the stream of information through different departments. The overall result in terms of productivity and efficiency is a positive one.

2.3.3.5 JIT delivery by suppliers (JITds)

Just-in-Time delivery by supplier (JITds) ensures that suppliers deliver the right quantity at the right time in the right place (Shah & Ward, 2007). Ansari and Modarress in their work (Ansari & Modarress, 1988) state that the base of this technique is a partnership between the Supplier and the Company. A high communication level is required for both parties, in order to avoid the need for inventories. Nowadays, the continuous exchange of information is possible by information technology tools (Seth * & Gupta, 2005). The study of Ansari and Modarress (Ansari & Modarress, 1988) also confirms that JITds contributes to the improvement of product quality and productivity of each kind of company. The typical features and activities related to JITds are listed below:

1. Reduced purchase lot-size
2. Reduced number of Suppliers
3. Advanced Suppliers selection and evaluation
4. Quality inspections completed by Suppliers
5. Development of design specifications
6. Advanced bidding and purchasing processes
7. Reduction in the amount of paperwork
8. Customized packaging

Wastages associated with a high level of inlet inventory have to be kept in consideration when a high variation in product mix or volume occurs and a company is forced to purchase fixed / large lot-size.

For this reason JITds can be considered a key feature for a production system targeting a high level of MIXF and VOLF.

2.3.3.6 Continuous Improvement Programs

Continuous Improvement (CI) is defined as a company-wide process of focused and continuous incremental innovation (Bessant, Caffyn, Gilbert, Harding, & Webb, 1994). Bhuiyan and Baghel (Bhuiyan & Baghel, 2005) extend this definition affirming that CI is a culture of sustained improvement aiming to eliminate the waste in all systems and processes of an organization. Lillrank and Kano (Lillrank & Kanō, 1989) consider Kaizen, the Japanese term for CI, as the "principle of improvement". Imai (Imai, 1986) reports three categories of Kaizen:

1. Management-oriented Kaizen focuses on the company strategy and involves everyone in the company.
2. Group-oriented kaizen is based on teams of employees leveraging with the goal of discovering and resolving issues suffered during the day-by-day operations. No control/support from management is usually provided.
3. Individual-oriented kaizen arises from the bottom-up design philosophy. The worker, who typically is the one experiencing the problem, acts as an expert in searching possible solutions.

2.3.4 Investment analysis on Lean tools

Kaplan (Kaplan, 1986) describes the difficulty faced by a manager in completing financial analysis to justify investments in computer-integrated manufacturing (CIM). In his study he identifies several tangible and intangible benefits of CIM, whose accounting is not easy, nevertheless required:

Tangible Benefits

1. Inventory savings

   This reduction in average inventory levels represents a large cash inflow that DCF analysis can easily capture.
2. Less floor space

   The reduction of shop area can be accounted considering the potential reduction in rental.
3. Higher quality

   Quality can be measured considering the decrease of waste, scrap and rework costs.

Intangible Benefits

1. Greater flexibility

   The low-cost production of high-variety, low-volume goods will show its potential only over time. Therefore, it is difficult to estimate how much this flexibility will be worth. Nonetheless, an order-of-magnitude estimate may be sufficient.

2. Shorter throughput & lead time

   Some of the benefits from greatly reduced throughput times are already included in the estimation of savings from inventory reductions. Being able to meet customer demands with short lead times and to respond promptly to market fluctuation are two benefits to be considered, at least with a high-level assessment.

3. Increased learning

   Some investments have important learning characteristics. Thus, even if calculations of the financial parameters present a negative figure, the investments could still be valuable by permitting managers to gain knowledge.

According to Sullivan, McDonald and Van Aken (Sullivan, McDonald, & Van Aken, 2002), this concept can be easily extended to the analysis of benefits in LM. In their paper, the use of value stream mapping, associated with a brief evaluation of cash flow, is utilized to justify the replacement of an outdated production system with a cellular layout. This PhD thesis follows a similar approach, associating an order-of-magnitude estimate of flexibility benefits with the typical costs associated with the introduction of Lean techniques.

2.4 *Overview of Value Stream Mapping and Software Simulation*

The next paragraphs describe the use of Value Stream Mapping and Software Simulations. The brief description of these techniques enable a better understanding of the research exposed in the following chapters of this thesis.

2.4.1 Introduction to Value Stream Mapping

Value stream mapping (VSM) is an improvement tool used to clearly visualize the material and information flows in a production process. The goal of this activity is the identification and the banishment of all types of waste in the value stream (Rother & Shook, 1999). According to Lasa et al. (Serrano Lasa, Ochoa Laburu, & de Castro Vila, 2008), VSM is a valuable tool for reshaping the productive systems, as per the lean principles. Its adoption deserves attention on the following key requirements: adequate resources training, suitable information systems and suitable management of the application phase. The analysis carried out by Singh et al. (B. Singh, Garg, & Sharma, 2009) focusing the possibility to decrease operational cost by VSM during recessionary times is remarkable. Singh and Sharma (B. Singh & Sharma, 2009) pointed out the VSM potential of presenting a case study showing benefits in terms of lead time reduction, processing time reduction, inventory reduction, manpower requirement reduction. Notwithstanding the benefits (Clegg, Pepper, & Spedding, 2010) just introduced, several limitations of this method are described in literature. Below some examples have been presented:

Chitturi et al. (Chitturi, Glew, & Paulls, 2007) explained practical issues, faced using a standard VSM, also describing VSM improvements to solve some of these restrictions.	Standard VSM practical issues in evaluating: - TAKT time - Defining where to place supermarket - where to use continuous flow processing - what process improvements can be done - how to handle different product families - how to gather information

Braglia et al. (Braglia, Carmignani, & Zammori, 2006) proposed a structured application of VSM based on non-linear value streams and on the preliminary analysis to recognize the critical production path.	Standard VSM constrains: - Limited accuracy level - Low level of manageable versions - Unsuitability for high mix–low volume processes

A large set of VSM software tools can also permit the user to have a dynamic view of the value stream, allowing a “real-time” appraisal of proposed improvements. Essentially this increases flexibility and information available to improvement teams. However, it is the relative simplicity of VSM that has made it such a powerful tool for change. Such complex analysis can be valuable and at the same time contrast with one of the key features of traditional VSM: the relative simplicity.

The use of VSM for the implementation of Lean principles is well documented through case studies in literature (Abdulmalek & Rajgopal, 2007) (Wee & Wu, 2009) (B. Singh & Sharma, 2009) (Gurumurthy & Kodali, 2011) (Chen, Li, & Shady, 2010). Grewal (Grewal, 2008) documents how Lean principles can be introduced in a small company using VSM. The successful case study presented shows significant improvements: reduction in lead time, cycle time, changeover time, inventory level. These results have been achieved by the adoption of VSM for the detection of wastages (i.e. high set-up times) and of Lean practices (i.e. SMED) for the relevant solution. Considering this, VSM is viewed as propaedeutic and synergic for all the goals of LM, including flexibility. Abdulmalek and Rajgopal (Abdulmalek & Rajgopal, 2007) confirm that the management decision on implementing LM is a critical step, and a lack of supporting evidences and justifications can lead to a failure. It is often not easy to obtain the approval and funds needed from the board, to implement the LM in small businesses. The improvement of a dated production system, based on traditional approaches, is always restrained by cultural resistance within the company. For this reason, even in the case of a widespread knowledge on lean and its theoretical approval by the manager, it is essential to predict the possible benefits of the new method quantitatively.

2.4.2 Simulation as support to Value Stream Mapping

Since it is almost impossible to quantify the achievable gains in terms of KPI (i.e. the Work-in-process inventory) with a future state map only, simulation constitutes an appropriate complementary tool (McDonald, Van Aken, & Rentes, 2002). The aforementioned model, capable of predicting the KPIs set for different system configurations, facilitates the evaluation of payback resulting from the use of LM's principles. This solution to evaluate the profitability of an investment is usually cost effective and generally cheaper than a practical on the field simulation. Many examples of this approach combining VSM and simulations are available in literature (J. Narasimhan, Parthasarathy, & Narayan, 2007) (Gurumurthy & Kodali, 2011) (McDonald et al., 2002) (Abdulmalek & Rajgopal, 2007) (Lian & Van Landeghem, 2007) (Bernards, van Engelen, Schrauwen, Cramer, & Luitjens, 1990) (Wang, Guinet, Belaidi, & Besombes, 2009). One of the most popular simulation tools available on the internet is Arena Simulation (Detty & Yingling, 2000) (Kelton, 2002) (Hammann & Markovitch, 1995). This software has been selected for the present work considering that its diffusion is wide and that its features, presented in section 3.2 Arena Simulation, have been successfully proven in similar studies (Detty & Yingling, 2000) (Lian & Van Landeghem, 2002). This method, allowing to compare the current performances of a production system with those of the future, represents an essential basis for the adoption of Lean (Detty and Yingling-(Detty & Yingling, 2000).

2.4.3 Value Stream Mapping process

VSM starts with the raw material purchase, continuing through the processing, until the supply of the finished product. The diagram icons and rules are usually self-explicable and a set of symbols is currently unified in literature (please refer to Rother and Shook (Rother & Shook, 1999) for additional details). The analysis of production flow efficiently points out wastes and suggests how to eliminate all the activities which are not generating added value to the finished product. The typical VSM process starts with the drawing of a Current State Map that is the essential baseline representing how operations are currently performed. The Current State Map can be sketched following simple steps:

2.3.1.1 Boundary Limits

The drawing of the VSM begins with the defining of boundary limits. The stream of a production department usually starts with the inlet of raw material and terminates with the outlet of finished products.

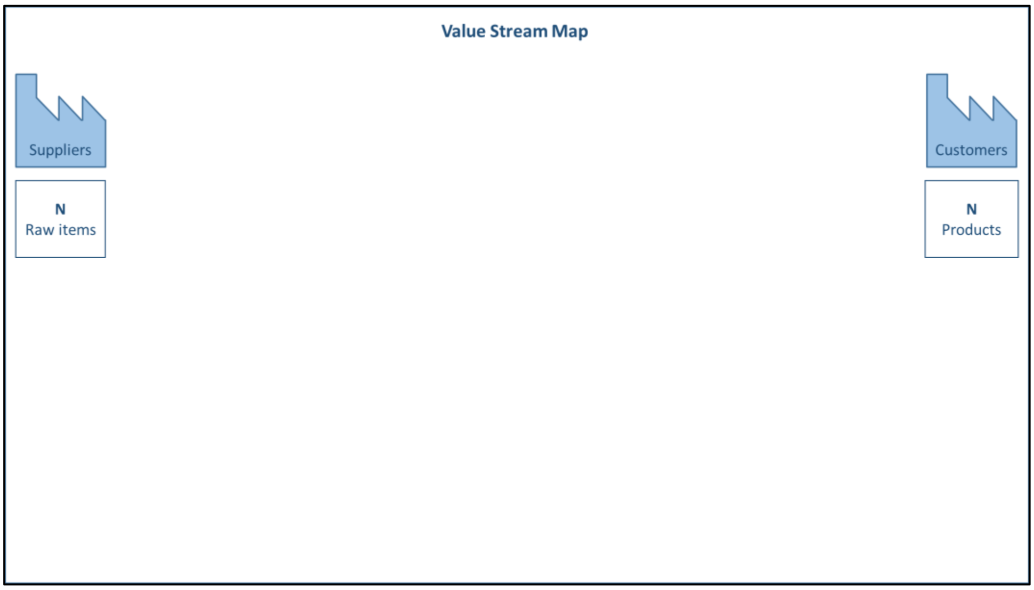

Figure 7 - Boundary Limits

2.3.1.2 Process steps

All the activities carried out during the production cycle constitute the milestones of the overall process. The acknowledgement of the activities sequence lays the basis for further analysis.

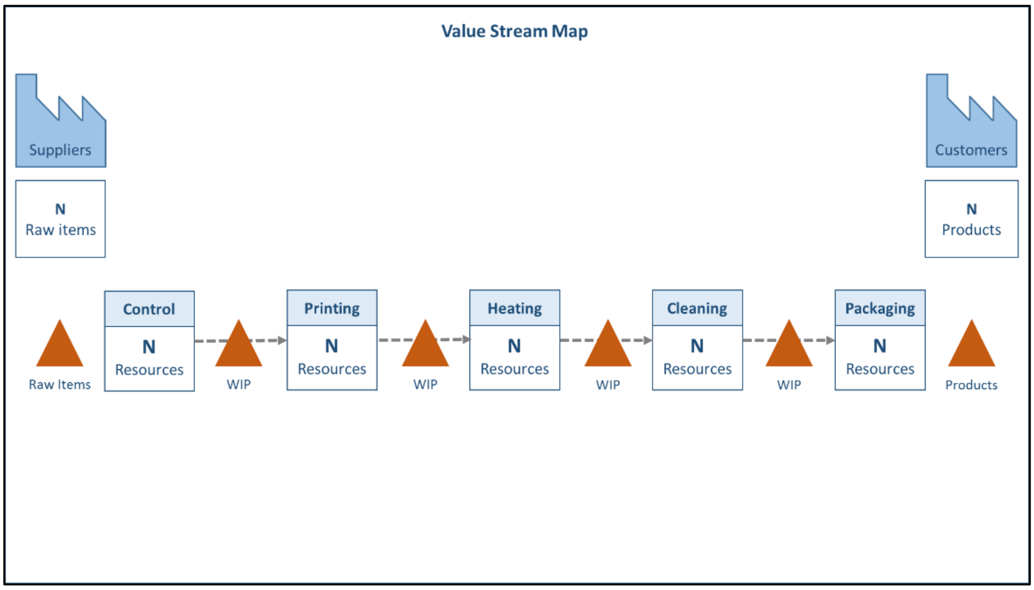

Figure 8 - Process Steps

2.3.1.3 Information Flows

Flows of information have to be shown as well as materials' streams in order to allow a detailed examination of the management system.

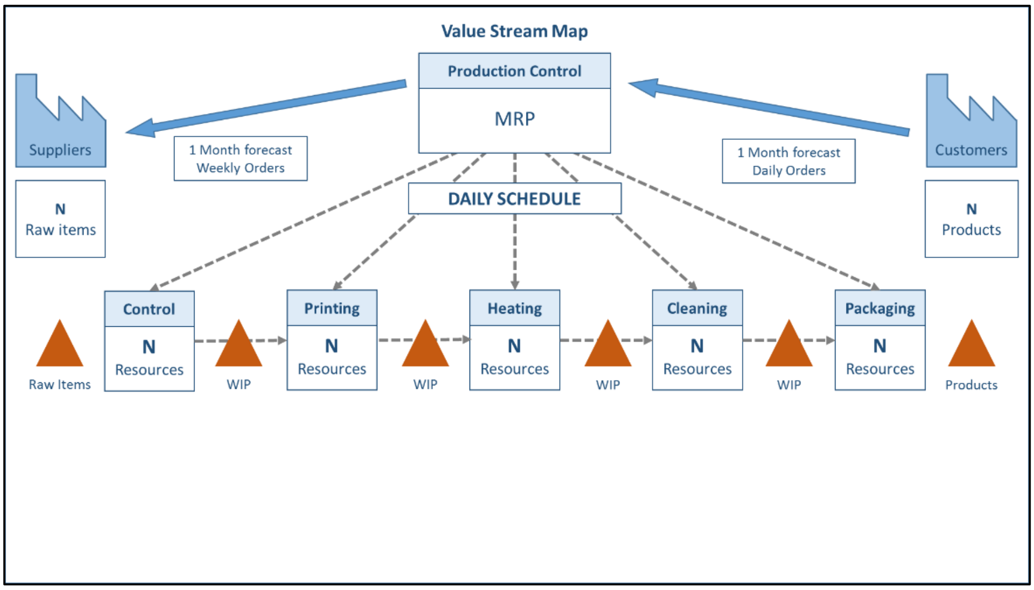

Figure 9 - Information Flows

2.3.1.4 Process Data

Data regarding the performance can be gathered through filed surveys or by examining production records. Examples of these indicators are: Inventory, Cycle time, Change over time, Number of operators, Shifts worked, Scrap rate, Batch Size.

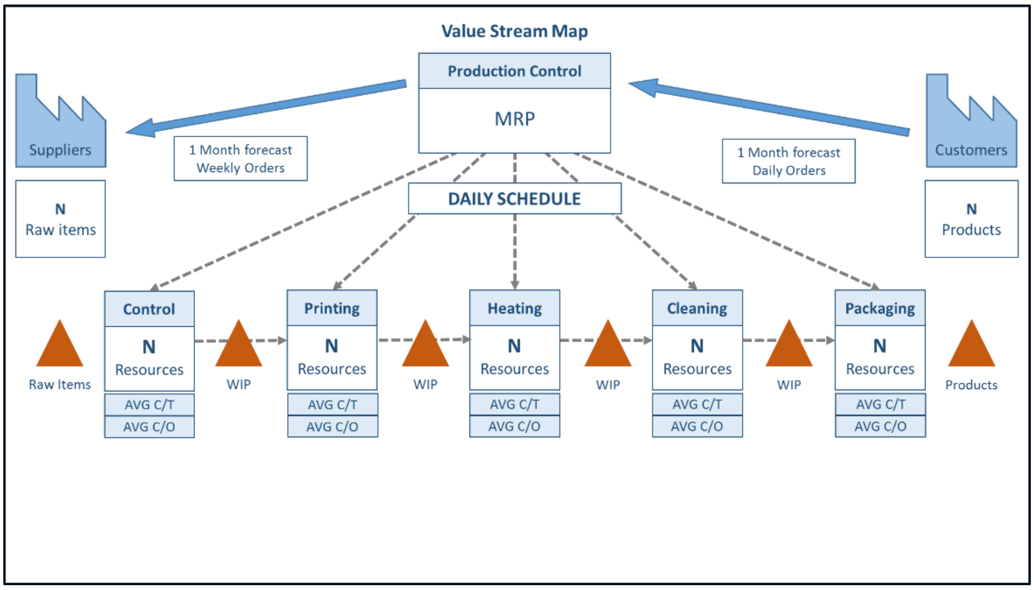

Figure 10 - Process Data

2.3.1.5 Time Line

Process times and lead times for inventory are required for a correct evaluation of performances. This information, combined with Process Data, represents the core of Current State Map and can be used to develop an improved Future State Map.

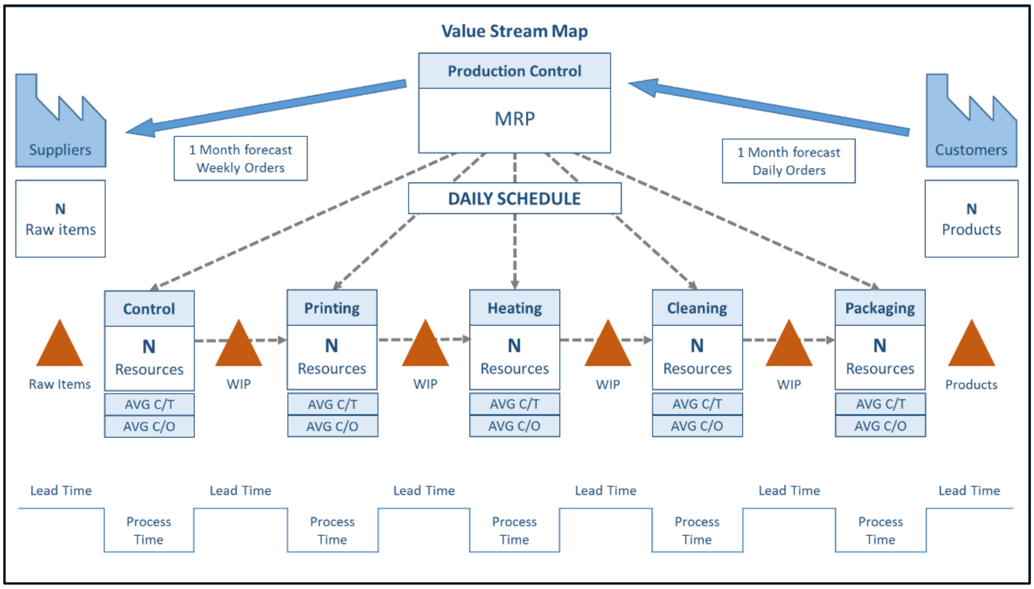

Figure 11 - Time Line

The second step consists of the development of a Future State Map, revised on the base of identified improvements. Through the VSM, it is possible to reshape the facility's layout profitably, reduce the current levels of WIP inventories and optimize the overall process. Once completed, the VSM can start highlighting additional possible improvements again, as part of a continuous development.

2.5 *Company and process background*

The core business of ALPHA is the decoration of glassware by screen printing. The overall catalogue of the company consists of a well-defined number of raw glass items to be processed on the base of various decoration styles, which can also be designed and personalized by customers. The average market demand is estimated as 11,000 units per month (Price Average: 21.26 €) and the distribution by product is the following:

	Percentage by unit quantity
Standard Decoration Design	70.7 %
Custom Decoration Design	29.3 %

Table 18 – Decorations by Products

The focus of this work is on the production of the most significant part of product list, whose main characteristics are briefly summarized below:

	Quantity	Notes
Raw Items	44	Arranged in 10 different product categories
Decoration styles	11	Not all the decoration styles are applicable for all the raw items
Total Finished Products	230	

Table 19 - Raw Items and Decorations

Production flow starts with a preliminary check of the raw material. Once the requested items have passed the visual control these are measured and grouped in batches. Then, each lot can be transferred by fork lift to an intermediate storage area, situated close to the production cell. As soon as the operator associated to the cell is available, he can proceed with the equipment setup. This task is made of two different sub-steps: firstly, the overall equipment must be configured to process the product (this adjustment is mainly based on items' dimensions), then a specific serigraphic frame should be installed in the machine (for the same item, each layer of printing requires a different frame; each finished product usually necessitates 2-3 layers). After the completion of a printing step, semi-finished goods are transferred in the pre-heating warehouse, located at the entrance of the oven. The heating process changes product by product on the base of parameters such as weight and shape. As soon as the treatment is completed, batch is stocked in the proximity of the polishing unit, waiting for the availability of the dedicated operator. After this stage, the items are ready for an additional silk-screen printing or for the final control and packing. In both cases, these are shifted towards the right depot. The plant works 5 days per week with a single shift 8 hours long. The overall production is currently scheduled daily in accordance with the purchase orders from customers and the stocks level in the factory outlet (a store located beside the facility).

3 Research Methodology

In this chapter the main research methods used in carrying out the work are discussed. The first section provides an overview on the Case Research and related literature. The second paragraph lists the main features of Arena Simulation, the tool used for the simulation. Finally, a brief narrative on Design of Experiment is given, and the factorial design is explained in details.

3.1 Overview of the Research Methodology

Empirical research in Operation Management (OM) is generally demanding and time consuming, hence it shall be conducted following a systematic approach in order to avoid affecting the credibility of the research itself ((Burgess, 1993; Flynn et al., 1990). The process consists of a sequence of six linked groups of activities: establishment of the theoretical foundation, selection of a Research Design, selection of a Data Collection Method, implementation, data analysis and publication. This PhD study builds on the OM theoretical knowledge available, in particular for LM and MIXF presented in chapter 2. Background and assessed in paragraph 2.1 Introduction to literature review. The selected Research Design is Single Case Study type, described in section 3.1.2.1 The type of design. The collection of data is based on field surveys, interviews and databases' examination. The implementation, data analysis propaedeutic to the publication of this thesis are presented respectively in chapters 4. Case Study: ALPHA, 5. Simulations and Results. The aim of the research is to answer questions and relate theory and data ((Bouma & Ling, 2004). The research questions of this PhD thesis have been introduced in para 1.4.2 Research Questions and hereinafter briefly reported:

1. HOW does Lean Manufacturing enhance production in respect to investment?
2. HOW are Lean Manufacturing and Manufacturing Flexibility connected in the SME context?

Crotty (Crotty, 1998) lists four elements to be clarified in the developing of a research:

1. What methods do we propose to use?
   The techniques or procedures to gather and analyze data related to research question or hypothesis
2. What methodology governs our choice and use of methods?
   The strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of methods to the desired outcomes.
3. What theoretical perspective lies behind the methodology in question?
   The philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria.
4. What epistemology informs this theoretical perspective?
   The theory of knowledge embedded in the theoretical perspective and thereby in the methodology.

The next section 3.2. Case research provides the justification of choosing the Single Case Study methodology for this PhD study, on the basis of an examination of existing literature about the topic.

The theoretical prospective of the work is also presented in paragraph 3.2.3. Object, questions, postulates and analysis unit.

3.2 Case research

Nowadays companies operate in a technological and economic environment characterized by a high variability. According to Voss, Tsikriktsis and Frohlich (Voss, Tsikriktsis, & Frohlich, 2002), this condition makes the Case Research one of the greatest investigation methods in Operations Management. In particular, the development of new theories demands a base of field evidences (Lewis, 1998). An introduction to this approach is presented in the following sections.

3.2.1 Case Study Overview

According to Yin (Yin, 2009), the case research (case study) is an empirical exploration aiming to investigate a contemporary phenomenon in its real context, when the boundaries between phenomenon and context are not clearly evident and where multiple sources of evidence are used. Based on this definition, it is clear that the Case Study differs from other research strategies. An experiment, for example, is defined as the reconstruction of a phenomenon within a controlled environment (the laboratory). This form of study, while referring to a context, reduces the number of variables to be analyzed, to simplify the investigation. Research approaches differ from each other depending on different way of collecting and analyzing empirical evidence. Each has specific advantages and disadvantages. In the past, it was believed that the Case Study would be suitable for the exploratory phase of a survey. It was also thought that Polls and Narratives were appropriate for the descriptive phase and that the Experiments were the only way to conduct explanatory or causal inquiries. However, every strategy (including Case Studies) can be used in many ways: exploratory, descriptive or explanatory. In addition to this, even though each strategy has its distinctive features, there are wide areas of overlap. Three factors drive the choice of the right strategy:

1. The survey target.
2. The possibility to carry out field surveys.
3. The focus on contemporary events rather than historical.

The adoption of a Case Study strategy is recommended when the following assumptions are met:

1. The links between the phenomenon and context are not evident, therefore both the phenomenon and the context within which it occurs must be included in the research boundaries.
2. The event cannot be reproduced in a laboratory, but collection of field data is possible.
3. The observed events are current.

4. The type of research question is typically “how” or “why”.

In a similar situation, well fitted with this doctoral work, the case study is an appropriate method because it allows the handling of a wide variety of data and adds two significant tools to the historical research techniques: field observation and interview. Although the case study is a form of empirical investigation, many researchers show strong resistance against it. The most frequent criticisms are attributed to:

1. The lack of rigor.
2. The difficulty of generalizing and replicating the results in different conditions.
3. The possible collection of huge documents, hard to be interpreted.

Each of these criticisms can be countered:

1. The rigor comes from the research procedures and the behavior of the researcher; as for any other form of study. Systematic reporting of all evidence is a way to mitigate this issue.
2. The difficulty of generalizing the results of a single case is also extensible to experiments that are not extendable to populations or universes. However, the purpose is to generalize to theoretical propositions, not to populations as in statistical research.
3. Although it is common for the case study to generate a large mass of illegible documents, it is also true that there are criteria and methods to handle similar issues. Time limits and writing formula depend on the choices of investigators.

3.2.2 Research Design

The first step in a research project is the development of a "Research Design" or "Research Plan". This action plan is an operational sequence aimed to guide the researcher in the formulation of a set of responses from an initial set of questions. The target can be accomplished through the following steps (Soy, 1997):

1. Statement of the research questions.
2. Identification and selection of data to be collected.
3. Preparation for data collection.
4. Data gathering.
5. Evaluation and analysis of data.

6. Processing conclusions and report.

Although the Case Study is widely recognized as a profitable research strategy, a set of standard Research Designs is not available. Empirical or semi-empirical studies require original ad-hoc plans. The Research Design is one key point of the study. The complexity inherent to the development and the flexibility required during its execution are two aspects critical to the project's success. The definition of these specific features is required:

1. The type of design.
2. The object of investigation (reference scenario, and research questions).
3. One or more theoretical postulates (even conflicting).
4. One or more units of analysis.

3.2.2.1 The type of design

The literature on case research shows that different types of study can be distinguished based on the following two parameters:

1. The number of cases examined by the study: one single study or multiple cases.
2. The possible purposes of the study: Holistic or Embedded.

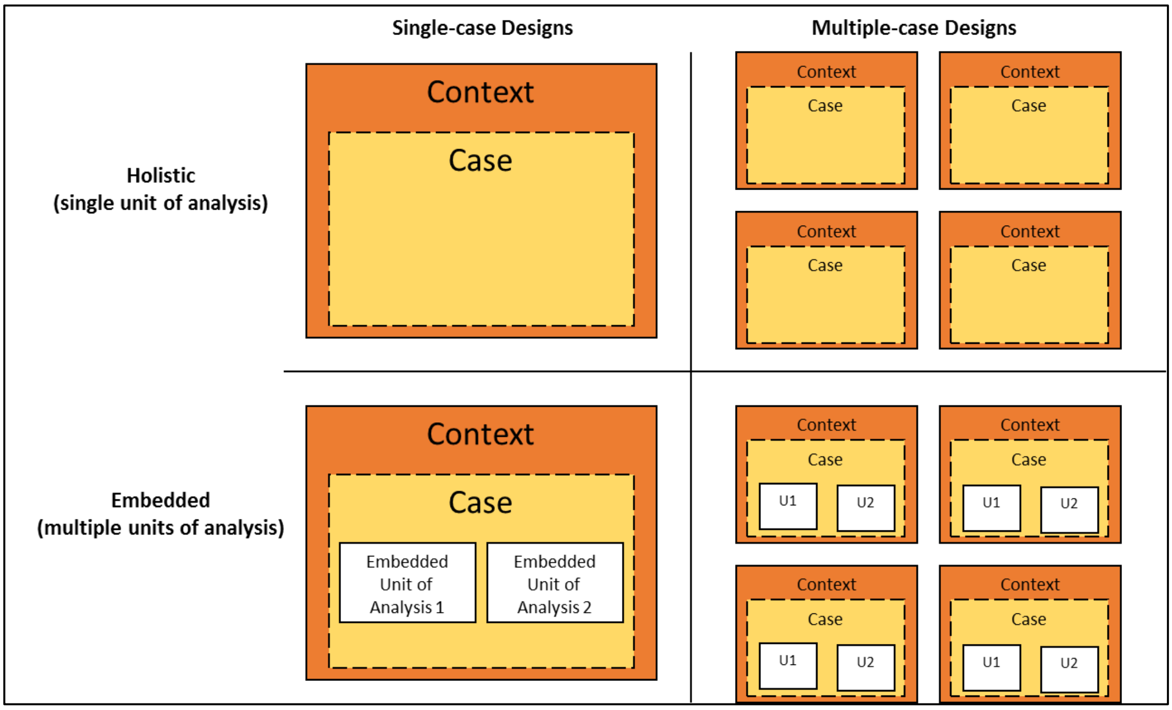

Figure 12 - Types of designs

Each variant of the case study has strengths and weaknesses:

Single-case Study

The single-case study is the most common design, which focuses on a case only and can be used in three different circumstances, when the study aims to:

1. Test the correctness of a well-formulated theory.
2. Analyze a unique or rare event, when it is impossible to use any common pattern.
3. Observe and analyze a phenomenon not undertaken to scientific investigation so far. In this circumstance, the search can be conducted as exploratory prelude to a future study.

The use of single-case study in theory building is considered valuable when the case is revelatory, when it is exemplar, or when it permits the study of uncommon research subject (Yin, 2009) (Eisenhardt & Graebner, 2007). In addition, Eisenhardt and Graebner (Eisenhardt & Graebner, 2007) recognize that single cases can enable the development of complicated theories: in single-case research, new theories can fit the many details of a particular case; in multiple-case research only the relationships across the cases are usually focused (Eisenhardt & Graebner, 2007). Tsoukas (Tsoukas, 2009) points out that a single-case study may lead to important theory developments if the peculiarities of the case are considered as chances to adjust the already structured understanding of a phenomenon.

Multiple-case Study

A multiple-case design is possible when two or more cases are analyzed within the same study, so that they are one confirmation (or replication) of the other. This type of design deserves a careful choice of each case and a replication logic (literal or theoretical) as an alternative to sampling. The cases can be selected according to the following criteria:

Criteria	Definition
Contrasting cases	Cases that criticize the theory to be tested
Relevant cases	Cases relevant for the phenomenon studied
Feasibility	Persons or groups - volunteer as an object of study

Table 20 - Multiple-cases study

Holistic Analysis

In the holistic designs, just one single unit is included in the analysis. This could be used if the aim of the study is limited to the global nature of the phenomenon. Since no logical sub-units are considered, the generalizability of the results could be impacted.

Embedded Analysis

In the embedded designs, multiple units are included in the analysis. The study can include main and sub units placed on different levels. Therefore, even within the single case, a reliable array of indication across units is achievable.

This PhD research, by its very nature, implements a single-case study. This type of research has been chosen as it is considered a proper option to provide managers with a detailed in-depth analysis of how important subjects such as LM and MF interact in an under-investigated context: SMEs. The main goal is not to seek the general laws that operate in the particular case, but to allow a better view, a better explanation, this is in line with the single-case study approach (Tsoukas, 2009). However, the present work is considered a starting point, whose results would stimulate further investigations to be completed by the evaluation of additional cases. The results already achieved in the present work will also speed up the analysis of additional samples. Considering that three years have been required for the introduction of a structured 5-step approach specifically devised (Presented in section 5.1. Overview on the Design of Experiment) and the completion of a first explanatory sample, the expected lead time for additional cases is one year each. Table 21 summarizes the time dedicated to field and computational activities, and provides an overview of the efforts required for future analysis of similar small-medium manufacturing facilities.

Activity	Time	Who provides information
VSM	15 days	Operation Manager
Manufacturing times data	120 days	Operators
Cross-check with company database	60 days	Production Planner
VSM validation, time database	15 days	Operation Manager
Consultancy of Sales Records	10 days	Sales Manager
Simulations and results analysis	120 days	N/A

Table 21 – Efforts and references of case research

Even if the evidences are based on a single case, general considerations may nevertheless be formulated about cause-effect relationships and operational modes. Furthermore, a holistic approach is selected to focus a manufacturing facility that cannot be molded into embedded sub-units.

3.2.2.2 The object of investigation

The most important step in the design of the case study is the definition of the object of investigation, namely that the definition of research questions. This activity is mainly affected by the following factors:

1. The theoretical framework by which the researcher is inspired during the defining of the basic assumptions.
2. The researcher's culture representing the set of opinions concerning the way things should be.
3. The degree of predictable reactivity, which is defined as the degree of influence that the search technique can have on the data, up to alter the phenomenon studied.
4. The available literature on the subject. The literature has a large quantity of material available to be tested in the field, even contrasting.

The research questions must be defined, in relation to the phenomenon to be described and its critical ingredients, starting from a careful analysis of one or more possible scenarios. This analysis aims to capture the essence of the object of investigation, through the formulation of the most important questions that reliable answers are sought after.

3.2.2.3 One or more theoretical postulates

A theoretical postulate is an assertion assumed to be true but not yet proven. Each postulate helps in identifying required academic evidence and determining where these can be searched. In the absence of a postulate, researchers might incorrectly try to collect everything. On the contrary, the necessary amount of data analysis can be maintained under allowable limits if the study uses specific postulates.

3.2.2.4 One or more units of analysis

The units of analysis are critical elements in a case study. These units provide the base data of the research, allow the formulation of reliable answers to the research questions and, finally, enable the generalization of the study findings in similar cases. In other words, the entire design of the case study, as well as its theoretical potential, is strongly ruled by the way units are defined.

3.2.3 Object, questions, postulates and analysis unit

The description of the PhD research has been described in Chapter 1, now it is briefly revived according to the format just introduced in the previous paragraphs:

Design	Single-case, Holistic
Object	Use of Lean Thinking within SMEs
Questions	HOW does Lean Manufacturing enhance the production in respect to the investments? HOW are Lean Manufacturing and Manufacturing Flexibility connected in the SME context?
Postulate	Lean Techniques enhance the Flexibility of a production system
Analysis Unit	ALPHA (Italian Company, SMEs category)

Table 22 - PhD Research

3.3 Arena Simulation

In this section of chapter 3 an overall description of the Arena Simulation Software is provided: the tool used to simulate the production department of ALPHA.

3.3.1 Presentation Software Arena

The software Arena is a powerful tool that allows the modeling of complex systems and the evaluation of their performances. In fact, Arena makes it possible to complete the following actions:

1. Modelling of processes, flow of items, information and signals.
2. Simulation of the future performance of the system to understand complex relationships and identify possibilities of improvement.
3. Advanced control of transactions with dynamic graphic animation.
4. Analysis of how the system will perform in its configuration "as-it is" and in many other alternatives "to-be" so that the best way to manage the production line is chosen confidently.

The dynamics' model designed for the simulation is represented by the setting up of an appropriate sequence of blocks.

3.3.2 Arena language and features

Arena uses its own built-in language called SIMAN (Simulation Modeling Analysis). As a result of this it is not necessary to write the code lines because the whole simulation model for the creation process is graphical, visual and integrated. This way, Arena users can take advantage of benefits such as a dedicated high-level programming code and ad-hoc pre-designed constructs for standard systems. Nevertheless, a specific knowledge of the software is required to cope with a possible time consuming modeling stage and an extended debugging. The Arena language is based on some basic elements:

1. **ENTITIES**: Objects that flow through the system, such as customers, pieces, parts, lots, vehicles, etc. or information, logical elements, etc.
2. **QUEUE**: Waiting areas where the movement of the entity is temporarily suspended.
3. **RESOURCES**: System components that need to be allocated to entities, such as machines, operators, robots, switchboards, etc.
4. **ATTRIBUTES**: Values associated to individual entities, such as the type of processing, the arrival time, etc.

5. **VARIABLES:** These values describe the status of the system or process, such as the number of machines available, the number of setup, etc.

Arena Simulation version 14.00 has been used for the PhD study. The IT Company that commercializes the software, Rockwell Automation, provides various versions of Arena, sold online through the website (https://www.arenasimulation.com/). The Arena Standard version contains everything needed for mapping, simulation and analysis of business processes. Advanced and specialized versions, such as Arena Professional, are also available. It is possible to integrate the Standard release of Arena with some options, such as: Access to SIMAN code, Custom Template Building/Reusable Modules, High-Speed Packaging and Flow/Continuous Process Modeling (in the Professional Version all these options are already included). An academic product, with a limited set of features, is available for free (Student version).

Functionality	Standard	Professional
Easy Flowchart Modeling Methodology	✓	✓
Unlimited Model Size	✓	✓
Business Graphic Dashboards	✓	✓
Scenario Analysis	✓	✓
Custom Reports	✓	✓
2D and 3D Animation	✓	✓
Access to SIMAN code		✓
Custom Template Building/Reusable Modules		✓
High-Speed Packaging		✓
Flow/Continuous Process Modeling		✓

Table 23 - Arena Simulation versions (https://www.arenasimulation.com/)

The faster the PC, the better the system will run. The processing of animations or large simulations can be computing intensive, therefore a faster processor with additional memory can lead to an improved performance. Moreover, a large monitor with a screen resolution of at least 1024 x 768 are recommended for a proper monitoring of the animations.

<u>Rockwell Arena Minimum System Requirements</u>

1. Adobe Acrobat Reader 9.1.0 or later recommended to view documentation.
2. Hard drive with 1GB free disk space (or more).
3. 2GB RAM (or more).

Rockwell Arena Recommended System Requirements

1. Adobe Acrobat Reader 9.1.0 or later recommended to view documentation.
2. Hard drive with 4GB free disk space (or more).
3. 4GB RAM (or more).
4. Intel® dual-core processor (or more), 3GHz or faster.
5. Internet access for installing Factory Talk activations.

3.3.3 Arena Environment

Each process simulated in Arena is based on a sequence of blocks (so called MODULES), that define the flowchart of objects and data. All the parameters required to model a system are stored in these modules. According to this, the first step of a good modeling is the selection of blocks suitable for representing of the stream of entities (e.g. Value Stream Map of a production facility). Eight types of Basic Modules can be found in the Basic Process section of the software:

Name	Shape	Description
Create		It is the start of the process flow. Entities enter the simulation here.
Dispose		It is the end of the process flow. The entities are removed from the simulation here.
Process		It is an activity, usually performed by one or more resources and that requires a bit of time to complete
Decide		It constitutes a branch of the process flow. One branch is considered.
Batch		It collects a series of entities, then a common Batch continues the process.
Separate		It duplicates entities or separates an amount of previously grouped entities.
Assign		It changes the value of certain parameters (during simulation), as the entity type or a model variable.
Record		It collects a statistic, such as a count of the entity or the cycle time.

Table 24 - Arena Simulation basic modules

The simple modules listed above are typically included in every simulation; their behavior can be enhanced through the adoption of other elements (e.g. Advanced Modules for Transfer, Process etc.) that are used to align as much as possible the software model with the real system. The entities handled by Modules are those elements (for example: documents, customers, goods) that are produced, served or anyway considered in the process. In business processes, entities are often documents (checks, contracts, requisitions, purchase orders). In service systems, entities are usually people (customers to be served in a restaurant, a hospital, airport, etc.). In production models, as the production department studied in this work, entities generally have some kind of part that runs through the process, whether it be of a raw material, a subcomponent, or of the finished product. Other models may have different types of entities, such as data in the network analysis, packages or letters and boxes in the parcel handling systems. You can have different types of entities in the same model. For example, passengers moving through in a train station could be separated into regular and first-class types of entities. In some cases, the entity types may belong to completely different categories. For example, in a restaurant, the dishes could be modeled as entities, which pass through the filling phase. At the same time, clients may require the attention of the waiters: they could also be modeled as an entity.

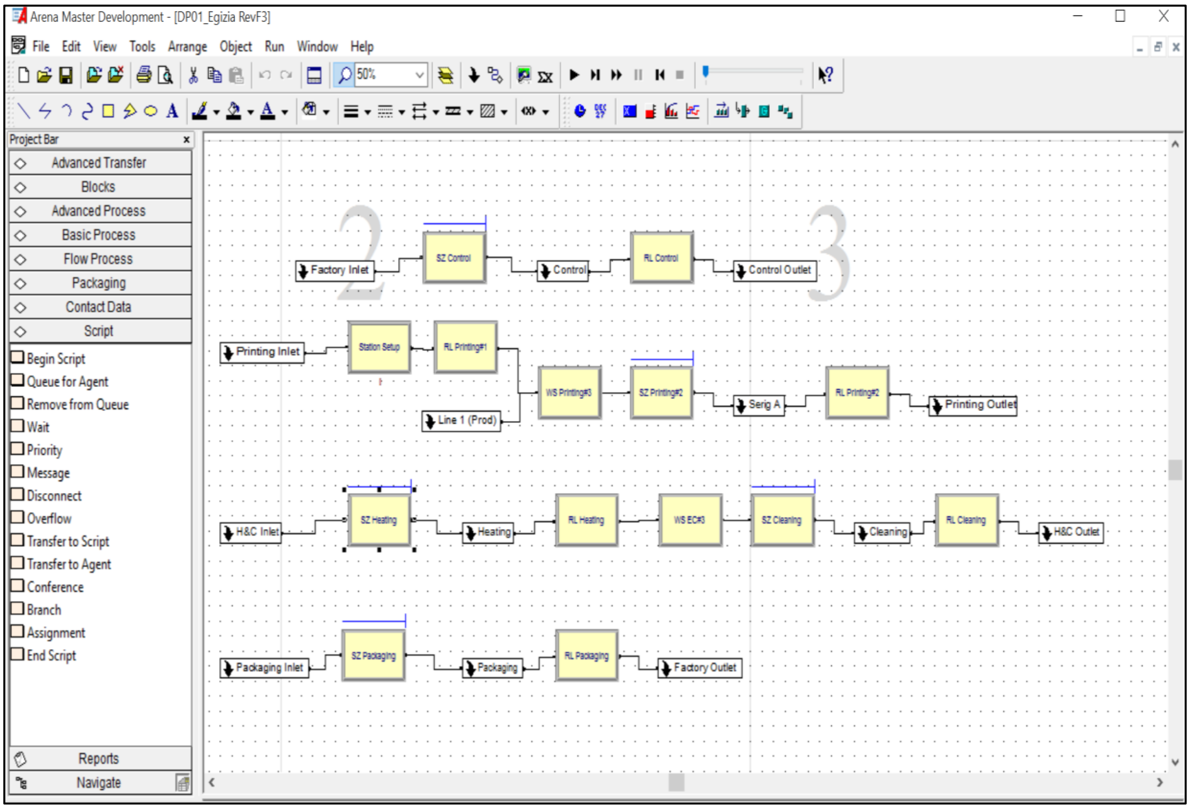

Figure 13 - Arena Simulation operating window

The interface of Arena Simulation is an operating window that can be divided in two main areas:

1. The Project Bar (Project Bar) hosts panels with main types of objects.

The Basic Process panels, Advanced Process and Advanced Transfer contain forms of modeling, called modules, which can be used to define your own process.

The Panel Reports contain the reports available to visualize the simulation results.

The Navigate panel, finally, allows you to display different views of the model, including navigating through hierarchical sub models.

2. The model window.

   The flowchart Visual (Flowchart View) contains all the graphics models, including the elements of the flow chart process, animation and other design elements. Lower down, the Visual spreadsheet (Spreadsheet View) shows the data models, such as time, cost and other parameters.

3.4 Design of Experiments and Factorial Design

In the two following paragraphs a general outline on Design of Experiments is shown with the aim to highlight its importance in the Empirical Research as confirmed also by many authors ((Kackar, 1989) (Alagumurthi, Palaniradja, & Soundararajan, 2006) (Condra, 2001) (Rowlands, Antony, & Knowles, 2000)). The Factorial Design is also described since it constitutes the method adopted in the present PhD Study.

3.4.1 Overview on the Design of Experiments

An experiment can be defined as the investigation on a process or a system by changing the input data, observing the changes that occur in the output data and drawing relationships. It is possible to systematically verify the effects of different inputs on the output variables in order to develop an effective process model.

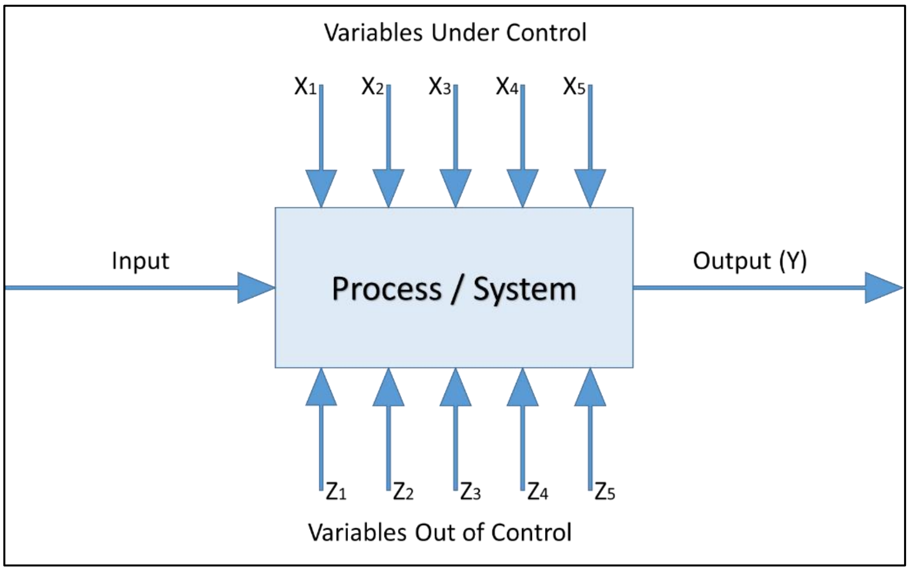

Figure 14 - Experiment on a Process / System

The most common objectives of the experiments are the following:

1. Determine the variables (Xn or Zn) that have the greatest effect on the response
2. Determine how to handle variables (Xn) so that the output remains within a range of acceptable values
3. Determine how to handle variables (X_n) in order to minimize the variability of the output

A good experiment must be efficient: as the number of factors increases, the experiment efficiency acquires importance. An experiment is efficient if:

1. It answers the research questions
2. It leads to correct conclusions
3. It requires few resources

There is a correlation between items 2 and 3 above: in point 2 the allowable tolerance should be specified; once the error margin has been set, only the required resources should be used. According to Law and Kelton (Law & Kelton, 1982) the Design of Experiment (DOE) is a way of choosing which particular configurations to simulate so that the desired information can be obtained with the least amount of simulations. Its adoption is fundamental for research since each run of simulation entails time for tests and resources allocated. The DOE is much more efficient than an alternative unsystematic approach based on a random generation of alternative sequence of runs. It is worth trying to limit the effort required in a single test, enabling the use of unemployed resources for other purposes. In addition, the aprioristic choice of the configurations, leveraging on widely adopted DOE methodologies as the Factorial Design enables the possibility to use a well proven statistical analysis procedures. Examples of this approach are easily available in literature (Sandanayake, Oduoza, & Proverbs, 2008) (Gregor, Štefánik, & Hromada, 2008) (Yücesan & Fowler, 2000). It is obvious that the smaller the number of cases, the more incomplete and inaccurate the collected information is. The statistical approach to the experimental design is necessary to obtain significant conclusions from the data which are subject to errors and / or stochasticity of the input values. A design of an experimental plan must follow three basic principles for gaining statistical confidence:

1. **Reproducibility**: The repetition of the experiment in correspondence of the same set of input data, to obtain a more precise result (average sample) and estimate the experimental error (sample standard deviation).
2. **Randomizing**: Carrying out experiments in random order, to dissociate the conditions of a run from those of preceding and subsequent runs and thus avoiding the introduction of bias.
3. **Block Execution**: Grouping experiments carried out with similar external factors, to reduce the sources of variability and improve accuracy.

3.4.2 Factorial Design

In literature (Law & Kelton, 1982) the practice of One Factor At a Time strategy (OAT, Figure 15) is frequently used. The performance of Factorial Design are in line with the purpose of this PhD work aimed to understand the influence of few parameters in the performances of a manufacturing system. The method consists of two phases. Firstly, an initial value for each factor is chosen. The second phase involves varying the levels of each factor in its range of variation, keeping the other constant factors to their base or central level.

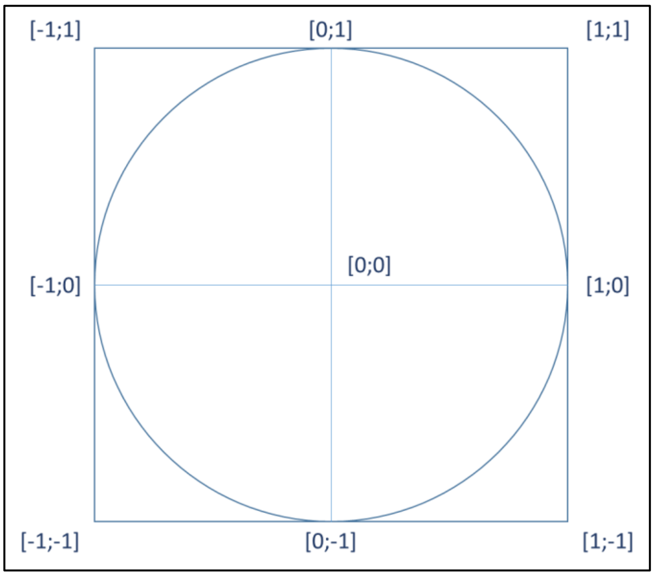

Figure 15 - OAT Strategy

A disadvantage of this strategy is the limitation of the analysis to a region of space. With reference to Figure 15, the areas at the four corners of the square, which is included in the external square but outside the circle, are not considered in the experiment. A valid approach to conduct researches with many factors is to use a factorial design of experiments. According to this approach, all the factors vary jointly rather than one at a time. The most important feature of the factorial design is the extremely efficient use of the experimental data. Two base definitions of the Factorial Design are shown below.

1. **Main effect of a Single Factor**: the difference between the values assumed by the response variable Y at different levels of the same factor.
2. **Interaction between 2 or more Factors**: the difference between the values assumed by the response variable Y at cross values (between upper and lower) of the factors considered.

An extension of the OAT method, all possible combinations of factor levels can be investigated through an analysis called Full Factorial. When all factors are investigated with the same number of levels, a set of factorial planes with L-levels and k-factors is defined and called L^k: in this case, L^k is the number of tests needed for a complete characterization of the system.

4 Case Study: ALPHA

In this chapter a deep evaluation of the production line of ALPHA is discussed. An overview on the products is provided, along with the data gathered during the field activities. The second section defines all the activities conducted for the construction of the Arena Simulation model, step by step. Finally, the last paragraph describes the simulation activities, aimed to verify the impacts of LM on MF.

4.1 Analysis on ALPHA

As mentioned in the Introduction, the present work is based on a Single Case Study: ALPHA. The assessment on the Company has been possible through a set of field activities: interviews to Management, field surveys, data collection and analysis. The following narrative shows the result of these preliminary activities, which represent the base for the subsequent activities (Software modeling and experiments).

4.1.1 Product Line

ALPHA was founded in 1949 in an industrial area near Siena. Since the company was formed its operating area has been the decorative aesthetics of crystal articles. Recently the investments in new premises and the increased technology level have been linked with the artistic talent and crafts skill of the resources, developed within the company. The style of both standard and new products, created exclusively for prestigious brands (domestic and foreign), are known and appreciated worldwide. Over the years, the management has been entrusted to the family's members who founded the company. In the last 30 years, ALPHA has improved the production plant and has gradually attracted the attention of national and foreign markets. However, the weight of the economic crisis in the entire Italian economic structure, is pushing the company's managers to seek new ways of production, more aligned to contemporary challenges. The manual silk-screening is the core of the decorative activities carried out by ALPHA. Craftsmanship, decorative refinement, quality and the absolute indelibility are guaranteed by extremely sophisticated technique, developed through the years. The procedure consists in printing shapes (through a silk frame on which a part of the decoration is engraved) directly on the glass or crystal. The base of the decoration material can be: one or more colors (flat or thick), metals (e.g. gold, platinum or silver) and crystal sands. Through the mix of the innumerable techniques it is possible to create many shapes, which easily

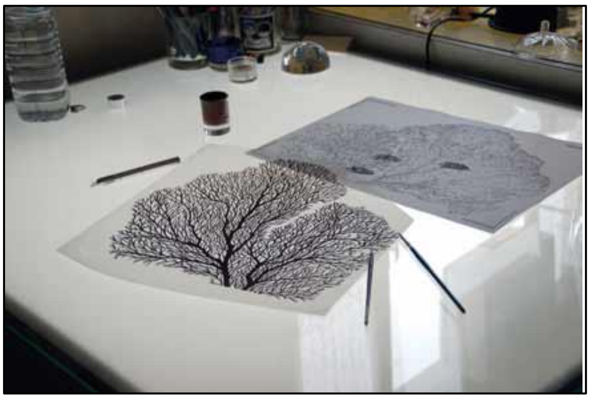

Figure 16 - Development of a new design

Figure 17 - Manual silk-screening

cover the market demands. At the end of the production process, those materials get vitrified in an oven with one or more heating sequences, which may vary from 450°C up to about 600°C. After heating, in an advanced and fully automated facility, all objects are subjected to a careful packaging phase, according to the various customers' needs. The overall catalogue of the company consists of a well-defined number of raw glass items to be processed on the base of various decoration styles, which can be also designed by the customer. The main income of the company derives from the sale of pre-engineered products, already in the catalogue. However, a significant portion of sales also relates to items specifically designed for meeting customer requirements. The data on this subject are showed below:

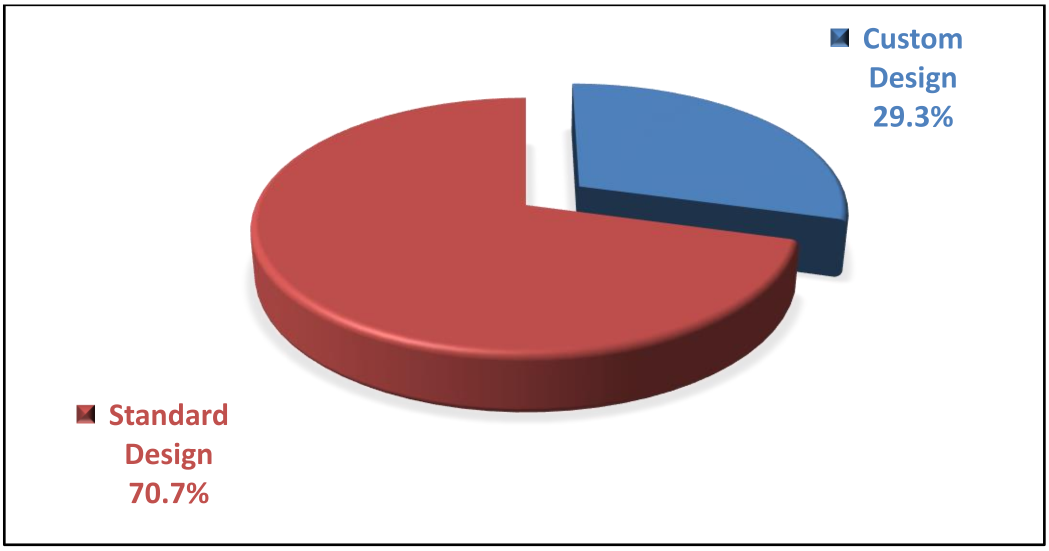

Figure 18 - Standard Products vs. Custom Products

The performance analysis on the manufacture system of the company is based on the study of the pre-engineered products only. These items represent the most significant part of the revenues and their production increases statistical significance of data gathering. These objects are coded in a systematic way, depending on the raw base and the type of decoration. Below the syntax for the pattern identification is presented:

Item Code:	E	###	§§§	$

###	Identification code of the DECORATION
§§§	Identification code of the RAW BASE
$	Identification code of the RAW SIZE

The features of the eleven styles are illustrated below with photos of the products and their respective description:

Ramages Argento

DECORATION Code:	447

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Ramages Oro

DECORATION Code:	483

Hand-made silk-screen printing with 24 Carat Gold, raised matt and polished finish. Fired twice at 530°C.

Samarcanda Argento

DECORATION Code:	494

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Samarcanda Oro

DECORATION Code:	496

Hand-made silk-screen printing with 24 Carat Gold, raised matt and polished finish. Fired twice at 530°C.

Valencienne

DECORATION Code:	514

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Omaggio a Antony Berrus 1870

DECORATION Code:	530

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Silver Velvet

DECORATION Code:	531

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Chateau Sevignè

DECORATION Code:	532

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Desdemona

DECORATION Code:	533

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Fontainebleau Argento

DECORATION Code:	484

Hand-made silk-screen printing with Sterling Silver (980/1000), raised matt and polished finish. Fired twice at 560°C.

Fontainebleau Oro

DECORATION Code:	490

Hand-made silk-screen printing with 24 Carat Gold, raised matt and polished finish. Fired twice at 530°C.

The decorative styles differ by the theme and the material used for the screen printing. Both parameters affect the costs of the finished products. The adding costs are due to the length time used for the printing (varying with the complexity of the drawings) and the value of the metal used (usually silver or gold). The combination of different raw materials and decoration styles produces a total of 230 goods in the catalogue. Not all the decorations can be applied to the full set of raw items. Some styles, because of the nature of their textures, are relevant only to a limited number of shapes. The finished items are divided into ten homogeneous categories, based on shape and size, to enhance the understanding of the study, without losing meaningful details.

These ten categories are listed below, along with the associated characteristics and their relevant codes:

Small Glass

Dimensions: Height 6-11 cm Diameter 3.5-5 cm
Batch Quantity: 180 Items
Raw Items: 5

BASE	SIZE
702	0
603	5
709	0
535	3
653	5

Glass

Dimensions: Height 9-16 cm Diameter 7-9 cm
Batch Quantity: 180 Items
Raw Items: 4

BASE	SIZE
912	4
912	7
695	4
695	7

Bottle

Dimensions: Height 8-15 cm Diameter 25-40 cm
Batch Quantity: 50 Items
Raw Items: 3

BASE	SIZE
135	0
356	0
667	0

Small Bowl

Dimensions: Height 12.5 cm Diameter 21 cm
Batch Quantity: 50 Items
Raw Items: 1

BASE	SIZE
655	1

Bowl

Dimensions: Height 20 cm Diameter 21 cm
Batch Quantity: 50 Items
Raw Items: 1

BASE	SIZE
655	0

Small Plate

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 120 Items
Raw Items: 3

BASE	SIZE
851	1
851	4
851	5

Plate

Dimensions: Height 2 cm Diameter 31-35 cm
Batch Quantity: 60 Items
Raw Items: 9

BASE	SIZE
000	2
000	3
000	4
000	5
911	3
851	0
851	6
863	0
693	0

Box

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 50 Items
Raw Items: 4

BASE	SIZE
545	0
545	1
694	1
694	2

Cylindrical Vase

Dimensions: Height 2 cm Diameter 31-35 cm
Batch Quantity: 60 Items
Raw Items: 9

BASE	SIZE
700	0
600	1
848	1
049	0
557	1
557	2
869	0
869	1

Conic Vase

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 50 Items
Raw Items: 6

BASE	SIZE
536	0
552	1
553	1
379	1
280	2
692	0

4.1.2 Overview on Sales

The management of ALPHA provided some statistics on the sales for the years 2010, 2011 and 2012. The data was discussed in interviews, to maximize the usefulness and understanding of the possible implications in academic research. According to this information, we can obtain a general indication of the economic environment in which the company is currently operating. Furthermore, it is possible to understand the reason which drives the managers towards finding a Lean approach.

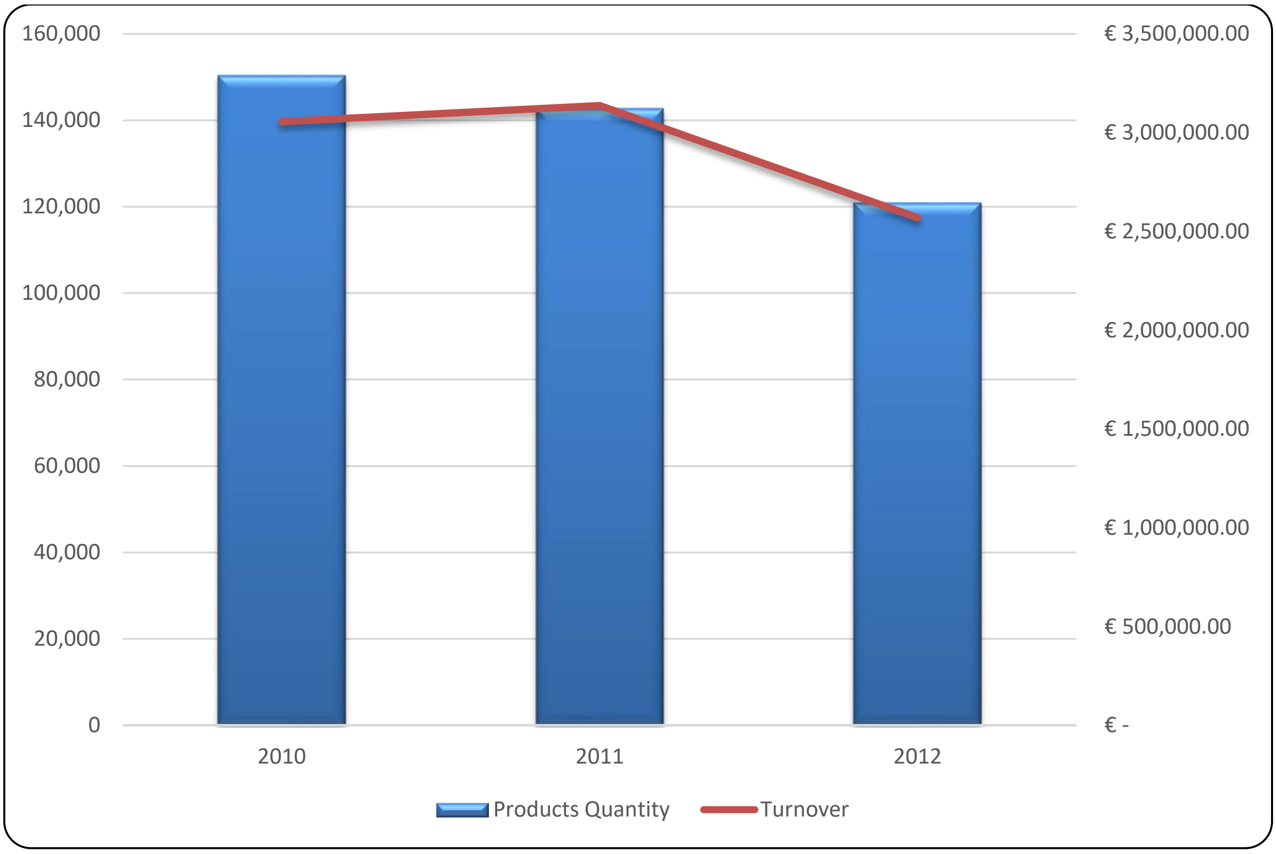

Figure 19 - Sales 2010, 2011, 2012

The graph above clearly shows a decreasing trend in sales. The reduction of items sold from 2010 to 2011 is balanced by a higher specific value of marketed goods. Such mitigation did not occur in 2012, when there was a reduction of 18% in revenue over the previous year. This worrying trend, faced by many Italian SMEs, has fortunately not required drastic actions by management so far. As shown by the goods' average prices, during those three-years, significant reductions in contribution margins were not implemented. In an interview, the director of the company stated that, in the current economic environment a low level of production might continue for a few years to come, so that the coverage of basic costs will be a key point for the future of the firm. The need for a LM system, able to adjust costs to the real market demand, is necessary. This need is opposed to the old conception, where the cost minimization could be done in respect of a constant-growing productive level. In this scenario, one of the most promising Lean Techniques for the optimization of basic costs (e.g. salaries) seems to be the Cellular Manufacturing. With the adoption of this principle, the not required production units can be temporarily disabled, whilst keeping the efficiency high. In this way a part of the fixed costs becomes variable.

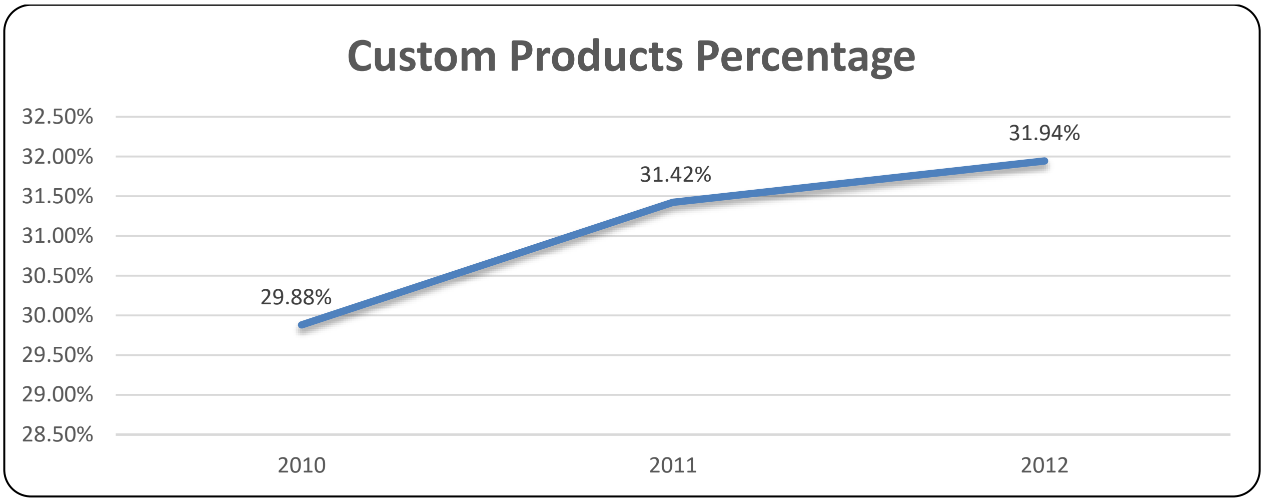

Figure 20 - Revenue from Custom Products

The current, global weakness requires companies to prove their value, in terms of product quality. The graph above shows the trend of the percentage of custom products in respect of the total turnover. It is clear that, with the sales' decrease, the market niche for customized products has an above-average performance. From this evidence, we understand that even for standard products flexibility is a critical requirement and it will be awarded in terms of Mix.

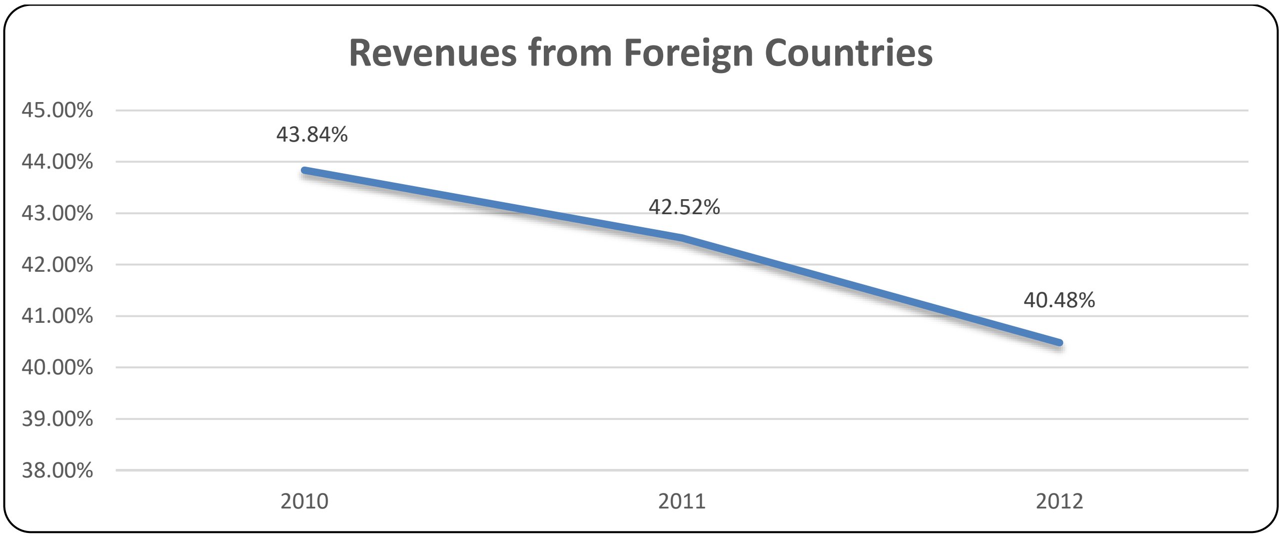

Figure 21 - Revenues from foreign countries

The income derived from foreign countries represents more than half of the total turnover of ALPHA: the percentage was 40.48% in 2012. This portion of the company's portfolio has had a negative trend, almost linear, in the years under review. The phenomenon shown in the graph is a symptom of the growing level of competitiveness that companies face nowadays. Globalization pushes firms to seek new business opportunities worldwide. Small corporations must adapt their organization and mindset to be able to react to the aggression from more structured entities. The key aspects highlighted in this paragraph (decrease in sales, importance of production flexibility, the need to compete globally) have pushed the leaders of ALPHA to adopt Lean Thinking. In the following sections, academic research also aims to help the company in such investigation.

4.1.3 Production Flow

The production site of the company consists in a facility manufacturing of about 1200 square meters, dedicated to all the activities relative to decoration, packing and storing. The production is divided into different areas. Within each area a different working phase is performed. The picture below reports the layout of the factory for further analysis:

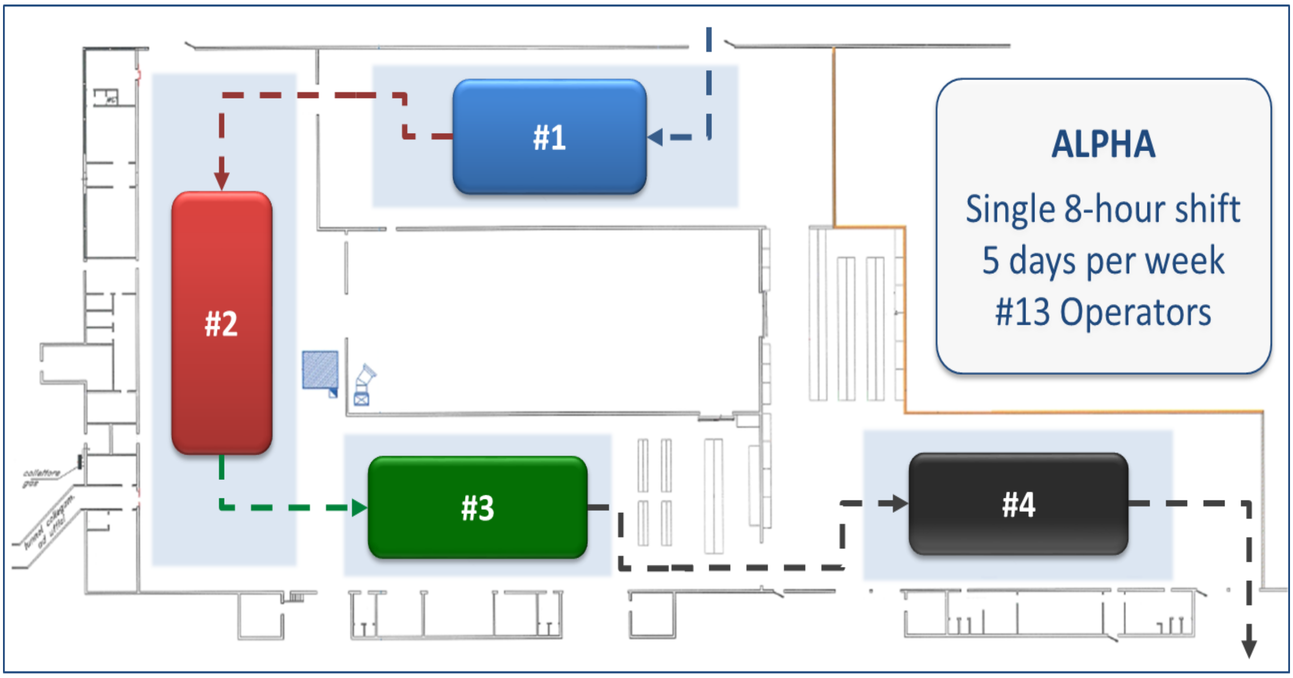

Figure 22 - Layout of the Factory

In the picture above 4 areas are highlighted, which enclose the key activities for the goods' production:

1. Raw Material Control.

2. Hand-made Silk-screen Printing.
3. Heating & Cleaning.
4. Packaging.

These sections are described below, in detail, to clarify the understanding of the process.

The Raw Material Control (Figure 20) is the first process to be carried out on the raw material at the entrance of the factory. This activity is particularly important, not only because it verifies the quality of the material, but also because it distributes the material evenly into batches. The manual screen printing is a process sensible even to small geometric variations of the items, so that the division of the objects allows to limit the number of tools used during the production.

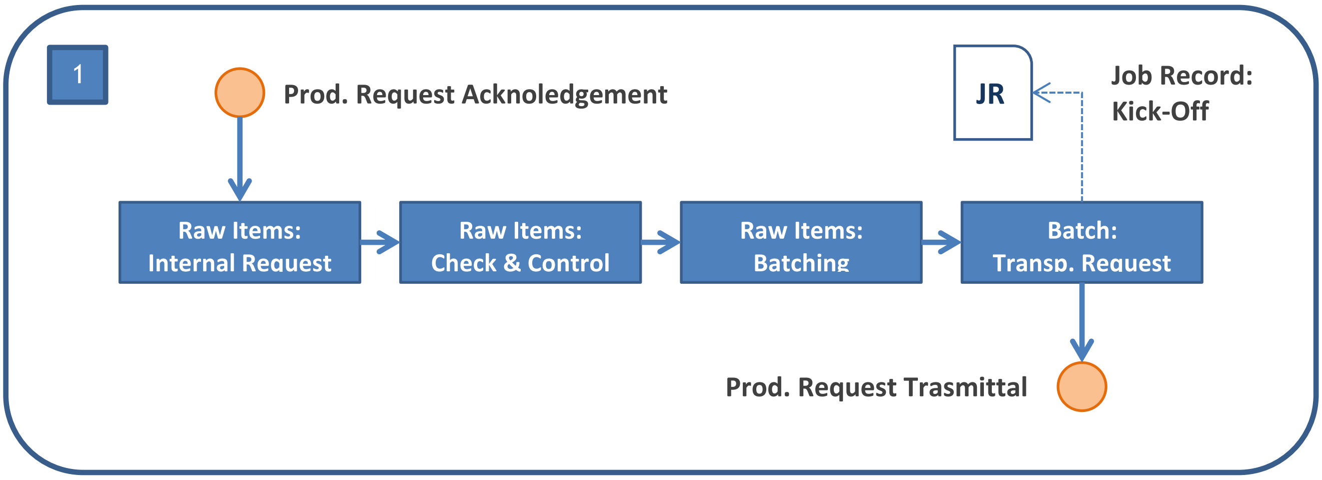

Figure 23 - Raw material check in

Both main activities, Raw Items Control and batching, carried out in this department, do not bring added value, but are necessary. For this reason, according to the principles of LM, the use of resources at this stage must be minimized. In the current production configuration six resources are employed full time in the check in step.

The Hand-made Silk-screen Printing (Figure 21) is the most critical stage of the décor. This is carried out in the central part of the plant, where 6 dedicated stations are installed. As already mentioned, this operation is totally manual and consists in applying a coating on a glass raw through a pre-shaped frame. The process is illustrated in Figure 22 below.

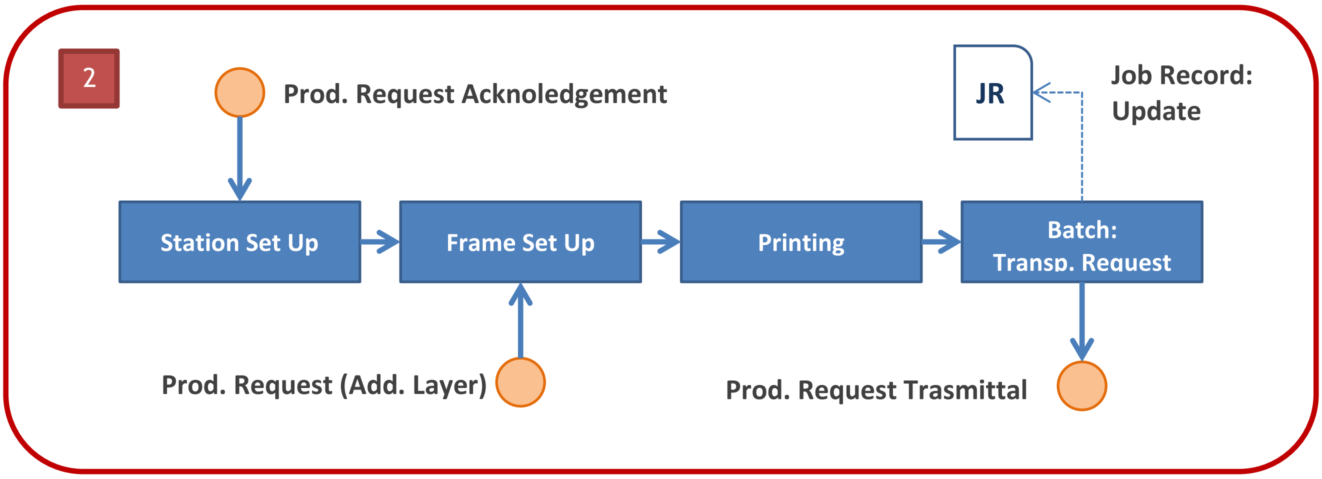

Figure 24 - Hand-made silk-screen printing

During this phase the quality of the application of the decoration directly affects the result. This aspect is amplified when two drawings are superimposed in the decoration.

Figure 25 - Hand-made Silk-screen Printing

The press is a value-added process which joins NAV activities, such as the set-up of the workstation or the frame. Suffering for the time waste during the tooling, an increasing demand for MIXF is requested. In the current production configuration 6 resources are employed full time in the check in step.

The Heating & Cleaning department (Figure 23) is located in the third area, between the decoration and packaging department. The verification of the coating occurs inside these automatic devices. The parameters used for the operation are calculated on the basis of the piece dimensions and design features. Although the process is automatic, the monitoring by an operator is required, to avoid breakage or defects. In the same area, there is also the station for manual cleaning of the objects, after the heating. This is required both when the pieces are ready for packaging and when they are supposed to get an additional decoration.

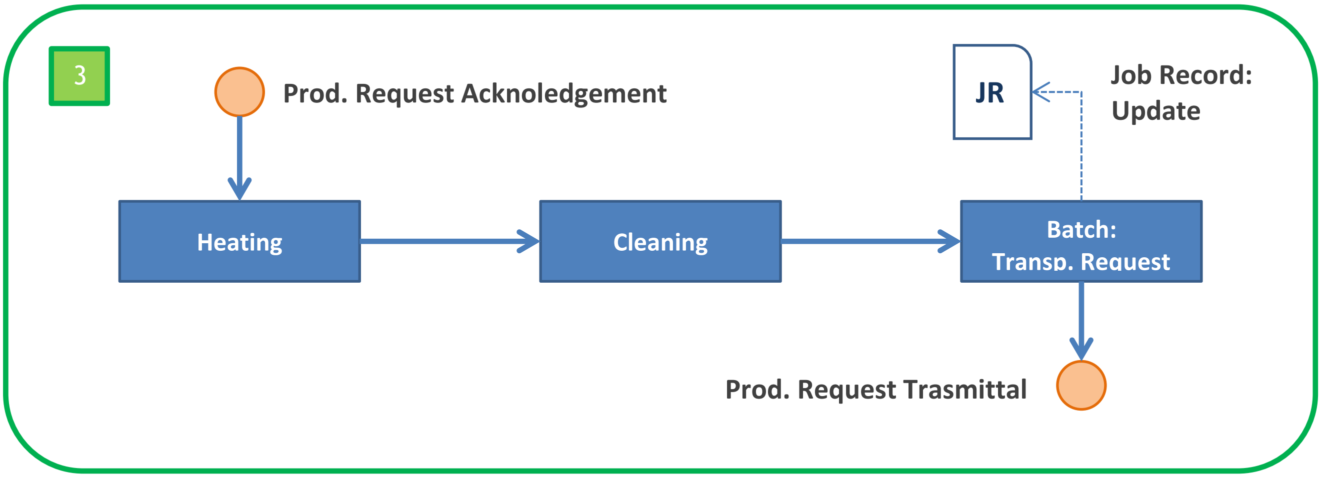

Figure 26 - Heating and Cleaning

Both heating and cleaning operations are a value-added and, in the current process, are covered by 6 dedicated operators.

The Packaging area (Figure 24) is located close to the warehouse. In this department, all the finished goods are checked and placed into boxes.

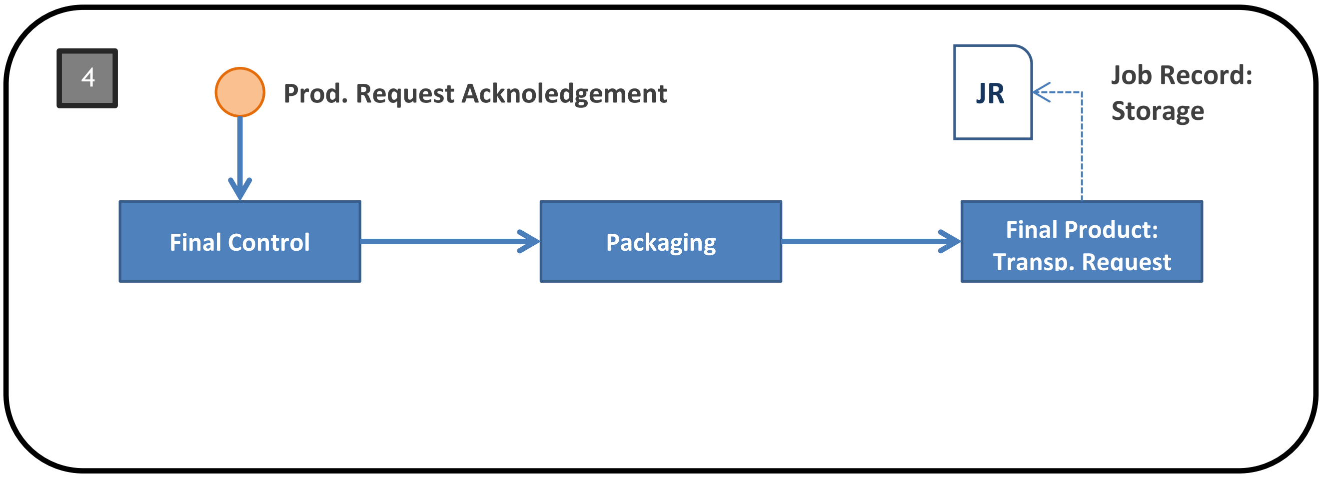

Figure 27 - Packaging

The packaging itself is considered an added value activity. On the contrary the final control of the finished products could be theoretically avoided or, at least, simplified through visual techniques. Currently 6 operators carry out the operation in this department.

4.1.4 Value Stream Map

As anticipated in the previous paragraph, the overall manufacturing process of ALPHA can be broken down into 4 sub-parts, 2 of these are usually traversed more than once. Below the illustration of the Value Stream Map of the company in the current configuration.

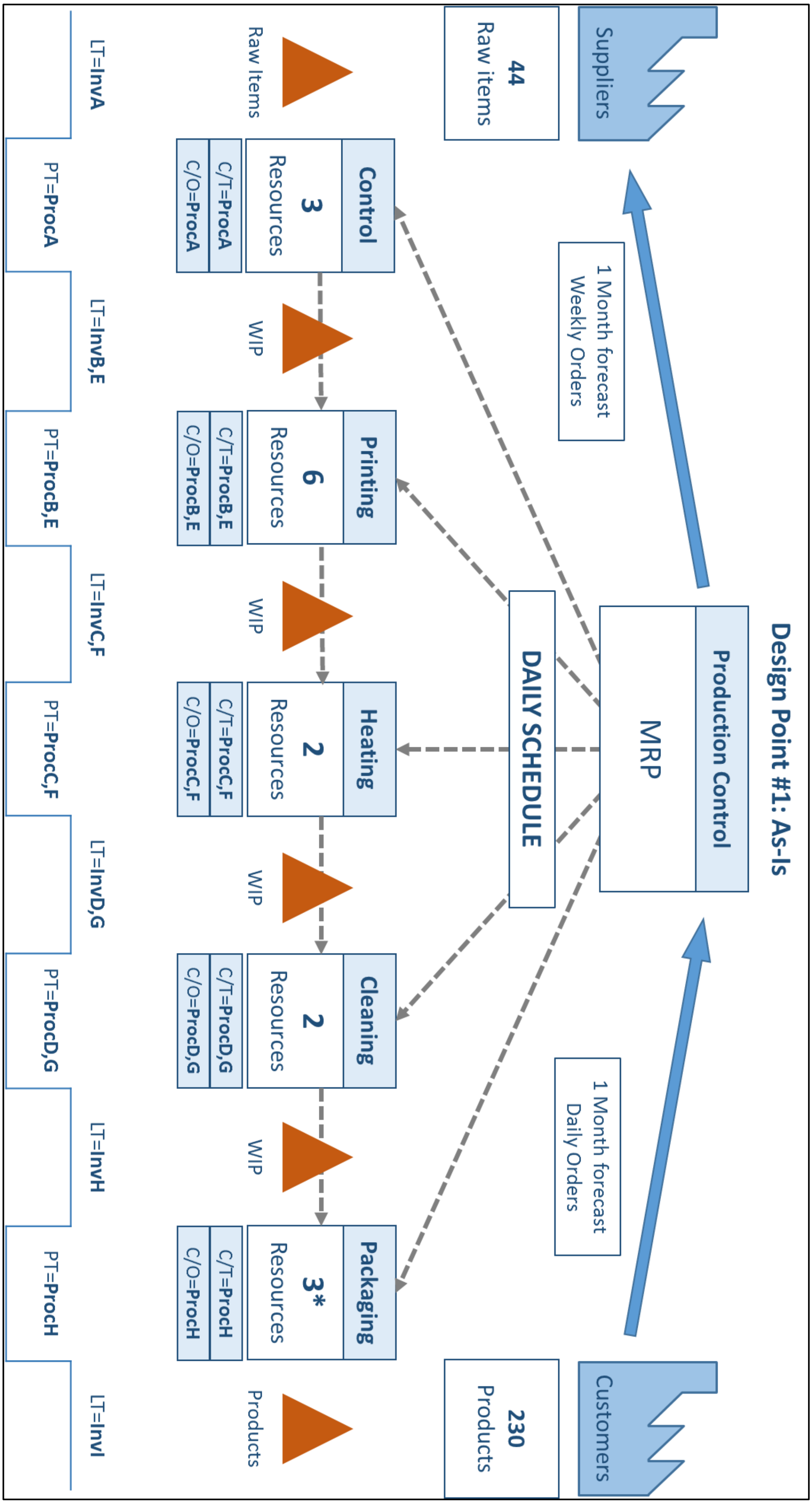

Figure 28 - VSM ALPHA "As-Is"

4.2 Arena Simulation Model

The set of information acquired on ALPHA has been used to design a software model in Arena Simulation. The main steps required to align this model to the real behavior of the production line starts with the selection of a proper sequence of Elements in the tool, continues with the provision of simulation parameters and ends with a test.

4.2.1 Design of Simulation Model

The Value Stream Map presented in the previous paragraph is the basis for the design of the Arena Simulation model of ALPHA. The system's design started with the introduction of logic blocks representing the production departments, continued by defining the logic flow of materials and ended with the setup of the production parameters of each single item. The complete model is shown here below, in order to provide an overview on its arrangement.

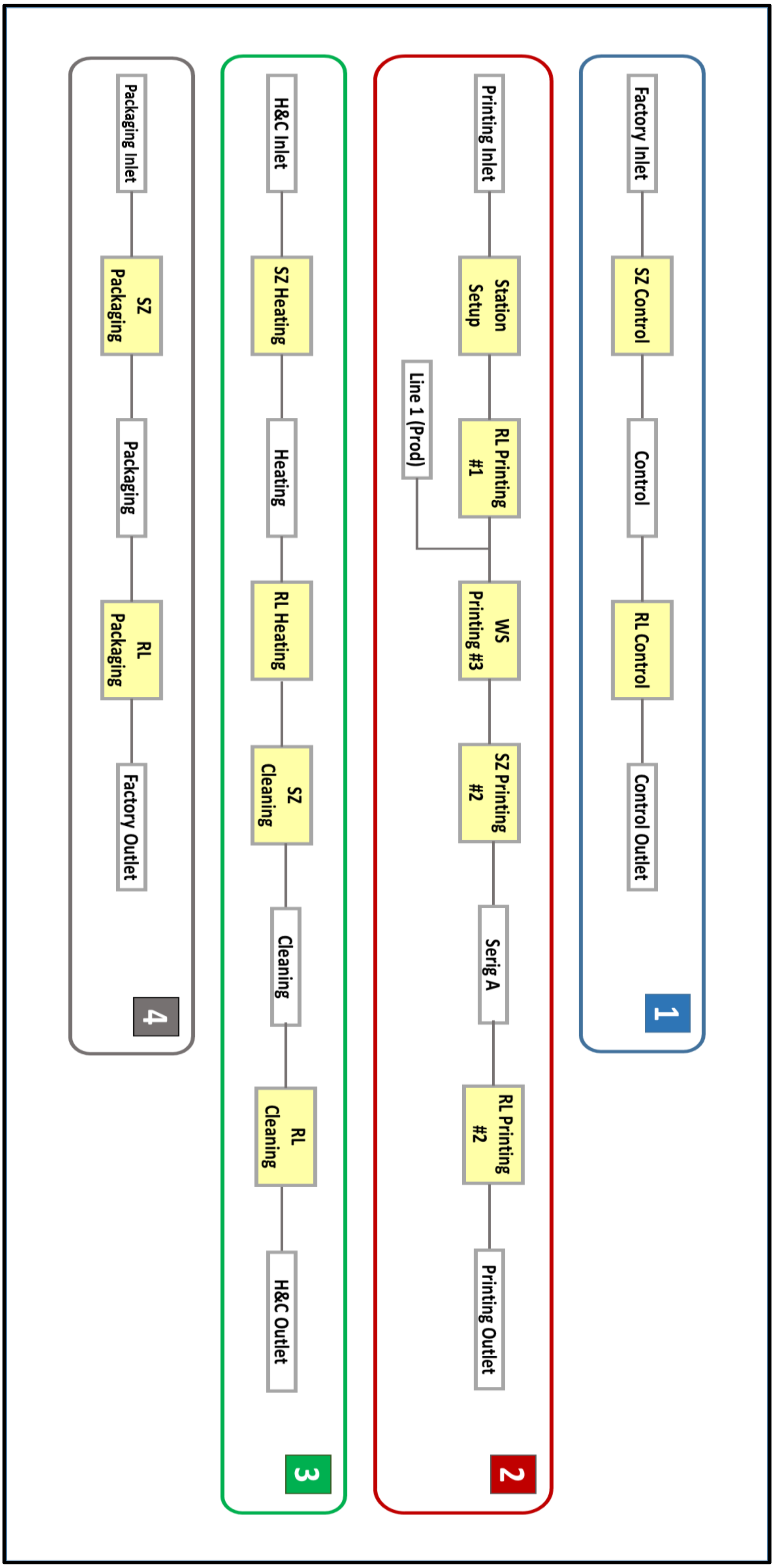

Figure 29 - Complete Arena Simulation model

The structure of the four sub-components is analyzed in detail hereinafter.

#1 Raw Material Control

The first entity in Section#1 is labeled "Factory Inlet" (Sub-model Type) and is a logic block containing some sub-parts (shown in Figure 30). The first 4 entities (Start, Assign Attributes, Delay Start, and Separate Inlet) are required to generate a flow of products' batches, synchronized with a pre-defined inlet sequence.

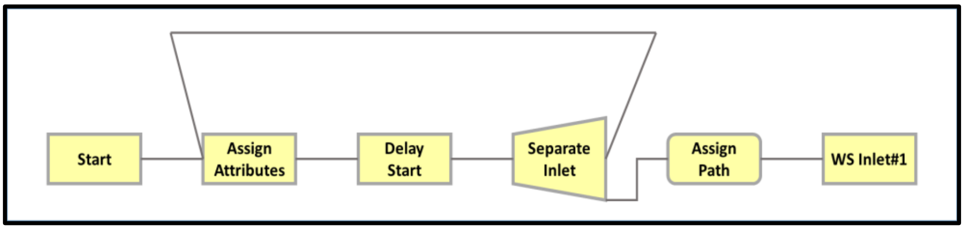

Figure 30 - Factory Inlet

The attributes of each object, entering the system, are assigned through an entity (Assign Attributes – ReadWrite Type) which transfers this information from the Input Excel file. The "Assign Path" block (Assign Type) defines the picture of each batch. "WS Inlet#1" (ReadWrite Type) records the entry time in the Output Excel file. "SZ Control" (Seize Type) subtracts a resource to those available for the inlet control operations.

"Control" (Sub-model Type) contains 5 sub entities (showed in Figure 31). "WS Control#1"

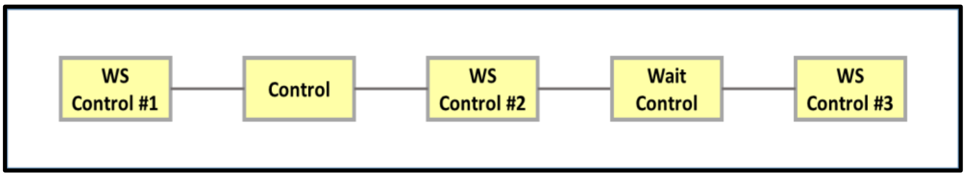

Figure 32 – Control

(ReadWrite Type) records the starting time of the Check In operations. "Check In" (Process Type) represents the inlet control of each item. "WS Control#2" (ReadWrite Type) records the ending time of Control operations for the single item. "Wait Control" (Process Type) provides the wait time for each object of a lot, while the others are checked. "WS Control#3" (ReadWrite Type) records the ending time of Check In operations for all the batches. "RL Control" (Release Type) adds a resource to those available for the inlet control operations.

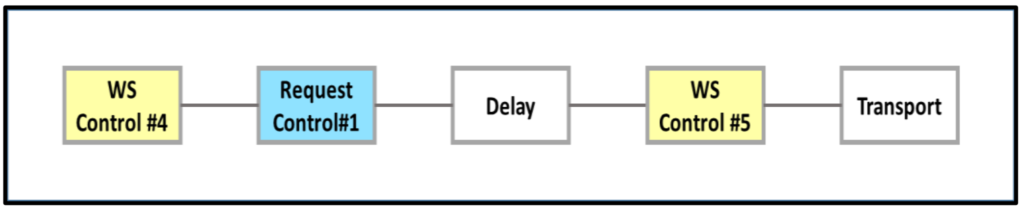

Figure 31 – Control Outlet

"Control Outlet" (Submodel Type) contains 5 sub entities (showed in Figure 32). "WS Control#4" (ReadWrite Type) records the exit time from the Raw material check in department. The other 4 entities are logic operators, handling the transport of products by forklifts.

#2 Hand-made silk-screen printing

Section#2 is composed by a stream which starts with a Sub-model "Printing Inlet" (Sub-model Type), showed in Figure 33. "E Printing#1" (Enter Type) is the products' arrival station.

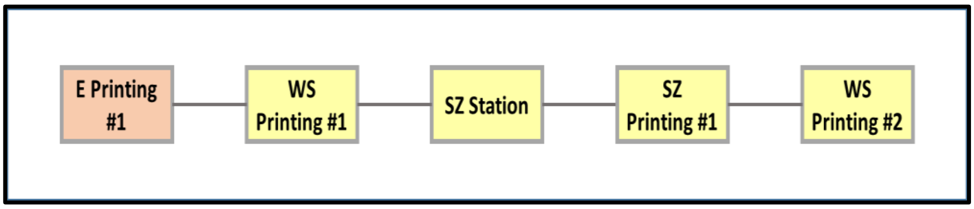

Figure 33 – Printing Inlet

"WS Printing#1" (ReadWrite Type) records the starting time of the printing process. "SZ Station" and "SZ Printing#1" (Seize Type) subtracts respectively a production station and a resource to those available for the serigraphic operations. "WS Printing#2" (ReadWrite Type) records the starting time of station setting up in the Output Excel file. Proceeding with the flow, "Station Setup" (Process Type) represents the station setting up operation. "RL Printing#1" (Release Type) adds a resource to

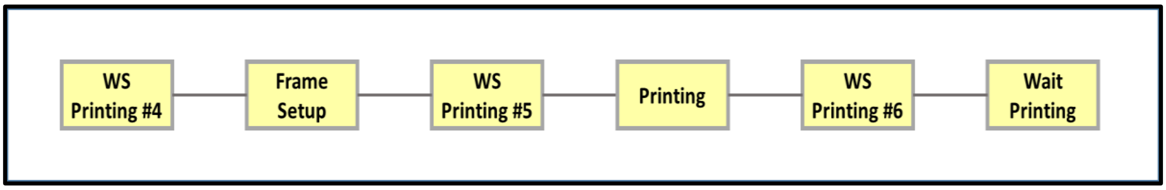

Figure 34 - Serig A

those available for the serigraphic operations. "WS Printing#3" (ReadWrite Type) records the arrival time at the queue for an available frame in the Output Excel file. "SZ Printing#2" (Seize Type) subtracts a serigraphic frame to those available for the printing operations. "Printing" (Sub-model Type) contains 6 sub-entities (showed in Figure 34). "WS Printing#4" (ReadWrite Type) records the starting time of serigraphic frame setting up in the Output Excel file. "Frame Setup" (Process Type) represents the serigraphic frame setting up operation. "WS Printing#5" (ReadWrite Type) records the starting time of printing operations in the Output Excel file. "Printing" (Process Type) represents the serigraphic printing operation. "WS Printing#6" (ReadWrite Type) records the ending time of serigraphic printing for the single item in the Output Excel file. "Wait Printing" (Process Type) provides the wait time for each object of a lot, while the others are printed. "RL Printing#2" (Release

Type) adds a serigraphic frame to those available for the serigraphic operations. “Printing Outlet” (Sub-model Type) contains 5 sub-entities (showed in Figure 35).

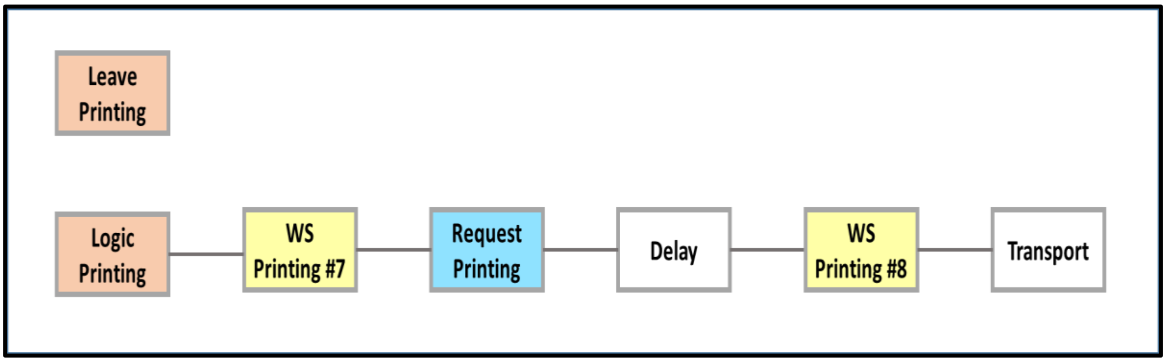

Figure 35 - Printing Outlet

The first 2 entities in the Sub-model are “Leave Printing” (Leave Type) and “Logic Printing” (Enter Type), both are used for system logic purpose only. “WS Printing#7” (ReadWrite Type) records the ending time of serigraphic printing for all the batches. The other 4 entities are logic operators, handling the transport of products by forklifts. “Line 1 (Prod)” (Submodel Type) represents the inlet point to the Hand-made silk-screen printing Department for batches which have already undergone a first decoration.

#3 Heating & Cleaning

Section#3 starts with “H&C Inlet” (Sub-model Type) whose subparts are illustrated in Figure 36.

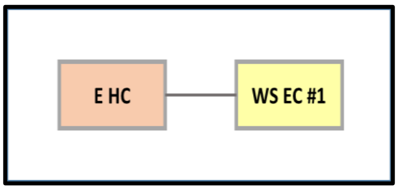

Figure 36 – Oven (Inlet)

“E HC” (Enter Type) is the arrival station for the products. “WS EC#1” (ReadWrite Type) records the arrival time in the Section#3. “Seize Heating” (Seize Type) subtracts an operator to those available for the heating operations. “Heating” (Sub-model Type) contains 2 sub entities (showed in Figure 37).

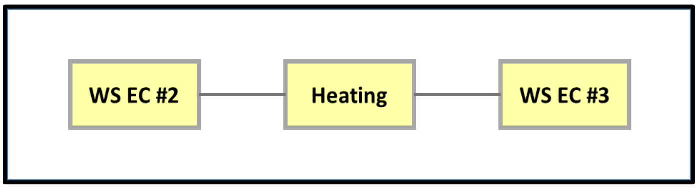

Figure 37 - Oven

“WS EC#2” (ReadWrite Type) records the starting time of the heating operations. “Heating” (Process Type) represents the heating operation. “RL Heating” (Release Type) adds an operator to those available for the heating operations. “WS EC#3” (ReadWrite Type) records the ending time of the heating operations. “SZ Cleaning” (Seize Type) subtracts an operator to those available for the heating operations.

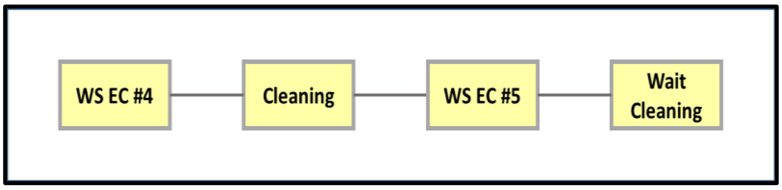

Figure 38 - Polish

“Cleaning” (Sub-model Type) contains 4 sub entities (showed in Figure 38). “WS EC#4” (ReadWrite Type) records the starting time of the cleaning operations. “Cleaning” (Process Type) represents the cleaning operation. “WS EC#5” (ReadWrite Type) records the ending time of cleaning for the single item in the Output Excel file. “Wait Cleaning” (Process Type) provides the wait time for each object of a lot, while the others are cleaned. “RL Cleaning” (Release Type) adds an operator to those available for the cleaning operations.

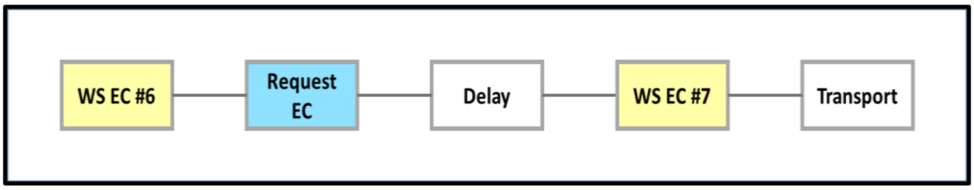

Figure 39 – E&C Outlet

“E&C Outlet (Sub-model Type) contains 5 sub entities (showed in Figure 39). “WS EC#6” (ReadWrite Type) records the ending time of cleaning for all the batches. The other 4 entities are logic operators, handling the transport of products by forklifts.

#4 Packaging

Section#4 begins with “Packaging Inlet” (Sub-model Type), whose subparts are illustrated in Figure

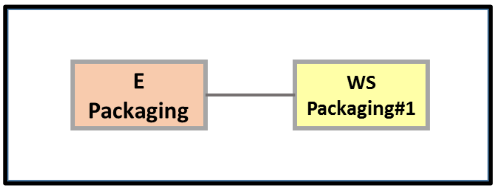

Figure 40 - Packaging

40. “E Packaging” (Enter Type) is the arrival station for the products. “WS Packaging#1” (ReadWrite Type) records the arrival time in the Section#4. “SZ Packaging” (Seize Type) subtracts an operator to those available for the packing operations.

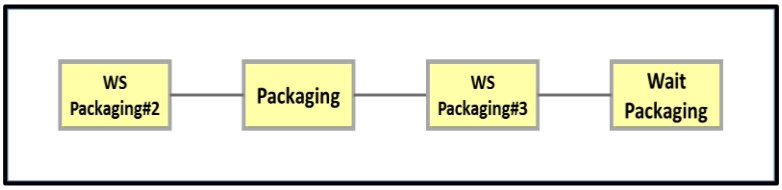

Figure 41 - Packaging

"Packaging" (Submodel Type) contains 4 sub entities (showed in Figure 41). "WS Packaging#2" (ReadWrite Type) records the starting time of the packing operations. "Packaging" (Process Type) represents the packing operation. "WS Packaging#3" (ReadWrite Type) records the ending time of packing for the single item in the Output Excel file. "Wait Packaging" (Process Type) provides the wait time for each object of a lot, while the others are packed. "Release Packing" (Release Type) adds an operator to those available for the packaging operations.

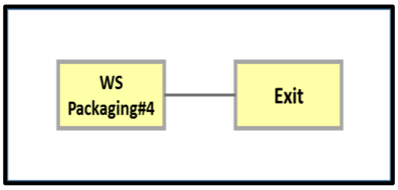

Figure 42 - Factory Outlet

"Factory Outlet" (Sub-model Type) contains 2 sub entities (showed in Figure 42). "WS Packaging#4" (ReadWrite Type) records the ending time of the step. The last entity represents the exit of the products from the system.

4.2.2 Introduction of Parameters

The arena model, described in the previous section, simulates the process of the production system during the operation. The production steps, which are traversed by batches of products, require different times, depending on the state of the system and on some product parameters. The state of the system is constantly evolving and is managed by the same model; the parameters instead only depend on the product code. These variables are set inside the first Sub-model of the scheme "Factory Inlet".

These parameters are listed below, with a brief description.

Parameter	*Department(s)*	*Description*
Batch Quantity	All	Quantity of item per Batch
Control Avg	#1 Raw Material Control	Time Average required for Control operations.
Control StdDev	#1 Raw Material Control	Time Standard Deviation required for Control operation.
Set-up Station Avg	#2 Hand-made silk-screen printing	Time Average required for the Set-up of a Station.
Set-up Station StdDev	#2 Hand-made silk-screen printing	Time Standard Deviation required for the Set-up of a Station.
Set-up Frame Avg	#2 Hand-made silk-screen printing	Time Average required for the Set-up of a Frame.
Set-up Frame StdDev	#2 Hand-made silk-screen printing	Time Standard Deviation required for the Set-up of a Frame.
Printing Avg	#2 Hand-made silk-screen printing	Time Average required for Printing.
Printing StdDev	#2 Hand-made silk-screen printing	Time Standard Deviation required for Printing.
Heating	#3 Heating & Cleaning	Time required for Heating (Deviation negligible).
Cleaning Avg	#3 Heating & Cleaning	Time Average required for Cleaning.
Cleaning StdDev	#3 Heating & Cleaning	Time Standard Deviation required for Cleaning.
Packaging Avg	#4 Packaging	Time Average required for Packaging.
Packaging StdDev	#4 Packaging	Time Standard Deviation required for Packaging.

Table 25 - Parameters List

All parameters listed above have been evaluated for all the products described in paragraph 4.1.1. Product Line. As suggested by Voss et al. (Voss et al., 2002), the evaluation of these parameters has been based on the triangulation of different sources, in particular these sources belong to the following three categories:

1. Experimental measurements

   Field records gathered by the researcher represent the main source of data, the samples have been calculated on the basis of at least 50 measurement samples in order to enable statistical considerations.

2. <u>Data from available databases</u>

   Corporate database has been utilized mainly as test data for the experimental measurements, with the aim to detect and clear any misalignment. Those data are based on production time cards filled by operators for each product batch flowing in the manufacturing system.

3. <u>Interviews</u>

   The validation of the parameters has been completed by discussing the results to the operators, considered as experts, and by reporting the final values to the production manager.

The parameters can be grouped in three different categories: Fixed Parameters, Parameters based on Raw Material and Parameters based on Item Code. Below a detailed analysis for each group is presented.

Fixed Parameters

In the current configuration of the production system, two parameters are considered constant: the quantity of goods in a production batch (fixed number set by management) and the time required for heating (fixed time for technical reasons):

	Items / Batch	**Heating [min]**
Glass	180.00	21.00
Small Glass	180.00	9.51
Bottle	50.00	13.61
Bowl	50.00	50.00
Small Bowl	50.00	50.00
Small Plate	120.00	22.00
Plate	60.00	25.16
Box	50.00	14.17
Cylindrical Vase	50.00	21.50
Conic Vase	50.00	49.17

Table 26 - Fixed parameters

The number of objects in each batch is examined in the following chapters, while the time required for the verification of décor is already optimized.

Two other parameters are considered fixed and independent from the shape of the object: the times of instrument setup. The values showed in Table 27 were calculated on the basis of 50 measurement samples.

	Set-up Average [min]	Set-up StdDev
Station	21.56	4.031
Frame	13.78	2.326

Table 27 - Set-up times

Parameters based on Raw Material

Analyzing the process through field survey, it is evident that, the time required to Control, Clean and Package the final products is a function depending only on the dimension of raw material. This is due to the fact that only the size (weight) and manageability (shape) affect the handling. Field measurements have been performed to evaluate exactly the time required for these manual operations. A sample of 50 items for each code, listed in the following tables, has been measured to safeguard the statistical significance of the study. Moreover, the convergence of the values measured with the values expected according to corporate database have been checked with a positive outcome. The results of Control Operations are reported below.

		Control [sec/ (#)]		LAYERS		
		Average	StdDev		Min	Max
E5326954	**Glass**	13.32	2.249	1.00	9.00	20.00
E5146957	**Glass**	13.22	2.571	1.00	9.00	18.00
E4835353	**Small Glass**	6.54	1.374	1.00	5.00	9.00
E4966535	**Small Glass**	6.40	1.183	1.00	5.00	10.00
E5311350	**Bottle**	44.16	8.271	1.00	24.00	65.00
E4963560	**Bottle**	46.50	8.115	1.00	26.00	65.00
E4906550	**Bowl**	36.02	5.795	1.00	26.00	47.00
E4906551	**Small Bowl**	38.16	6.217	1.00	23.00	54.00
E5338515	**Small Plate**	17.68	3.886	1.00	9.00	25.00
E5320003	**Plate**	65.52	10.893	3.00	41.00	90.00
E5336930	**Plate**	21.52	3.233	1.00	15.00	30.00
E4966941	**Box**	36.20	6.255	1.00	24.00	58.00
E4846942	**Box**	35.18	6.784	1.00	19.00	48.00
E5310490	**Cylindrical Vase**	28.62	4.845	1.00	19.00	41.00
E5325571	**Cylindrical Vase**	26.64	5.222	1.00	17.00	39.00
E5143802	**Conic Vase**	33.14	8.200	1.00	14.00	47.00
E4776920	**Conic Vase**	32.00	7.715	1.00	19.00	49.00

Table 28 - Field survey: Control

By following the categories of products specified in paragraph 4.1.1. Product Line, the parameters retrievable are:

	Control [min / (#*Layers)]	
	Average	StdDev
Glass	0.22	0.003
Small Glass	0.11	0.002
Bottle	0.76	0.020
Bowl	0.60	0.014
Small Bowl	0.64	0.015
Small Plate	0.29	0.006
Plate	0.52	0.010
Box	0.59	0.015
Cylindrical Vase	0.46	0.012
Conic Vase	0.54	0.019

Table 29 - Control Parameters

Below the values of the Cleaning operations:

		Cleaning [sec/ (#)]		LAYERS		
		Average	StdDev		Min	Max
E5326954	**Glass**	12.28	1.563	1.00	8.00	16.00
E5146957	**Glass**	12.42	1.185	1.00	9.00	15.00
E4835353	**Small Glass**	9.36	1.035	1.00	8.00	13.00
E4966535	**Small Glass**	9.48	0.922	1.00	8.00	11.00
E5311350	**Bottle**	18.42	1.343	1.00	16.00	22.00
E4963560	**Bottle**	18.72	1.638	1.00	15.00	22.00
E4906550	**Bowl**	26.62	1.917	1.00	23.00	31.00
E4906551	**Small Bowl**	25.70	1.591	1.00	22.00	29.00
E5338515	**Small Plate**	12.28	1.470	1.00	10.00	16.00
E5320003	**Plate**	51.58	3.175	3.00	45.00	60.00
E5336930	**Plate**	16.56	1.186	1.00	14.00	20.00
E4966941	**Box**	17.36	1.841	1.00	12.00	21.00
E4846942	**Box**	17.20	1.833	1.00	13.00	21.00
E5310490	**Cylindrical Vase**	21.56	2.080	1.00	16.00	25.00
E5325571	**Cylindrical Vase**	21.60	1.649	1.00	18.00	24.00
E5143802	**Conic Vase**	25.54	2.913	1.00	20.00	31.00
E4776920	**Conic Vase**	25.10	2.610	1.00	19.00	29.00

Table 30 - Field survey: Control

By following the categories of products specified in paragraph 4.1.1. Product Line, the parameters retrievable are:

	Cleaning [min / (#*Layers)]	
	Average	**StdDev**
Glass	0.21	0.002
Small Glass	0.16	0.001
Bottle	0.31	0.004
Bowl	0.44	0.005
Small Bowl	0.43	0.004
Small Plate	0.20	0.002
Plate	0.40	0.004
Box	0.29	0.004
Cylindrical Vase	0.36	0.004
Conic Vase	0.42	0.007

Table 31 - Control Parameters

Below the values of the Packaging operations:

		Packaging [sec/ (#)]		LAYERS		
		Average	**StdDev**		**Min**	**Max**
E5326954	**Glass**	25.28	2.514	1.00	8.00	16.00
E5146957	**Glass**	24.74	2.152	1.00	9.00	15.00
E4835353	**Small Glass**	19.86	2.280	1.00	8.00	13.00
E4966535	**Small Glass**	20.28	2.743	1.00	8.00	11.00
E5311350	**Bottle**	77.74	7.881	1.00	16.00	22.00
E4963560	**Bottle**	79.04	8.156	1.00	15.00	22.00
E4906550	**Bowl**	115.92	9.269	1.00	23.00	31.00
E4906551	**Small Bowl**	65.22	8.196	1.00	22.00	29.00
E5338515	**Small Plate**	37.90	4.522	1.00	10.00	16.00
E5320003	**Plate**	215.12	18.316	3.00	45.00	60.00
E5336930	**Plate**	71.00	6.171	1.00	14.00	20.00
E4966941	**Box**	82.62	7.054	1.00	12.00	21.00
E4846942	**Box**	82.74	6.036	1.00	13.00	21.00
E5310490	**Cylindrical Vase**	58.40	4.919	1.00	16.00	25.00
E5325571	**Cylindrical Vase**	57.30	5.651	1.00	18.00	24.00
E5143802	**Conic Vase**	71.50	7.333	1.00	20.00	31.00
E4776920	**Conic Vase**	69.42	7.826	1.00	19.00	29.00

Table 32 - Field survey: Control

By following the categories of products specified in paragraph <u>4.1.1. Product Line</u>, the parameters retrievable are:

	Packaging [min / (#)]	
	Average	**StdDev**
Glass	0.42	0.003
Small Glass	0.33	0.003
Bottle	1.31	0.019
Bowl	1.93	0.022
Small Bowl	1.09	0.019
Small Plate	0.63	0.007
Plate	1.73	0.019
Box	1.38	0.015
Cylindrical Vase	0.96	0.013
Conic Vase	1.17	0.018

Table 33 - Control Parameters

Parameters based on Item Code

The time required for the hand-made silk-screen printing operation depends on the shape/size of the raw material and on the drawing printed on. Basically, for each item code in the catalogue the length time process differs. The management of ALPHA has a table linking all the 230 possible codes with the expected time of their printing. The values stored in the corporate database are expected to be accurate with a probability of 95% and a tolerance of + -10% (normal distribution around the indicated average) by ALPHA production manager. Based on that, the parameter values are calculated as follows:

Printing Avg Value indicated in the database

Printing StdDev (***Printing Avg*** * 0,1 / (1,96))

The reliability of this evaluation has been studied using a statistical test. The production of objects 50 for each of the 10 codes items showed in Table 34 has been timed.

Item Code	Category	Sample	Serigraphy [sec/ (Cycles*#)]		ALPHA Internal Data [sec/ (Cycles*#)]		Sign. Level
			Avg	StdDev	Avg	StdDev	
E4966942	Box	50,00	58,32	2,929	59,00	3,01	1,597
E4905521	Conic Vase	50,00	116,08	5,094	117,00	5,97	1,090
E5337090	Small Glass	50,00	37,50	1,921	38,00	1,94	1,824
E4776550	Bowl	50,00	98,10	3,801	99,00	5,05	1,260
E4830490	Cylindrical Vase	50,00	53,30	2,326	54,00	2,76	1,797
E4835360	Conic Vase	50,00	81,20	4,015	82,00	4,18	1,352
E4776920	Conic Vase	50,00	146,82	6,069	148,00	7,55	1,105
E5325571	cylindrical Vase	50,00	64,34	2,574	65,00	3,32	1,407
E5306954	Glass	50,00	46,34	2,224	47,00	2,40	1,946
E5318630	Plate	50,00	21,72	1,096	22,00	1,12	1,764

Table 34 - Test for Mean

Hypothesis Test for Mean Significance level		
20%	**10%**	**5%**
1.282	1.645	1,96

According to those results, we realize that the values contained in the corporate database can be trusted with a reasonable level of significance. This level increases with the average time, probably due to the fact that shorter operations are more subject to percentage change in the production time. The summary of Production Parameters for the 10 Categories/Reference Items is showed in Table 35.

Reference Item		QUANTITY	Control / (#)		Cleaning / (Cycles*#)		Packaging/(#)		Heating / (Cycles*#)	Set-up Station		Set-up Frame / (Cycles)		Printing / (Cycles*#)	
			Avg [min]	StdDev	Avg [min]	StdDev	Avg [min]	StdDev	Avg [min]	Avg [min]	StdDev	Avg [min]	StdDev	Avg [min]	StdDev
Glass	ITEM1	180	0.22	0.003	0.21	0.002	0.42	0.003	21.00	21.56	4.031	13.78	2.326	0.73	0.003
Small Glass	ITEM2	180	0.11	0.002	0.16	0.001	0.33	0.003	9.51	21.56	4.031	13.78	2.326	0.65	0.002
Bottle	ITEM3	50	0.76	0.020	0.31	0.004	1.31	0.019	13.61	21.56	4.031	13.78	2.326	1.06	0.008
Bowl	ITEM4	50	0.60	0.014	0.44	0.005	1.93	0.022	50.00	21.56	4.031	13.78	2.326	1.67	0.012
Small Bowl	ITEM5	50	0.64	0.015	0.43	0.004	1.09	0.019	50.00	21.56	4.031	13.78	2.326	1.40	0.010
Small Plate	ITEM6	120	0.29	0.006	0.20	0.002	0.63	0.007	22.00	21.56	4.031	13.78	2.326	0.57	0.003
Plate	ITEM7	60	0.52	0.010	0.40	0.004	1.73	0.019	25.16	21.56	4.031	13.78	2.326	1.01	0.007
Box	ITEM8	50	0.59	0.015	0.29	0.004	1.38	0.015	14.17	21.56	4.031	13.78	2.326	0.96	0.007
Cylindrical Vase	ITEM9	50	0.46	0.012	0.36	0.004	0.96	0.013	21.50	21.56	4.031	13.78	2.326	1.11	0.008
Conic Vase	ITEM10	50	0.54	0.019	0.42	0.007	1.17	0.018	49.17	21.56	4.031	13.78	2.326	1.77	0.013

Table 35 - Production Parameters

4.2.3 Execution of the Model

The execution of the simulations is based on the link between two files:

1. Arena Simulation Model.
2. Excel Input–Output Database and Analysis Tool.

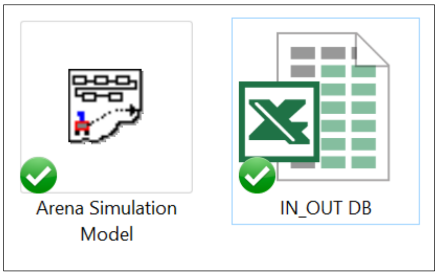

Figure 43 - Files for simulation

The first document "Arena Simulation Model" is a .DOE file, executable under the software Arena Simulation, which contains all the features specified in chapter 4.2. Arena Simulation Model. The second file "IN_OUT DB" is an .XLS file, executable under the software Excel, which allows three main functions:

1. It is the Input Parameter Database: all the parameters listed in Table 35 plus the production schedule time of the items (TArrival Variable) is contained in the first sheet of the .XLS file (See figure 44).

Item #	Item Code	QTY	C/T Control Avg	C/T Control StdD	C/T Cleaning Avg	C/T Cleaning StdD	C/T Packaging Avg	C/T Packaging StdD	C/T Heating	C/O Station Avg	C/O Station StdD	C/O Frame Avg	C/O Frame StdD	C/T Printing Avg	C/T Printing StdD	TArrival [>1]
1	ITEM5	50	0.64	0.015	0.43	0.004	1.09	0.019	50.00	21.56	4.031	13.78	2.326	1.40	0.010	1
2	ITEM5	50	0.64	0.015	0.43	0.004	1.09	0.019	50.00	21.56	4.031	13.78	2.326	1.40	0.010	1
3	ITEM10	50	0.54	0.019	0.42	0.007	1.17	0.018	49.17	21.56	4.031	13.78	2.326	1.77	0.013	1
4	ITEM8	50	0.59	0.015	0.29	0.004	1.38	0.015	14.17	21.56	4.031	13.78	2.326	0.96	0.007	1
5	ITEM8	50	0.59	0.015	0.29	0.004	1.38	0.015	14.17	21.56	4.031	13.78	2.326	0.96	0.007	1
6	ITEM4	50	0.60	0.014	0.44	0.005	1.93	0.022	50.00	21.56	4.031	13.78	2.326	1.67	0.012	1
7	ITEM9	50	0.46	0.012	0.36	0.004	0.96	0.013	21.50	21.56	4.031	13.78	2.326	1.11	0.008	1
8	ITEM7	60	0.52	0.010	0.40	0.004	1.73	0.019	25.16	21.56	4.031	13.78	2.326	1.01	0.007	1
9	ITEM7	60	0.52	0.010	0.40	0.004	1.73	0.019	25.16	21.56	4.031	13.78	2.326	1.01	0.007	1
10	ITEM8	50	0.59	0.015	0.29	0.004	1.38	0.015	14.17	21.56	4.031	13.78	2.326	0.96	0.007	1
11	ITEM4	50	0.60	0.014	0.44	0.005	1.93	0.022	50.00	21.56	4.031	13.78	2.326	1.67	0.012	481
12	ITEM1	180	0.22	0.003	0.21	0.002	0.42	0.003	21.00	21.56	4.031	13.78	2.326	0.73	0.003	481
13	ITEM4	50	0.60	0.014	0.44	0.005	1.93	0.022	50.00	21.56	4.031	13.78	2.326	1.67	0.012	481
14	ITEM3	50	0.76	0.020	0.31	0.004	1.31	0.019	13.61	21.56	4.031	13.78	2.326	1.06	0.008	481
15	ITEM5	50	0.64	0.015	0.43	0.004	1.09	0.019	50.00	21.56	4.031	13.78	2.326	1.40	0.010	481

Figure 44 - Input Parameters Database

2. It is the Output Database. The execution times of each object which undergoes the manufacturing process are stored in the sheet shown in Figure 45.

Item #	Time Inlet#1	Time Control#1	Time Control#2	Time Control#3	Time Control#4	Time Control#5	Time Printing#1	Time Printing#2	Time Printing#3	Time Printing#4
1	**1.00**	83.46	84.12	115.28	115.28	**123.28**	**124.08**	287.45	306.67	306.67
2	**1.00**	62.49	63.10	94.27	94.27	**106.50**	**107.30**	277.58	298.58	298.58
3	**1.00**	62.25	62.83	89.43	89.43	**100.26**	**100.83**	263.47	290.22	290.22
4	**1.00**	53.74	54.32	83.46	83.46	**91.46**	**92.26**	203.20	220.26	220.26
5	**1.00**	32.49	33.11	62.25	62.25	**67.92**	**68.72**	68.72	88.13	88.13
6	**1.00**	32.49	33.07	62.49	62.49	**76.72**	**77.52**	77.52	106.92	106.92
7	**1.00**	30.73	31.17	53.74	53.74	**59.41**	**59.97**	59.97	85.23	85.23
8	**1.00**	1.00	1.52	32.49	32.49	**40.49**	**41.05**	41.05	63.09	63.09
9	**1.00**	1.00	1.52	32.49	32.49	**46.72**	**47.29**	47.29	73.08	73.08
10	**1.00**	1.00	1.59	30.73	30.73	**30.73**	**31.53**	31.53	48.58	48.58

Figure 45 – Extract of the Output Database

3. It automatically generates the Performance Reports. The database is used by a number of VBA macro that automatically extracts process KPI. In the file there are several sheets, helping clarifying all the process peculiarities (time of execution, use of resources, and Work In Progress inventory). The two most general tables are showed below in Figure 46 and T Figure 47.

Item #	**C/T Total**	**Tran Time Total**	**C/O Total**	**Wait Time Total**	**Process Lead Time**	**ITEM**	**Time In**	**Time Out**	**Quantity**
1	105.41	4.53	53.05	606.86	769.84	ITEM5	1.00	770.84	50.00
2	105.34	4.53	46.43	526.46	682.76	ITEM5	1.00	683.76	50.00
3	104.46	4.40	58.31	667.09	834.26	ITEM10	1.00	835.26	50.00
4	32.80	4.53	44.09	593.25	674.67	ITEM8	1.00	675.67	50.00
5	32.84	4.53	51.22	296.13	384.72	ITEM8	1.00	385.72	50.00
6	106.72	4.53	56.70	407.48	575.43	ITEM4	1.00	576.43	50.00
7	47.35	4.40	60.32	320.85	432.93	ITEM9	1.00	433.93	50.00
8	55.37	4.40	47.12	330.23	437.12	ITEM7	1.00	438.12	60.00
9	55.39	4.40	55.85	347.73	463.37	ITEM7	1.00	464.37	60.00
10	32.78	4.53	45.20	238.73	321.25	ITEM8	1.00	322.25	50.00

Figure 46 - Performance Table Process

Table Inventory

	A Control		**B** Printing#1		**C** Heating #1		**D** Cleaning #1		**E** Printing#2		**F** Heating #2		**G** Cleaning #2		**H** Packaging		**I** Shipping	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Wait. Time	54.17	3.55	290.74	96.64	88.67	1.99	1.18	0.26	32.65	0.82	87.76	1.84	1.00	0.24	49.82	2.42	69.60	1.04
WIP Inv.	91.18	6.51	490.22	167.70	149.37	8.31	1.99	0.45	55.00	2.96	147.83	7.90	1.69	0.42	83.88	5.03	117.19	5.16

Table Process

	A Control		**B** Printing#1		**C** Heating #1		**D** Cleaning #1		**E** Printing#2		**F** Heating #2		**G** Cleaning #2		**H** Packaging	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Process time	0.47	0.01	1.09	0.03	27.49	1.23	0.32	0.01	1.09	0.03	27.49	1.23	0.32	0.01	1.09	0.03
Trans. time			0.71	0.01	0.88	0.00			0.88	0.00	0.88	0.00			1.13	0.00
C/O time			35.31	0.35					13.77	0.15						

Table Resources

	A Control **H** Packaging		**B** Printing#1 **E** Printing#2		**C** Heating #1 **G** Cleaning #2		**H** Packaging	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Resources Utilization	67.67%	1.17%	68.13%	1.07%	55.10%	2.61%	45.42%	0.79%
Resources Quantity	3		6		2		2	

Table KPIs

	A VA Time		**B** Trans Time		**C** C/O Time		**D** Wait Time		**E** Cycle Time		**F** WIP Inventory		**G** Res. Utilization	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
DP01 – As-Is Hmix; 100%	59.37	1.74	4.48	0.01	49.08	0.38	675.61	96.79	788.53	96.80	1138.36	168.40	62.5%	0.8%

Figure 47 - Performance Table KPIs

The aim of the first simulation in Arena is the completion of a comparison between calculated data and real production records. The operation of the model is subject to some preliminary decisions that are made about setting up the experiment and some degrees of freedom the software allows. Below all the settings for this specific case are described:

Model and Inputs

The "As-Is" configuration of the system has been tested with a random generated list of entries at 100% of its load capability. This is the current logic for planning, since the market is pushing for a just-in-time approach. In addition to that, the insufficient demand does not require a higher manufacturing flow that would be achievable optimizing the sequence and reducing tooling time.

Maximum capability

The maximum capability of the system has been calculated through a dedicated simulation in which the departments were saturated for 500 simulation days. The average production in this test (10.2 batches a day) is well aligned with the expected limit of the plant that is producing 6.9 beaches/day at about 70% of the achievable load, as the manager suggested.

Resources

The operators currently employed at the plant are 13: 3 employees are shared by the Control and Packaging department, 6 work in the Printing area, 3 in the heating control section and 2 in the cleaning department.

Statistical features

The experiment is based on 30 repetitions of an operating period of 20 working days. The warm-up of the system is ensured by 5 starting days when the recorded data are not considered.

The overall experiment parameters are summarized below:

Factory Layout	As-Is
Resources Control and Packaging	3 Operators
Resources Printing	6 Operators
Resources Heating	2 Operators
Resources Cleaning	2 Operators
Warm-up period	five days
Sample	20 working days
Repetitions	30
Mix of products	High (random list)
Production Capacity	High (10.2 Batches/day)

Table 36 - Simulation Parameters

The analysis of the performance simulated by the model is fully automatic and operated by VBA code. This study begins with the control of the inventory level, since its trend shows if the system has been subjected to excessive stress. In case of overproduction, the level of WIP should increase steadily. Furthermore, the storage of products, along with the production cycle, is directly related to waiting time, spent for each item. For this reason, the increase in stocks has a double negative effect on overall system performance: frozen assets and high cycle times. The total simulation time has been 600 days (plus 5 days dedicated to warm up but not considered). The inventory trend during the period is showed in Figure 47.

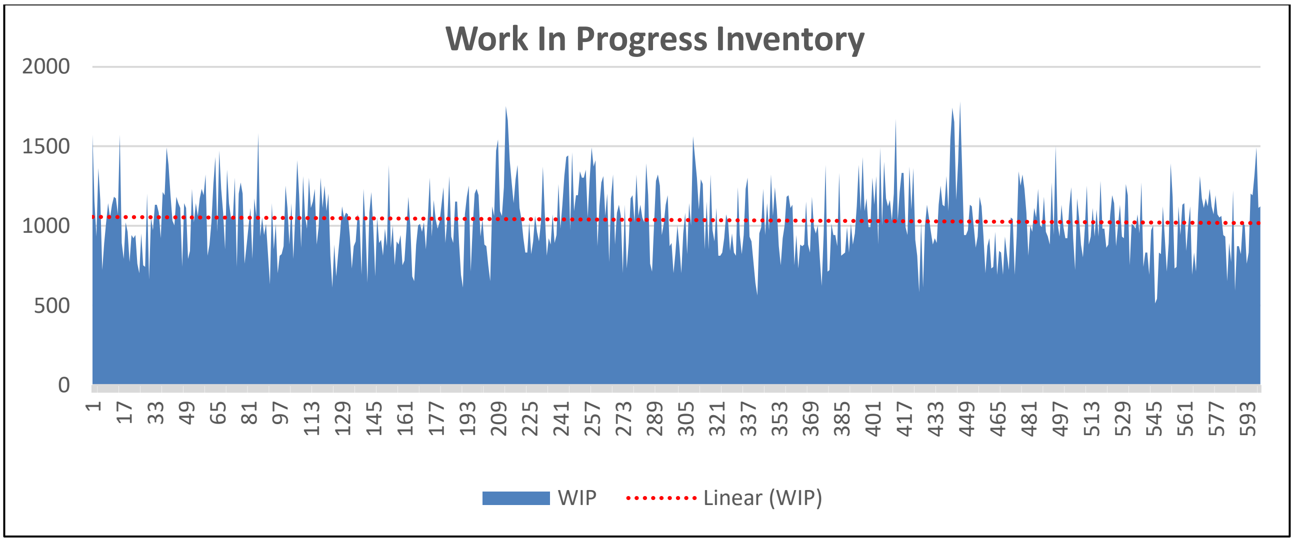

Figure 48 - WIP Inventory

The average Working-In-Progress Inventory of the manufacturing department is 1138 items (marked in red) and the expected waiting time of the whole process for each item is 676 minutes. Details on the calculation are provided below:

	Control		Printing x 2		Heating x 2		Cleaning x 2		Packaging		Shipping	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Wait. Time	54.17	3.55	161.70	24.36	88.22	0.96	1.09	0.12	49.82	2.42	69.60	1.04
WIP Inv.	91.18	6.51	272.61	42.67	148.60	4.05	1.84	0.22	83.88	5.03	117.19	5.16

Table 37 - Waiting times and WIP

From the database of the production times (an example is showed in Figure 45), we can deduce the statistics on process times, transport and waiting for each department. This detailed analysis is useful in the verification of the impacts that a redesign of the plant has on performance. The data relating to the first simulation are presented in Table 38.

	Control		Printing		Heating		Cleaning		Packaging	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Process time	0.47	0.01	1.09	0.01	27.49	0.62	0.32	0.00	1.09	0.03
Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
C/O time			24.54	0.13						

Table 38 - Process, Transport, and C/O times

Analyzing the database of the times from another perspective, it is possible to determine the level of use of the operators in the various functions. This significant result highlights the overall performance of the system and suggests possible improvements/balancing. The data are showed in Table 39.

	Control		Printing		Heating		Cleaning	
	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Resources Utilization	67.67%	1.17%	68.13%	1.07%	55.10%	2.61%	45.42%	0.79%
Resources Quantity	**3**		**6**		**2**		**2**	

Table 39 - Resources Utilization

Based on the metrics listed in the tables above, the main Key Performance Indicators can be calculated to summarize in a few objective factors how the configuration under investigation is acting. These indicators are effective for comparison of several new possible configurations and their extensive use is described in the following chapter. Below the values of the current simulation:

Process Time		Transport time		C/O time		Wait Time		Cycle Time		WIP Inventory		Res. Utilization	
Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
59.4	1.7	4.5	0.1	49.1	0.4	675.6	96.8	788.5	96.8	1138.4	168.4	62.5%	0.8%

Table 40 - Key Performance Indicators

At the conclusion of the analysis, the statistics on the number of batches is presented to verify that the model has processed the correct quantity of batches. The values given in Table 41 confirm the correct execution of the experiment.

Avg Batched Quantity / Day	10.22
Std Dev Batches Quantity / Day	0.02

Table 41 - Batches / day

5 Simulations and Results

This chapter, which represents the core of the research, describes the simulation study on the connections between Flexibility and Lean Thinking. The first section provides an overview on the Experiment's Design. The second paragraph describes the details of all the simulations carried out in Arena Simulations. The conclusions of the experiments are illustrated in the last paragraph, where evidences are reported and commented.

5.1 Overview on the Design of Experiment

The theoretical base of the experimental design was introduced in Chapter 3 and, in particular, the factorial approach was presented in section 3.4.2. Factorial Design. This technique is used in the present doctoral research to plan and optimize the computer simulations. The details of the simulations' structure are presented below, along with the basic assumptions and the statistical objectives.

5.1.1 Assumptions and Statistical Objectives

The current production system of ALPHA has been exhaustively analyzed in the previous chapters and its own computer modeling was completed and tested. Some Key Performance Indicators have been identified to allow guesses and comparative evaluations. The level flexibility, which represents the main investigation area of the PhD, can be evaluated on the basis of the correlation between KPIs and some distinguishing factors. As mentioned in paragraph 2.1. Manufacturing Flexibility, the most interesting types of flexibility for a SME are possibly:

1. Volume Flexibility: Quantity of goods produced in a defined time frame.
2. Mix Flexibility: Variability of product types in the production schedule.

For this reason, the present research focuses on these two categories, characterized by the units of measures, described in Table 42.

Flexibility Type	Unit of measure	Range of measure
Volume	$\frac{Production\ Level}{Maximum\ Capacity}$	[0%; 100%]
Mix	*Quantity of Identical Batches in the Sequence.*	[All Identical Products; Random Production List]

Table 42 - Flexibility parameters

The production system can run within an operating window, whose vertices are the extreme conditions of flexibility parameters. The two-dimensional area is represented in Figure 49. The possible operations in the theoretical field are restricted to a part of the graph (highlighted in green)

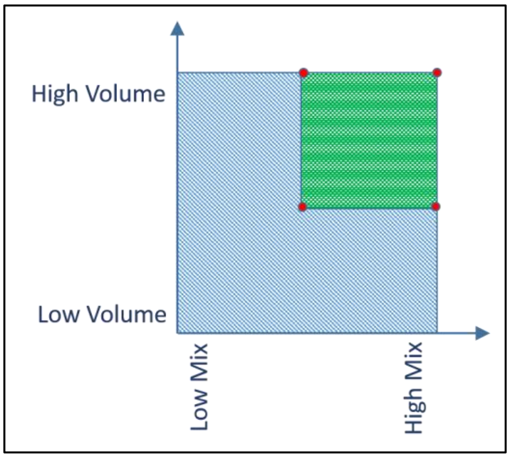

Figure 49 - Operating Windows

which delimits the field where the establishment acts. In fact, the minimum acceptable level of the production company is about 50% and the market does not allow an optimization of higher production sequence of 2 batches identical in series. The intersections between the real limits in the possible ranges of measure are marked with red spots.

The coordinates of these 4 points are listed below:

1. Production at 100% of maximum capacity; Random Production List
2. Production at 100% of maximum capacity; 2 batches identical in series
3. Production at 50% of maximum capacity; Random Production List
4. Production at 50% of maximum capacity; 2 batches identical in series

The flexibility of a system can be computed from a set of Key Performance Indicators, evaluated on the four operating points mentioned above.

Some of the KPIs introduced in paragraph 4.2.3. Execution of the Model will be adopted for the investigation on flexibility. The process, needed to quantify the flexibility level, leads to the calculation of three objective indicators through 5 steps.

Step 1 – Calculation of Maximum Capacity

The calculation of the maximum capacity is required to define the list of products to be operated by the simulation model at the 2 level of Volume (100% and 50% of maximum capacity). Two dummy productive lists (one for Low-Mix and one for High-Mix), requiring the manufacturing of 25 batches a day, are used to determine how many items the system can actually process.

Step 2 – Generation of the Production Lists

Each plant configuration, for which an assessment on the flexibility is required, must be simulated according to 4 sequences of objects that are generated, so that the pairs of Mix and Volume indicated above are considered. The additional criteria to generate the lists are the following: 5 days of warm up, actual simulation of 600 days (the period divided into 30 samples of 20 days each).

Step 3 – Simulation of the System

The Arena model, which represents a specific system configuration, is subjected to 4 simulations, each one completed considering the 4 lists previously generated. The results obtained from the four tests are checked to exclude eventual errors. In particular, the trend of WIP Inventory is checked (its steadiness is a reliable indicator for the study).

Step 4 – Storage of Data

The main key performance indicators are automatically generated and stored. For each of the 30 samples (index "***s***") in the 4 simulations of a production arrangement (index "***t***"), the values of Production Capacity, WIP inventory, Resource Utilization are recorded in a specific KPIs Summary. These parameters, as anticipated in paragraph 2.2.1 Introduction to Manufacturing Flexibility, are sensible indicators for the evaluation of MF.

	Production Capacity Avg Values (Arrays)	**WIP Inventory** Avg Values (Arrays)	**Resources Utilization** Avg Values (Arrays)
1# - 100%; Random	$BD\#1A_{s,t}$	$WIP\#1A_{s,t}$	$RU\#1A_{s,t}$
2# - 100%; 2 Batches	$BD\#2A_{s,t}$	$WIP\#2A_{s,t}$	$RU\#2A_{s,t}$
3# - 50%; Random	$BD\#3A_{s,t}$	$WIP\#3A_{s,t}$	$RU\#3A_{s,t}$
4# - 50%; 2 Batches	$BD\#4A_{s,t}$	$WIP\#4A_{s,t}$	$RU\#4A_{s,t}$

Table 43 – KPIs Summary of the 4 operating points

Step 5 – Flexibility Indicators

The flexibility of the system is assessed on the base of key responses. These responses are calculated starting from the KPIs Summary presented above (Table 44) as follow:

$R_{1,s,t}$= ***CAPACITY*** $\frac{(BD\#2A_{s,t} - BD\#1A_{s,t})}{Max \text{ Capacity}}$

Capacity Response is defined as the normalized difference in capacity between a system operating with low mix and with high mix.

Considering the measurement of VOLF provided by Parker and Wirth (Parker & Wirth, 1999), this response evaluates the stability of VOLF for a system subjected to mix uncertainty.

$R_{2,s,t}$= ***INVENTORY*** $\frac{(WIP\#1A_{s,t} + WIP\#2A_{s,t}) - (WIP\#3A_{s,t} + WIP\#4A_{s,t})}{2 * Max\ Capacity}$

Inventory Response is defined as the normalized difference in inventory between a system operating at maximum capacity and at half capacity.

Considering the relation between inventory and MIXF suggested by authors like Bartezzaghi (Bartezzaghi & Turco, 1989) (Mendonça Tachizawa & Giménez Thomsen, 2007) (A. Sohal et al., 1989), this response evaluates the stability of MIXF for a system subject also to volume uncertainty.

$R_{3,s,t}$= ***UTILIZATION*** $\frac{(RU\#3A_{s,t} + RU\#4A_{s,t})}{(RU\#1A_{s,t} + RU\#2A_{s,t})}$

Utilization Response is defined as the rate between resource utilization of a system operating at half capacity and at maximum capacity.

Considering the measurement of VOLF provided by Parker and Wirth (Parker & Wirth, 1999), this response evaluates the VOLF of a system.

Table 44 - Definition of Responses

This 5-step process can be completed for the comparison of different production layouts, shaped according to one or more LM techniques. The planning of the simulations with different models is discussed in the following section of the chapter.

5.1.2 Outline of the Simulations

Law and Kelton describe the 2^k Factorial Design in their book "Simulation Modeling and Analysis", providing guidance and examples. The study of this doctoral research perfectly fits with a 2^k approach where the quantity of parameters (Index "$\boldsymbol{K}$") is 3. Starting from the current configuration of the plant (named "As-Is"), the introduction of the most promising Lean Techniques is investigated by simulations. From a flexibility point of view, SMED (Single Minute Exchange of Die), JITds (Just in Time delivery by suppliers) and Cellular Manufacturing are considered the most favorable ones. To evaluate the combined effects of these methods (defined as factors), the factorial approach is creating the following table base for the 2^3Design Points:

	Factors					
	F_1= SMED		**F_2= JITds**		**F_3= CELLMFG**	
#1 – *As-Is*	$C_{1,1}$ =	-	$C_{1,2}$ =	-	$C_{1,3}$ =	-
#2 – *SMED*	$C_{2,1}$ =	+	$C_{2,2}$ =	-	$C_{2,3}$ =	-
#3 – *JITds*	$C_{3,1}$ =	-	$C_{3,2}$ =	+	$C_{3,3}$ =	-
#4 – *SMED + JITds*	$C_{4,1}$ =	+	$C_{4,2}$ =	+	$C_{4,3}$ =	-
#5 – *CELLMFG*	$C_{5,1}$ =	-	$C_{5,2}$ =	-	$C_{5,3}$ =	+
#6 – *CELLMFG + SMED*	$C_{6,1}$ =	+	$C_{6,2}$ =	-	$C_{6,3}$ =	+
#7 – *CELLMFG + JITds*	$C_{7,1}$ =	-	$C_{7,2}$ =	+	$C_{7,3}$ =	+
#8 – *CELLMFG + SMED+ JITds*	$C_{8,1}$ =	+	$C_{8,2}$ =	+	$C_{8,3}$ =	+

Table 45 - 2^3Design Points

The factors are commented below:

1. The *SMED* technique is interpreted in the context of this research as a method to reduce the setup time of the print stations, the setup time of the frames for the screen printing and the required handlings for the control of raw materials. The adoption of this technique is linked to the investments needed to modernize tools and equipment, currently used in the operations.
2. The adoption of *JITds* is based on the principle that raw materials must be received at the exact moment they are required, unlike the current situation whereby they are received once a day. The use of such a system entails that the supply chain can satisfy this requirement. Otherwise the possible reduction in the inventory would be simply transferred from a buffer inside the production system to an external warehouse.
3. The restructuring of the layout according to the concept of *Cellular Manufacturing* involves a major reorganization of functions. The factory is no more divided into departments, but organized into individual, self-sufficient production units. The transition requires investments for the adjustment of the layout, the training of the resources (who will need to play multiple

roles) and a period in which the facility must operate at a reduced capacity to allow the restructuring.

As explained in the previous section, each of the 30 samples of the 8 design points can be associated to 3 parameters: Response CAPACITY, Response INVENTORY and Response UTILIZATION.

The effect of a Lean Techniques ($\boldsymbol{F_n}$) on a Response ($\boldsymbol{R_{r,s,t}}$) can be calculated following the procedure described by Law and Kelton:

$$\boldsymbol{effect_{n,r}} = \frac{(\boldsymbol{C_{1,n}} * \boldsymbol{R_{r,s,1}} + \boldsymbol{C_{2,n}} * \boldsymbol{R_{r,s,2}} + \dots + \boldsymbol{C_{8,n}} * \boldsymbol{R_{r,s,8}})}{\boldsymbol{4}}$$

Furthermore, the interaction of 2 Lean Techniques ($\boldsymbol{F_n}, \boldsymbol{F_o}$) on a Response ($\boldsymbol{R_{r,s,t}}$) can be calculated using the following formula:

$$\boldsymbol{interaction_{n,o,r}} = \frac{(\boldsymbol{C_{1,n}} * \boldsymbol{C_{1,o}} * \boldsymbol{R_{r,s,1}} + \boldsymbol{C_{2,n}} * \boldsymbol{C_{2,o}} * \boldsymbol{R_{r,s,2}} + \dots + \boldsymbol{C_{8,n}} * \boldsymbol{C_{8,o}} * \boldsymbol{R_{r,s,8}})}{\boldsymbol{4}}$$

In the next paragraph the execution of the experiment is illustrated, with an accurate description of the simulations and the post processing on their results.

5.2 Description of the Experiment

This section of the chapter illustrates the execution of simulations of different models, representing variations to the case As-Is. These possible variants, differing on the numerous techniques using lean, are examined and catalogued. Subsequently, the results of this analysis are discussed to draw conclusions.

5.2.1 Simulations in Arena

As mentioned above, the plant layouts to be investigated are 2^3. The 6 steps process showed in paragraph 5.1.1. Assumptions and Statistical Objectives is described below for each of the 8 configurations. The standard evaluation boards for all layouts, along with the experiment parameters and its results are indicated as follows.

Configuration #1 – As-Is

The configuration number 1 is called "As-Is", no Lean Technique is introduced into the system. This model reflects the company's current state. The Value Stream Map of the configuration is showed in Figure 50.

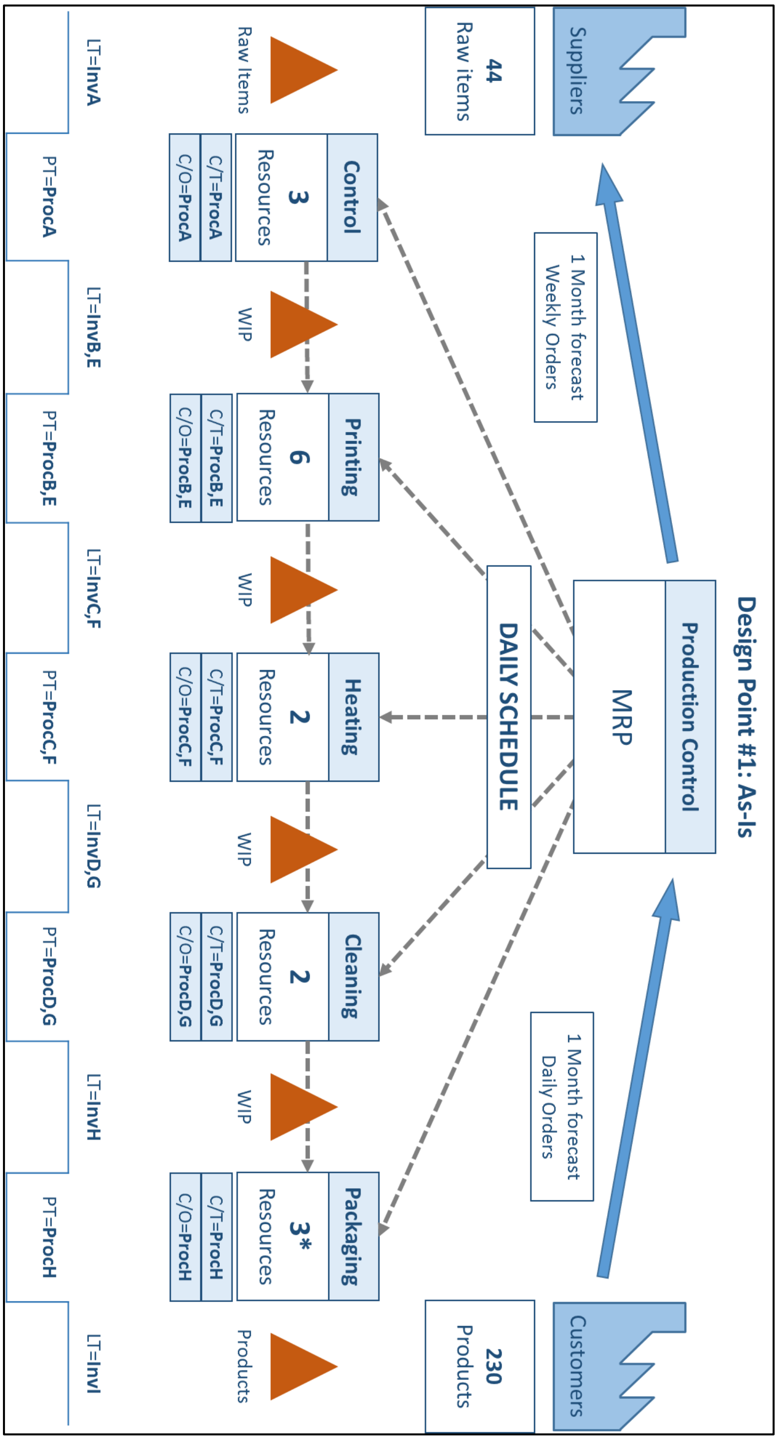

Figure 50 - VSM Design Point: #1 As-Is

Res. Control / Packaging	3	Res. Heating	2
Res. Printing 100% / 50%	6 / 3	Res. Cleaning	2

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 46.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	54.17	3.55	161.70	24.36	88.22	0.96	1.09	0.12	49.82	2.42	69.60	1.04
	WIP Inv.	91.18	6.51	272.61	42.67	148.60	4.05	1.84	0.22	83.88	5.03	117.19	5.16
Simulation #2 High Volume / Low Mix	Waiting Time	207.90	135.88	158.61	11.95	102.11	3.74	2.35	0.17	230.26	132.35	69.86	1.90
	WIP Inv.	449.92	273.99	349.84	28.32	225.00	9.38	5.18	0.44	499.27	264.11	153.93	7.49
Simulation #3 Low Volume / High Mix	Waiting Time	19.32	1.96	122.91	11.66	83.43	1.26	0.10	0.05	31.34	0.91	69.40	1.87
	WIP Inv.	16.69	1.92	106.76	12.22	72.18	2.96	0.09	0.04	27.09	1.85	59.95	3.58
Simulation #4 Low Volume / Low Mix	Waiting Time	33.94	3.29	171.36	28.90	83.03	2.11	0.17	0.05	36.99	2.41	69.63	1.78
	WIP Inv.	37.59	4.16	193.42	39.51	92.51	6.17	0.19	0.06	41.17	5.38	77.31	7.09

Table 46 - Waiting times and WIP

The other results, relevant to the Process, Transport, and C/O times, are presented in Table 47.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.47	0.01	1.09	0.01	27.49	0.62	0.32	0.00	1.09	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			24.54	0.13						
Simulation #2 High Volume / Low Mix	Process time	0.47	0.01	1.09	0.01	27.67	0.66	0.32	0.00	1.10	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.14	0.09						
Simulation #3 Low Volume / High Mix	Process time	0.47	0.02	1.09	0.02	27.30	0.77	0.32	0.01	1.09	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			24.57	0.16						
Simulation #4 Low Volume / Low Mix	Process time	0.48	0.03	1.09	0.02	27.43	0.85	0.32	0.01	1.11	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.21	0.15						

Table 47 - Process, Transport, and C/O times

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 48. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	WIP Inventory Avg Values (600 Days)	Resources Utilization Avg Values (600 Days)
1# - 100%; Random	10.22	1138	62.53%
2# - 100%; 2 Batches	13.98	2263	79.56%
3# - 50%; Random	5.13	462	41.62%
4# - 50%; 2 Batches	6.99	728	52.99%

Table 48 - Production Capacity, WIP Inventory, Resources Utilization (DP#1)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 49.

	Response Capacity	*Response Inventory*	*Response Utilization*
DP#1 – Sample1	0.27	112	0.68
DP#1 – Sample2	0.27	145	0.66
DP#1 – Sample3	0.27	155	0.67
DP#1 – Sample4	0.27	130	0.65
DP#1 – Sample5	0.27	97	0.68
DP#1 – Sample6	0.27	151	0.63
DP#1 – Sample7	0.27	148	0.65
DP#1 – Sample8	0.27	135	0.65
DP#1 – Sample9	0.27	168	0.64
DP#1 – Sample10	0.27	188	0.70
DP#1 – Sample11	0.27	177	0.70
DP#1 – Sample12	0.27	232	0.70
DP#1 – Sample13	0.27	292	0.67
DP#1 – Sample14	0.27	225	0.71
DP#1 – Sample15	0.27	195	0.67
DP#1 – Sample16	0.27	156	0.65
DP#1 – Sample17	0.27	166	0.66
DP#1 – Sample18	0.27	172	0.64
DP#1 – Sample19	0.27	118	0.65
DP#1 – Sample20	0.27	119	0.66
DP#1 – Sample21	0.27	148	0.68
DP#1 – Sample22	0.27	141	0.71
DP#1 – Sample23	0.27	130	0.66
DP#1 – Sample24	0.27	149	0.67
DP#1 – Sample25	0.27	103	0.67
DP#1 – Sample26	0.27	136	0.67
DP#1 – Sample27	0.27	171	0.67
DP#1 – Sample28	0.27	189	0.62
DP#1 – Sample29	0.27	162	0.64
DP#1 – Sample30	0.27	136	0.66

Table 49 - Reponses for 30 Samples (DP#1)

Configuration #2 – SMED

The configuration number 2 is called "SMED". The Value Stream Map of the configuration is showed in Figure 51.

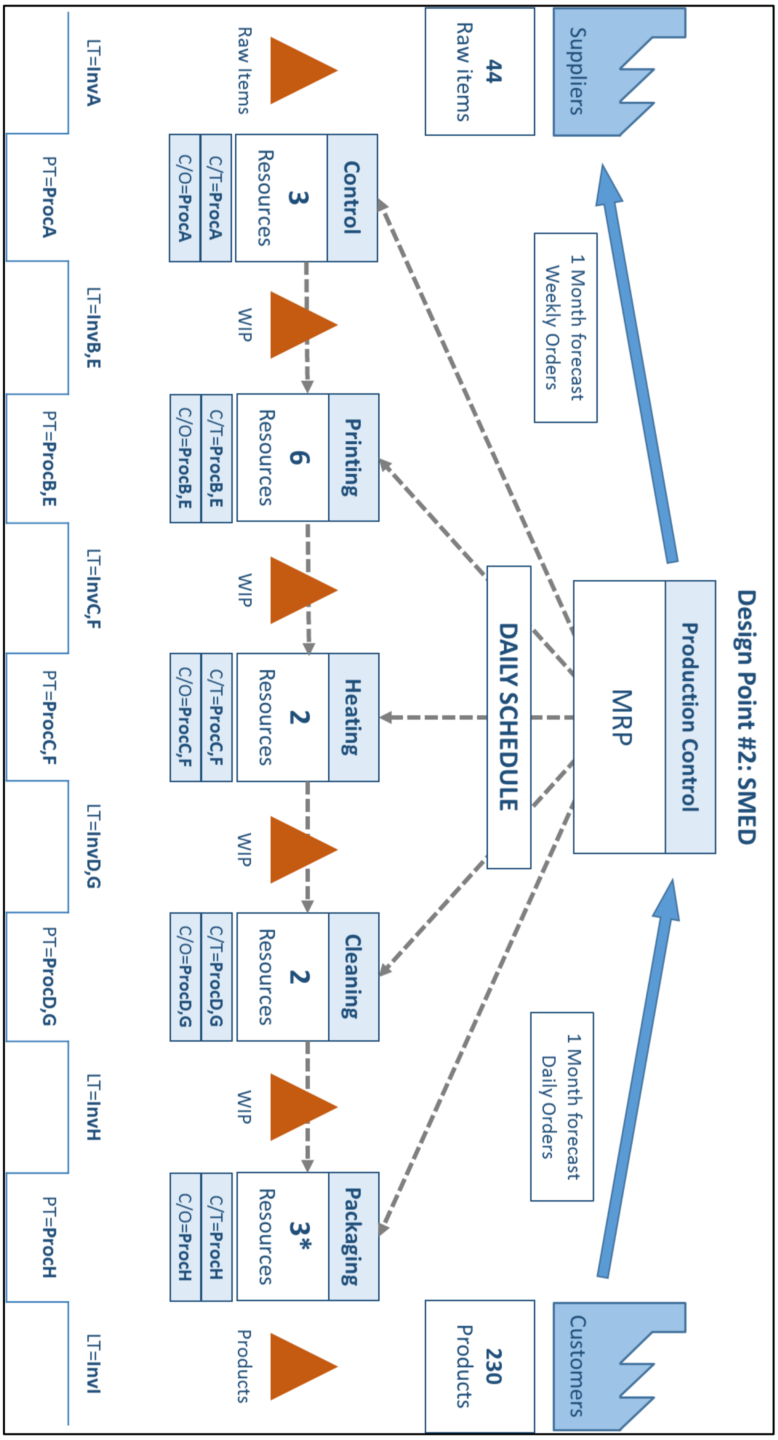

Figure 51 - VSM Design Point: #2 SMED

Res. Control / Packaging	3	Res. Heating	2
Res. Printing 100% / 50%	6 / 3	Res. Cleaning	2

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 50.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	38.44	3.57	190.04	46.67	89.63	1.06	1.44	0.16	40.68	1.68	69.81	1.22
	WIP Inv.	70.57	6.48	348.11	84.54	164.71	4.02	2.66	0.31	74.74	4.15	128.23	4.80
Simulation #2 High Volume / Low Mix	Waiting Time	74.39	6.32	134.66	7.59	107.18	4.91	2.81	0.28	78.36	7.26	69.60	1.28
	WIP Inv.	179.76	20.16	325.97	23.79	258.47	12.26	6.83	0.80	189.33	22.42	167.98	9.30
Simulation #3 Low Volume / High Mix	Waiting Time	12.62	1.59	112.72	9.68	84.20	1.42	0.16	0.06	30.58	1.20	70.12	1.43
	WIP Inv.	11.80	1.44	106.13	11.19	79.02	3.58	0.15	0.06	28.67	2.33	65.69	4.13
Simulation #4 Low Volume / Low Mix	Waiting Time	23.05	2.23	138.75	9.93	84.62	1.60	0.28	0.06	33.49	1.33	69.90	2.03
	WIP Inv.	28.35	3.35	171.93	17.63	104.31	5.43	0.35	0.08	41.24	3.96	86.03	7.11

Table 50 - Waiting times and WIP (DP#2)

The other results, relevant to the Process, Transport, and C/O times, are presented in Table 51.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.24	0.01	1.08	0.01	27.39	0.41	0.32	0.00	1.09	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.30	0.05						
Simulation #2 High Volume / Low Mix	Process time	0.24	0.01	1.09	0.01	27.50	0.50	0.32	0.00	1.09	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.59	0.05						
Simulation #3 Low Volume / High Mix	Process time	0.24	0.01	1.09	0.02	27.74	0.68	0.32	0.00	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.31	0.07						
Simulation #4 Low Volume / Low Mix	Process time	0.24	0.01	1.09	0.02	28.02	0.83	0.32	0.01	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.60	0.06						

Table 51 - Process, Transport, and C/O times

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of the 600 simulated days, are listed in Table 52. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	**WIP Inventory** Avg Values (600 Days)	**Resources Utilization** Avg Values (600 Days)
1# - 100%; Random	10.99	1305	61.04%
2# - 100%; 2 Batches	14.82	1720	79.33%
3# - 50%; Random	5.50	477	40.75%
4# - 50%; 2 Batches	7.41	709	52.73%

Table 52 - Production Capacity, WIP Inventory, Resources Utilization (DP#2)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 53.

	Response Capacity	*Response Inventory*	*Response Utilization*
DP#2 – Sample1	0.26	95	0.66
DP#2 – Sample2	0.26	124	0.65
DP#2 – Sample3	0.26	94	0.67
DP#2 – Sample4	0.26	99	0.66
DP#2 – Sample5	0.26	117	0.67
DP#2 – Sample6	0.26	117	0.67
DP#2 – Sample7	0.26	114	0.65
DP#2 – Sample8	0.26	148	0.68
DP#2 – Sample9	0.26	115	0.66
DP#2 – Sample10	0.26	118	0.65
DP#2 – Sample11	0.26	122	0.65
DP#2 – Sample12	0.26	117	0.65
DP#2 – Sample13	0.26	109	0.64
DP#2 – Sample14	0.26	92	0.66
DP#2 – Sample15	0.26	58	0.70
DP#2 – Sample16	0.26	112	0.66
DP#2 – Sample17	0.26	133	0.67
DP#2 – Sample18	0.26	121	0.67
DP#2 – Sample19	0.26	114	0.67
DP#2 – Sample20	0.26	88	0.67
DP#2 – Sample21	0.26	141	0.64
DP#2 – Sample22	0.26	142	0.66
DP#2 – Sample23	0.26	169	0.66
DP#2 – Sample24	0.26	169	0.70
DP#2 – Sample25	0.26	173	0.69
DP#2 – Sample26	0.26	161	0.66
DP#2 – Sample27	0.26	128	0.69
DP#2 – Sample28	0.26	137	0.70
DP#2 – Sample29	0.26	176	0.68
DP#2 – Sample30	0.26	118	0.66

Table 53 - Reponses for 30 Samples (DP#2)

Configuration #3 – JITds

The configuration number 3 is called "JITds". The Value Stream Map of the configuration is showed in Figure 52.

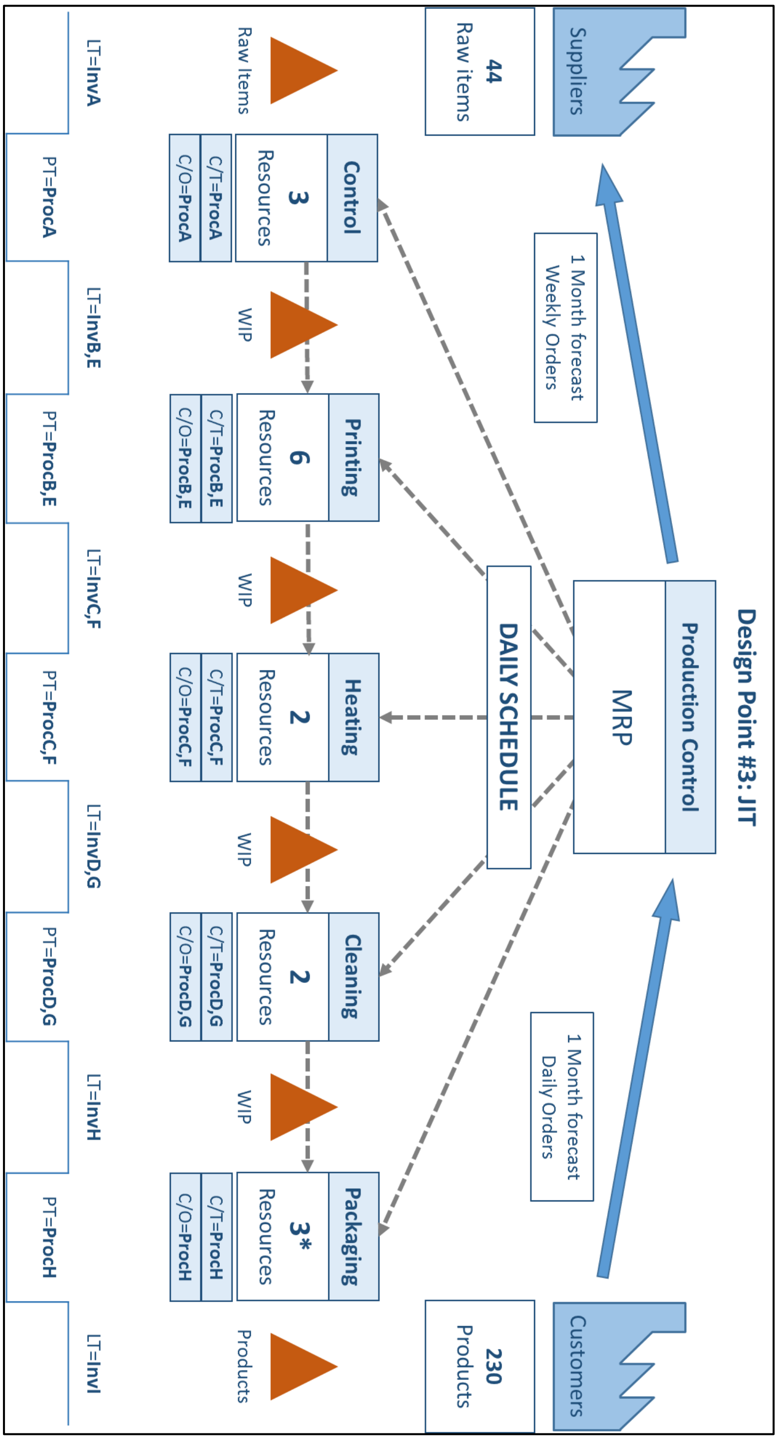

Figure 52 - VSM Design Point: #3 JITds

Res. Control / Packaging	3	Res. Heating	2
Res. Printing 100% / 50%	6 / 3	Res. Cleaning	2

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 54.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	4.19	0.88	87.09	12.92	88.44	0.96	1.11	0.14	35.59	0.86	69.39	1.32
	WIP Inv.	7.08	1.49	147.61	22.60	149.75	4.21	1.89	0.26	60.23	2.82	117.47	6.08
Simulation #2 High Volume / Low Mix	Waiting Time	147.73	126.59	144.71	18.72	99.76	3.82	2.16	0.18	177.89	124.42	69.86	1.88
	WIP Inv.	319.86	259.69	319.99	40.08	220.99	7.89	4.79	0.46	386.86	252.79	154.90	7.19
Simulation #3 Low Volume / High Mix	Waiting Time	0.13	0.22	61.27	7.45	82.92	1.31	0.12	0.07	28.91	0.96	69.39	1.82
	WIP Inv.	0.11	0.19	52.99	7.66	71.27	3.05	0.10	0.06	24.83	1.98	59.55	3.70
Simulation #4 Low Volume / Low Mix	Waiting Time	0.55	0.33	134.23	25.76	82.79	2.09	0.20	0.06	29.82	1.37	69.64	1.75
	WIP Inv.	0.62	0.38	154.09	35.64	93.47	6.09	0.23	0.07	33.63	4.07	78.34	6.80

Table 54 - Waiting times and WIP (DP#3)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 55.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.47	0.01	1.10	0.01	27.92	0.49	0.32	0.00	1.09	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			24.59	0.11						
Simulation #2 High Volume / Low Mix	Process time	0.47	0.01	1.09	0.01	27.67	0.65	0.32	0.00	1.10	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.17	0.08						
Simulation #3 Low Volume / High Mix	Process time	0.47	0.02	1.09	0.02	27.30	0.73	0.32	0.01	1.09	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			24.54	0.17						
Simulation #4 Low Volume / Low Mix	Process time	0.48	0.03	1.09	0.02	27.43	0.86	0.32	0.01	1.11	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.20	0.14						

Table 55 - Process, Transport, and C/O times (DP#3)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 56. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	**WIP Inventory** Avg Values (600 Days)	**Resources Utilization** Avg Values (600 Days)
1# - 100%; Random	10.25	783	63.05%
2# - 100%; 2 Batches	13.98	1953	80.06%
3# - 50%; Random	5.13	333	41.35%
4# - 50%; 2 Batches	6.99	608	53.68%

Table 56 - Production Capacity, WIP Inventory, Resources Utilization (DP#3)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 57.

	Response Capacity	Response Inventory	Response Utilization
DP#3 – Sample1	0.27	89	0.66
DP#3 – Sample2	0.27	125	0.66
DP#3 – Sample3	0.27	134	0.67
DP#3 – Sample4	0.27	116	0.66
DP#3 – Sample5	0.27	74	0.67
DP#3 – Sample6	0.27	112	0.63
DP#3 – Sample7	0.27	105	0.66
DP#3 – Sample8	0.27	106	0.66
DP#3 – Sample9	0.27	124	0.65
DP#3 – Sample10	0.27	164	0.67
DP#3 – Sample11	0.27	157	0.69
DP#3 – Sample12	0.27	218	0.68
DP#3 – Sample13	0.27	251	0.67
DP#3 – Sample14	0.27	206	0.69
DP#3 – Sample15	0.27	164	0.68
DP#3 – Sample16	0.27	138	0.66
DP#3 – Sample17	0.27	135	0.66
DP#3 – Sample18	0.27	160	0.66
DP#3 – Sample19	0.27	98	0.66
DP#3 – Sample20	0.27	101	0.65
DP#3 – Sample21	0.27	142	0.67
DP#3 – Sample22	0.27	81	0.68
DP#3 – Sample23	0.27	86	0.65
DP#3 – Sample24	0.27	116	0.67
DP#3 – Sample25	0.27	89	0.67
DP#3 – Sample26	0.27	64	0.66
DP#3 – Sample27	0.27	106	0.66
DP#3 – Sample28	0.27	176	0.64
DP#3 – Sample29	0.27	127	0.65
DP#3 – Sample30	0.27	88	0.65

Table 57 - Reponses for 30 Samples (DP#3)

Configuration #4 – SMED + JITds

The configuration number 4 is called "SMED + JITds". The Value Stream Map of the configuration is showed in Figure 53.

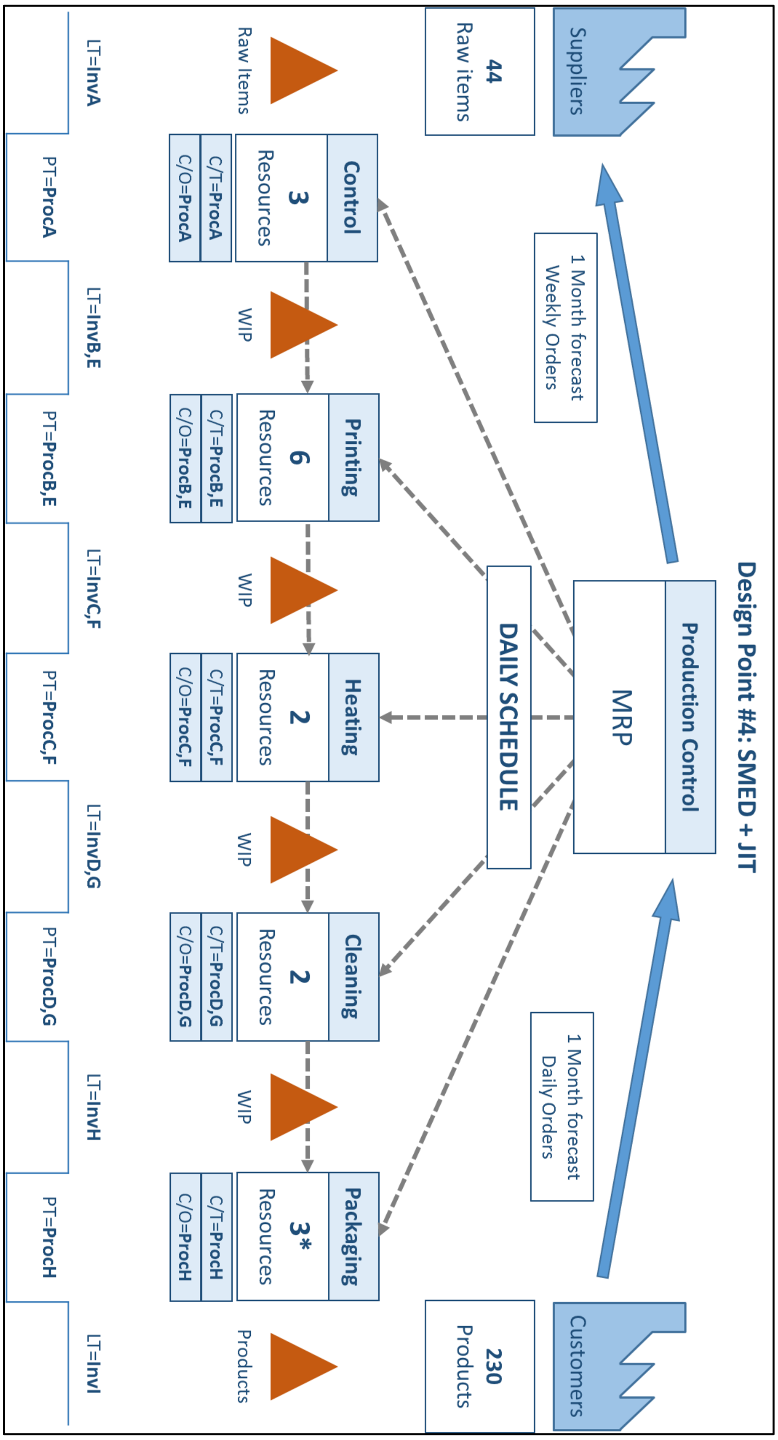

Figure 53 - VSM Design Point: #4 SMED + JITds

Res. Control / Packaging	3		Res. Heating	2
Res. Printing 100% / 50%	6 / 3		Res. Cleaning	2

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 58.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	4.02	0.84	55.45	8.30	89.07	1.03	1.31	0.13	33.95	0.85	69.58	0.88
	WIP Inv.	7.35	1.41	102.47	16.92	163.71	5.96	2.42	0.28	62.34	3.77	127.75	6.89
Simulation #2 High Volume / Low Mix	Waiting Time	28.39	9.37	101.48	14.92	106.12	4.80	2.66	0.32	58.83	9.67	69.59	1.50
	WIP Inv.	68.43	22.57	243.98	35.03	255.26	10.20	6.43	0.80	141.75	23.69	167.68	8.56
Simulation #3 Low Volume / High Mix	Waiting Time	0.38	0.28	47.07	5.67	83.72	1.25	0.13	0.05	29.10	1.09	69.94	1.48
	WIP Inv.	0.35	0.27	44.83	6.43	79.27	3.47	0.12	0.05	27.56	2.52	66.11	4.06
Simulation #4 Low Volume / Low Mix	Waiting Time	0.93	0.35	95.74	8.22	84.36	1.27	0.23	0.06	29.81	0.95	70.22	1.68
	WIP Inv.	1.14	0.43	118.95	12.44	104.49	4.01	0.29	0.07	36.91	2.82	86.91	5.44

Table 58 - Waiting times and WIP (DP#4)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 59.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.24	0.01	1.09	0.01	27.66	0.40	0.32	0.00	1.09	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.28	0.06						
Simulation #2 High Volume / Low Mix	Process time	0.24	0.01	1.09	0.02	27.70	0.69	0.32	0.00	1.10	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.60	0.04						
Simulation #3 Low Volume / High Mix	Process time	0.23	0.01	1.07	0.02	27.09	0.72	0.32	0.01	1.09	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.31	0.09						
Simulation #4 Low Volume / Low Mix	Process time	0.24	0.01	1.09	0.02	27.81	1.02	0.32	0.01	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.58	0.06						

Table 59 - Process, Transport, and C/O times (DP#4)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 60. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	**WIP Inventory** Avg Values (600 Days)	**Resources Utilization** Avg Values (600 Days)
1# - 100%; Random	10.99	735	61.51%
2# - 100%; 2 Batches	14.82	1389	79.79%
3# - 50%; Random	5.49	342	40.41%
4# - 50%; 2 Batches	7.41	572	53.06%

Table 60 - Production Capacity, WIP Inventory, Resources Utilization (DP#4)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 61.

	Response Capacity	Response Inventory	Response Utilization
DP#4 – Sample1	0.26	72	0.66
DP#4 – Sample2	0.26	73	0.66
DP#4 – Sample3	0.26	74	0.67
DP#4 – Sample4	0.26	97	0.66
DP#4 – Sample5	0.26	106	0.65
DP#4 – Sample6	0.26	106	0.67
DP#4 – Sample7	0.26	115	0.65
DP#4 – Sample8	0.26	74	0.66
DP#4 – Sample9	0.26	68	0.64
DP#4 – Sample10	0.26	84	0.65
DP#4 – Sample11	0.26	75	0.66
DP#4 – Sample12	0.26	73	0.65
DP#4 – Sample13	0.26	60	0.68
DP#4 – Sample14	0.26	72	0.65
DP#4 – Sample15	0.26	64	0.67
DP#4 – Sample16	0.26	84	0.68
DP#4 – Sample17	0.26	74	0.65
DP#4 – Sample18	0.26	94	0.66
DP#4 – Sample19	0.26	77	0.66
DP#4 – Sample20	0.26	121	0.66
DP#4 – Sample21	0.26	82	0.67
DP#4 – Sample22	0.26	83	0.65
DP#4 – Sample23	0.26	58	0.67
DP#4 – Sample24	0.26	78	0.69
DP#4 – Sample25	0.26	80	0.65
DP#4 – Sample26	0.26	81	0.67
DP#4 – Sample27	0.26	83	0.65
DP#4 – Sample28	0.26	73	0.68
DP#4 – Sample29	0.26	81	0.65
DP#4 – Sample30	0.26	83	0.68

Table 61 - Reponses for 30 Samples (DP#4)

Configuration #5 – CELLMFG

The configuration number 5 is called "CELLMFG“. The Value Stream Map of the configuration is showed in Figure 54.

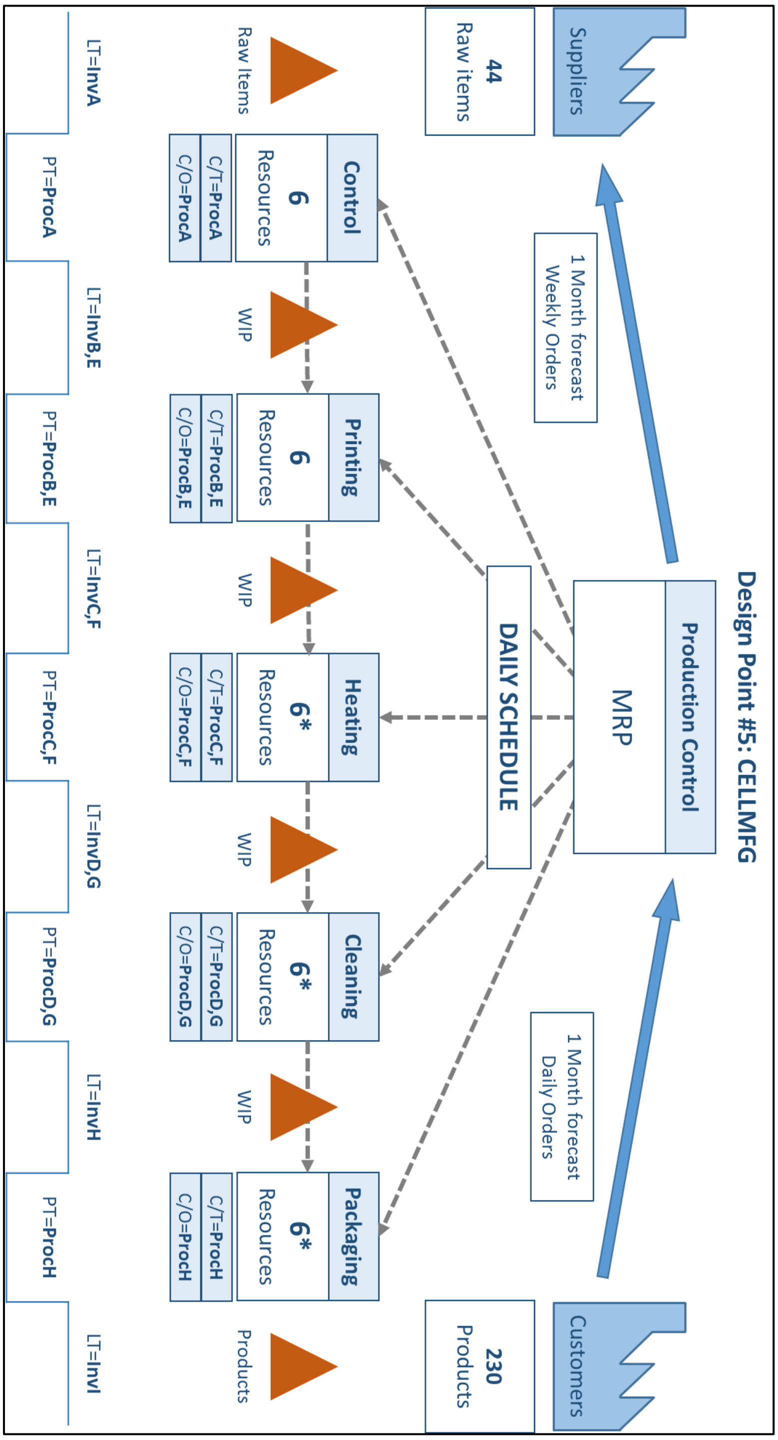

Figure 54 - VSM Design Point: #5 CELLMFG

Res. Printing 100% / 50% | 6 / 3 |

Res. Others 100% / 50% | 6 / 3 |

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 62.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1	Waiting Time	22.71	1.52	133.33	12.04	89.93	1.13	3.18	0.31	36.65	1.17	69.56	1.22
High Volume / High Mix	WIP Inv.	37.21	2.59	219.26	22.14	147.54	4.61	5.22	0.51	60.12	3.69	114.01	4.58
Simulation #2	Waiting Time	49.59	4.38	160.73	5.62	110.57	2.43	19.77	1.96	57.54	4.95	69.51	1.46
High Volume / Low Mix	WIP Inv.	106.42	9.42	345.55	16.14	237.61	8.23	42.37	4.11	123.58	11.79	149.36	8.43
Simulation #3	Waiting Time	24.38	2.67	124.43	14.49	88.50	1.52	4.41	0.69	31.38	1.26	69.36	1.62
Low Volume / High Mix	WIP Inv.	20.06	2.27	103.19	13.95	73.14	3.77	3.62	0.56	25.91	2.53	57.21	4.46
Simulation #4	Waiting Time	51.44	6.84	286.66	27.38	115.11	4.98	24.95	4.27	52.69	8.91	69.38	1.63
Low Volume / Low Mix	WIP Inv.	55.31	6.54	310.06	32.82	124.27	6.81	26.71	4.32	56.79	9.76	74.85	4.96

Table 62 - Waiting times and WIP (DP#5)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 63.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1	Process time	0.47	0.01	1.09	0.01	27.60	0.48	0.32	0.00	1.10	0.04
High Volume / High	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
Mix	C/O time			24.59	0.13						
Simulation #2	Process time	0.48	0.01	1.09	0.02	27.67	0.78	0.32	0.00	1.10	0.04
High Volume / Low	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
Mix	C/O time			19.18	0.09						
Simulation #3	Process time	0.47	0.02	1.08	0.02	27.02	0.77	0.32	0.01	1.09	0.06
Low Volume / High	Trans. time			0.79	0.09	0.88	0.00			1.13	0.00
Mix	C/O time			24.63	0.19						
Simulation #4	Process time	0.46	0.03	1.08	0.02	27.15	0.97	0.32	0.01	1.08	0.06
Low Volume / Low	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
Mix	C/O time			19.19	0.11						

Table 63 - Process, Transport, and C/O times (DP#5)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 64. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	WIP Inventory Avg Values (600 Days)	Resources Utilization Avg Values (600 Days)
1# - 100%; Random	9.85	955	66.13%
2# - 100%; 2 Batches	13.39	1630	84.46%
3# - 50%; Random	4.93	463	66.17%
4# - 50%; 2 Batches	6.70	1109	82.81%

Table 64 - Production Capacity, WIP Inventory, Resources Utilization (DP#5)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 65.

	Response Capacity	Response Inventory	Response Utilization
DP#5 – Sample1	0.26	102	0.96
DP#5 – Sample2	0.26	90	0.97
DP#5 – Sample3	0.26	58	1.01
DP#5 – Sample4	0.26	58	0.98
DP#5 – Sample5	0.26	52	1.03
DP#5 – Sample6	0.26	60	0.99
DP#5 – Sample7	0.26	82	1.00
DP#5 – Sample8	0.26	80	0.98
DP#5 – Sample9	0.26	92	1.00
DP#5 – Sample10	0.26	88	0.97
DP#5 – Sample11	0.26	72	0.96
DP#5 – Sample12	0.26	76	0.97
DP#5 – Sample13	0.26	111	0.97
DP#5 – Sample14	0.26	93	0.97
DP#5 – Sample15	0.26	72	1.03
DP#5 – Sample16	0.26	32	1.05
DP#5 – Sample17	0.26	80	0.98
DP#5 – Sample18	0.26	62	0.99
DP#5 – Sample19	0.26	63	1.00
DP#5 – Sample20	0.26	78	0.98
DP#5 – Sample21	0.26	60	0.99
DP#5 – Sample22	0.26	71	0.99
DP#5 – Sample23	0.26	56	0.99
DP#5 – Sample24	0.26	53	1.01
DP#5 – Sample25	0.26	65	1.02
DP#5 – Sample26	0.26	92	1.01
DP#5 – Sample27	0.26	118	0.98
DP#5 – Sample28	0.26	89	1.01
DP#5 – Sample29	0.26	72	0.97
DP#5 – Sample30	0.26	91	0.96

Table 65 - Reponses for 30 Samples (DP#5)

Configuration #6 – CELLMFG + SMED

The configuration number 6 is called "CELLMFG + SMED". The Value Stream Map of the configuration is showed in Figure 55.

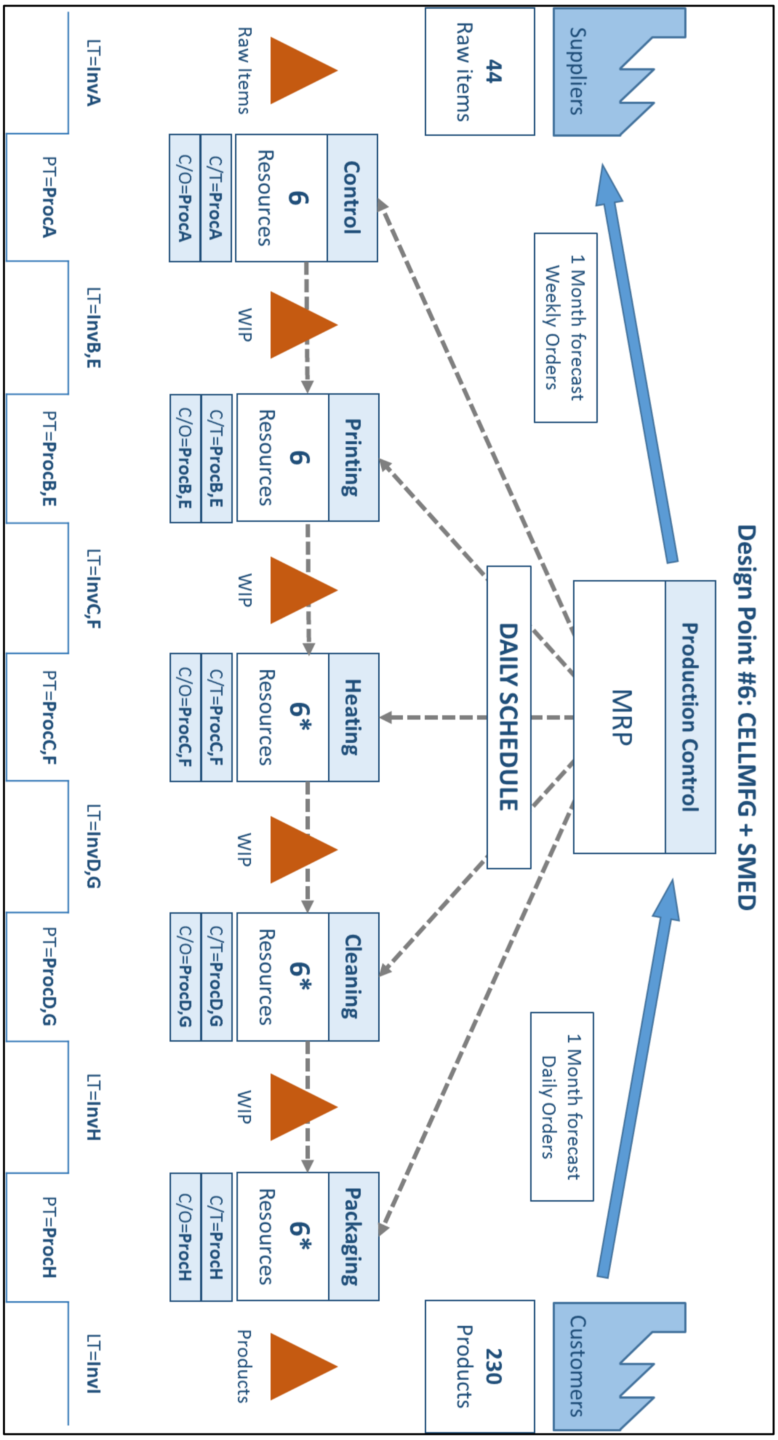

Figure 55 - VSM Design Point: #6 CELLMFG + SMED

Res. Printing 100% / 50% | 6 / 3

Res. Others 100% / 50% | 6 / 3

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 66.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	17.17	1.67	128.07	13.42	88.02	1.03	2.33	0.31	36.66	1.06	69.73	1.35
	WIP Inv.	30.84	3.24	230.72	26.53	158.15	4.38	4.17	0.53	65.83	3.12	125.22	5.16
Simulation #2 High Volume / Low Mix	Waiting Time	41.49	4.86	143.37	7.26	100.13	2.34	12.94	1.53	53.31	3.00	69.25	1.43
	WIP Inv.	94.91	11.89	328.64	21.05	229.43	10.10	29.57	3.51	122.03	9.90	158.56	10.83
Simulation #3 Low Volume / High Mix	Waiting Time	18.92	3.06	128.83	20.92	88.25	1.63	3.84	0.57	31.35	1.06	69.64	1.72
	WIP Inv.	17.36	2.92	118.99	21.41	81.12	3.66	3.51	0.50	28.79	2.25	63.90	3.61
Simulation #4 Low Volume / Low Mix	Waiting Time	42.51	6.37	201.62	29.02	104.47	3.33	18.47	2.77	46.23	4.93	70.11	2.69
	WIP Inv.	47.82	5.94	228.88	35.28	118.33	6.19	20.72	2.88	52.26	6.21	79.36	6.57

Table 66 - Waiting times and WIP (DP#6)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 67.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.24	0.01	1.09	0.01	27.73	0.53	0.32	0.00	1.10	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.29	0.07						
Simulation #2 High Volume / Low Mix	Process time	0.24	0.01	1.10	0.02	27.85	0.66	0.32	0.00	1.09	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.61	0.05						
Simulation #3 Low Volume / High Mix	Process time	0.24	0.01	1.09	0.02	27.45	0.75	0.32	0.01	1.09	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.30	0.07						
Simulation #4 Low Volume / Low Mix	Process time	0.24	0.01	1.10	0.03	28.12	1.05	0.32	0.01	1.10	0.07
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.59	0.07						

Table 67 - Process, Transport, and C/O times (DP#6)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 68. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	WIP Inventory Avg Values (600 Days)	Resources Utilization Avg Values (600 Days)
1# - 100%; Random	10.75	1008	65.45%
2# - 100%; 2 Batches	14.17	1551	82.36%
3# - 50%; Random	5.38	517	66.08%
4# - 50%; 2 Batches	7.09	915	81.51%

Table 68 - Production Capacity, WIP Inventory, Resources Utilization (DP#6)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 69.

	Response Capacity	Response Inventory	Response Utilization
DP#6 – Sample1	0.24	104	0.98
DP#6 – Sample2	0.24	101	1.01
DP#6 – Sample3	0.24	64	1.02
DP#6 – Sample4	0.24	86	0.98
DP#6 – Sample5	0.24	82	0.97
DP#6 – Sample6	0.24	94	1.00
DP#6 – Sample7	0.24	117	0.96
DP#6 – Sample8	0.24	109	0.97
DP#6 – Sample9	0.24	64	1.01
DP#6 – Sample10	0.24	83	0.98
DP#6 – Sample11	0.24	91	1.01
DP#6 – Sample12	0.24	73	1.01
DP#6 – Sample13	0.24	62	1.02
DP#6 – Sample14	0.24	62	0.99
DP#6 – Sample15	0.24	61	1.03
DP#6 – Sample16	0.24	69	1.02
DP#6 – Sample17	0.24	62	1.01
DP#6 – Sample18	0.24	79	1.01
DP#6 – Sample19	0.24	81	0.99
DP#6 – Sample20	0.24	116	0.97
DP#6 – Sample21	0.24	103	0.99
DP#6 – Sample22	0.24	90	1.00
DP#6 – Sample23	0.24	96	1.04
DP#6 – Sample24	0.24	127	0.98
DP#6 – Sample25	0.24	63	1.01
DP#6 – Sample26	0.24	53	1.03
DP#6 – Sample27	0.24	30	1.01
DP#6 – Sample28	0.24	63	0.95
DP#6 – Sample29	0.24	39	1.03
DP#6 – Sample30	0.24	62	0.99

Table 69 - Reponses for 30 Samples (DP#6)

Configuration #7 – CELLMFG + JITds

The configuration number 7 is called "CELLMFG + JITds". The Value Stream Map of the configuration is showed in Figure 56.

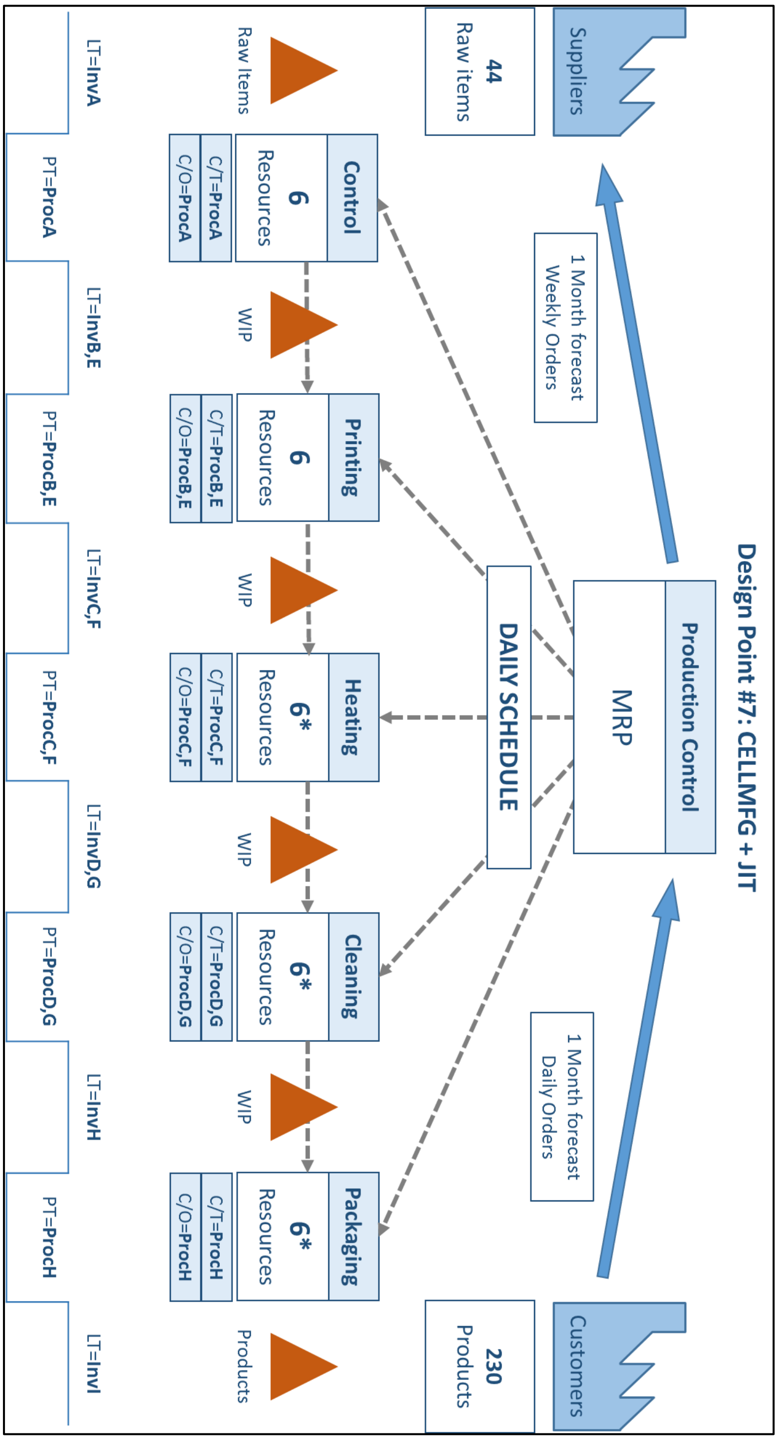

Figure 56 - VSM Design Point: #7 CELLMFG + JITds

Res. Printing 100% / 50% | 6 / 3

Res. Others 100% / 50% | 6 / 3

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 70.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	0.58	0.22	46.81	1.80	85.62	0.99	0.74	0.12	32.12	0.64	69.28	1.50
	WIP Inv.	0.94	0.36	77.07	4.12	140.95	4.80	1.22	0.19	52.86	3.24	113.98	6.31
Simulation #2 High Volume / Low Mix	Waiting Time	9.56	2.38	94.44	4.01	94.74	1.31	9.53	1.17	41.36	2.00	69.93	1.34
	WIP Inv.	20.91	4.59	208.20	12.58	208.55	7.02	20.83	2.27	90.94	5.49	153.84	8.33
Simulation #3 Low Volume / High Mix	Waiting Time	3.73	1.15	61.44	7.15	86.26	1.32	2.92	0.49	30.88	0.84	69.58	1.73
	WIP Inv.	3.06	0.89	50.71	6.44	71.09	2.64	2.40	0.39	25.44	1.76	57.30	3.48
Simulation #4 Low Volume / Low Mix	Waiting Time	16.31	4.20	151.30	27.04	99.12	2.56	16.22	2.02	43.61	3.73	69.38	2.23
	WIP Inv.	17.36	4.08	162.62	30.25	106.35	5.31	17.27	1.94	46.68	4.54	74.39	6.19

Table 70 - Waiting times and WIP (DP#7)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 71.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.47	0.01	1.09	0.02	27.59	0.57	0.32	0.00	1.09	0.04
	Trans. time			0.79	0.09	0.88	0.00			1.13	0.00
	C/O time			24.61	0.11						
Simulation #2 High Volume / Low Mix	Process time	0.47	0.02	1.09	0.02	27.67	0.62	0.32	0.00	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.20	0.09						
Simulation #3 Low Volume / High Mix	Process time	0.48	0.02	1.10	0.02	27.97	0.83	0.32	0.00	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			24.54	0.19						
Simulation #4 Low Volume / Low Mix	Process time	0.48	0.02	1.09	0.02	27.64	0.91	0.32	0.01	1.10	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			19.17	0.11						

Table 71 - Process, Transport, and C/O times (DP#7)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 72. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	**WIP Inventory** Avg Values (600 Days)	**Resources Utilization** Avg Values (600 Days)
1# - 100%; Random	9.85	606	66.24%
2# - 100%; 2 Batches	13.39	1141	85.97%
3# - 50%; Random	4.93	334	66.75%
4# - 50%; 2 Batches	6.69	711	84.85%

Table 72 - Production Capacity, WIP Inventory, Resources Utilization (DP#7)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 73.

	Response Capacity	Response Inventory	Response Utilization
DP#7 – Sample1	0.26	50	1.01
DP#7 – Sample2	0.26	56	0.99
DP#7 – Sample3	0.26	43	1.02
DP#7 – Sample4	0.26	77	0.96
DP#7 – Sample5	0.26	43	0.99
DP#7 – Sample6	0.26	36	0.98
DP#7 – Sample7	0.26	21	0.98
DP#7 – Sample8	0.26	40	0.99
DP#7 – Sample9	0.26	52	1.00
DP#7 – Sample10	0.26	58	1.00
DP#7 – Sample11	0.26	51	0.99
DP#7 – Sample12	0.26	41	1.01
DP#7 – Sample13	0.26	64	1.00
DP#7 – Sample14	0.26	67	0.97
DP#7 – Sample15	0.26	51	1.00
DP#7 – Sample16	0.26	43	1.02
DP#7 – Sample17	0.26	49	1.02
DP#7 – Sample18	0.26	40	0.99
DP#7 – Sample19	0.26	66	0.98
DP#7 – Sample20	0.26	58	1.00
DP#7 – Sample21	0.26	63	1.01
DP#7 – Sample22	0.26	58	1.01
DP#7 – Sample23	0.26	55	1.01
DP#7 – Sample24	0.26	50	1.01
DP#7 – Sample25	0.26	70	0.98
DP#7 – Sample26	0.26	62	0.99
DP#7 – Sample27	0.26	63	0.98
DP#7 – Sample28	0.26	67	0.97
DP#7 – Sample29	0.26	53	0.99
DP#7 – Sample30	0.26	28	1.02

Table 73 - Reponses for 30 Samples (DP#7)

Configuration #8 – CELLMFG + SMED+ JITds

The configuration number 8 is called "CELLMFG + SMED+ JITds". The Value Stream Map of the configuration is showed in Figure 57.

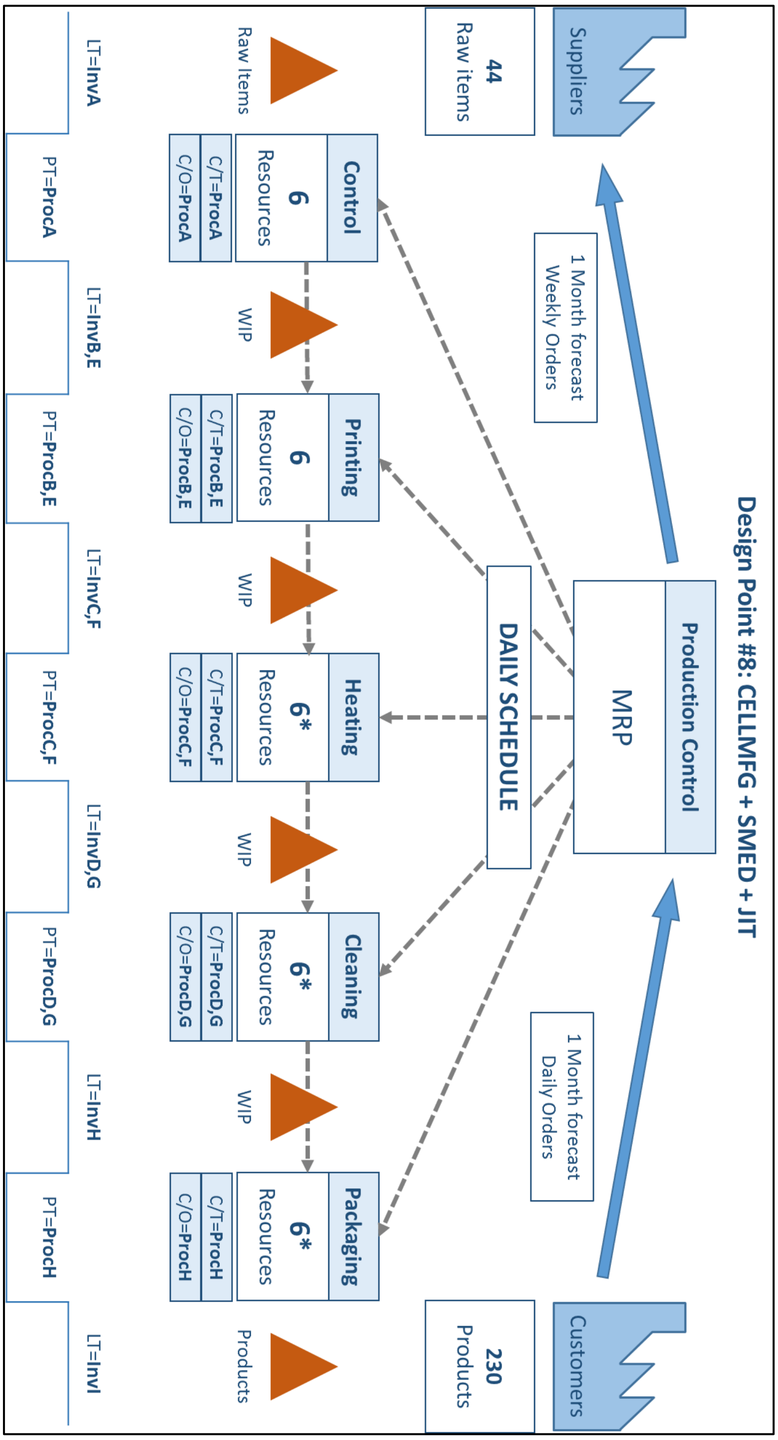

Figure 57 - VSM Design Point: #8 CELLMFG + SMED + JITds

Res. Printing 100% / 50% | 6 / 3

Res. Others 100% / 50% | 6 / 3

The results of the four simulations (associated to the different levels of Volume and Mix flexibilities), about the waiting times and inventory levels, are reported in Table 74.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)		Shipping (I)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Waiting Time	1.19	0.31	41.98	3.86	86.01	1.28	1.04	0.17	32.24	0.90	69.56	0.98
	WIP Inv.	2.13	0.59	75.47	8.38	154.00	5.37	1.86	0.32	57.70	3.48	124.43	5.97
Simulation #2 High Volume / Low Mix	Waiting Time	8.08	2.54	73.00	2.73	92.27	1.92	7.44	1.17	39.61	2.72	69.77	1.56
	WIP Inv.	18.89	5.87	170.87	9.18	215.73	7.92	17.38	2.70	92.59	8.23	163.02	8.98
Simulation #3 Low Volume / High Mix	Waiting Time	4.56	0.89	58.38	16.61	86.28	1.69	3.01	0.47	31.03	0.77	69.60	1.88
	WIP Inv.	4.09	0.82	52.45	14.79	77.63	3.42	2.70	0.41	27.90	2.09	62.56	4.26
Simulation #4 Low Volume / Low Mix	Waiting Time	15.28	3.34	103.74	14.96	96.76	2.64	12.75	1.70	40.91	3.13	69.55	1.68
	WIP Inv.	18.14	4.36	124.07	20.66	114.95	6.55	15.13	2.13	48.58	5.90	82.45	6.68

Table 74 - Waiting times and WIP (DP#8)

The other results, relevant to the Process, Transport, and C/O times, are illustrated in Table 75.

		Control (A)		Printing (B,E)		Heating (C,F)		Cleaning (D,G)		Packaging (H)	
		Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev	Avg	StdDev
Simulation #1 High Volume / High Mix	Process time	0.24	0.01	1.10	0.01	27.70	0.56	0.32	0.00	1.10	0.03
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.28	0.05						
Simulation #2 High Volume / Low Mix	Process time	0.24	0.01	1.09	0.02	27.61	0.75	0.32	0.00	1.10	0.04
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.60	0.05						
Simulation #3 Low Volume / High Mix	Process time	0.24	0.01	1.09	0.02	27.66	0.77	0.32	0.00	1.10	0.05
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			12.32	0.09						
Simulation #4 Low Volume / Low Mix	Process time	0.23	0.01	1.08	0.02	27.08	0.68	0.32	0.01	1.08	0.06
	Trans. time			0.79	0.00	0.88	0.00			1.13	0.00
	C/O time			9.59	0.07						

Table 75 - Process, Transport, and C/O times (DP#8)

The indicators underlying the experiment responses are defined in paragraph 5.1.1. Assumptions and Statistical Objectives: Production Capacity, WIP inventory and Resources Utilization. The average values of these indicators, calculated on the total of 600 simulated days, are listed in Table 76. The Table is intended to provide reference values for the configuration under examination.

	Production Capacity Avg Values (600 Days)	WIP Inventory Avg Values (600 Days)	Resources Utilization Avg Values (600 Days)
1# - 100%; Random	10.75	647	65.27%
2# - 100%; 2 Batches	14.17	1082	83.55%
3# - 50%; Random	5.38	360	65.48%
4# - 50%; 2 Batches	7.08	657	83.22%

Table 76 - Production Capacity, WIP Inventory, Resources Utilization (DP#8)

The calculation of the response list is completed for each of the 30 simulated samples. These responses, which will be used for the comparison of various production configuration, are listed in Table 77.

	Response Capacity	Response Inventory	Response Utilization
DP#8 – Sample1	0.24	57	0.98
DP#8 – Sample2	0.24	44	1.01
DP#8 – Sample3	0.24	56	0.99
DP#8 – Sample4	0.24	52	1.01
DP#8 – Sample5	0.24	48	0.99
DP#8 – Sample6	0.24	73	0.97
DP#8 – Sample7	0.24	39	1.02
DP#8 – Sample8	0.24	59	1.00
DP#8 – Sample 9	0.24	71	0.93
DP#8 – Sample10	0.24	58	1.01
DP#8 – Sample11	0.24	79	0.97
DP#8 – Sample12	0.24	51	1.01
DP#8 – Sample13	0.24	61	0.99
DP#8 – Sample14	0.24	41	1.02
DP#8 – Sample15	0.24	18	1.02
DP#8 – Sample16	0.24	29	1.03
DP#8 – Sample17	0.24	50	1.00
DP#8 – Sample18	0.24	25	1.03
DP#8 – Sample19	0.24	33	1.02
DP#8 - Sample20	0.24	60	1.02
DP#8 – Sample21	0.24	45	1.02
DP#8 – Sample22	0.24	57	0.99
DP#8 – Sample23	0.24	58	0.98
DP#8 – Sample24	0.24	38	1.00
DP#8 – Sample25	0.24	36	1.00
DP#8 – Sample26	0.24	55	1.00
DP#8 – Sample27	0.24	43	1.01
DP#8 – Sample28	0.24	69	0.96
DP#8 – Sample29	0.24	61	0.97
DP#8 – Sample30	0.24	39	1.03

Table 77 - Reponses for 30 Samples (DP#8)

5.2.2 Results of Simulations

The objective of this doctoral research is a practical investigation on Lean Thinking performances. The results of the simulations show the potential of this approach, with specific emphasis to the impact on MIXF and VOLF. Even if evidences are based on a single case, general considerations may be nevertheless formulated about cause-effect relationships and operational modes (Yin, 2009). On the basis of the data presented in the previous paragraph, the answers to the two research questions raised in Chapter 1 are discussed below:

5.2.2.1 HOW does Lean Manufacturing enhance the production in respect to the investments?

The improvements achievable through the use of SMED, JITds and CELLMFG methodologies are well documented in literature. Such benefits have been summarized in section 2.3.3 Lean Techniques. The present simulation study shows that these enhancements, quantified through wide diffused KPIs , i.e. Shah and Ward (Shah & Ward, 2003), Yang-Hua Lian, Hendrik Van Landeghem (Lian & Van Landeghem, 2002), Rother and Shook (Rother & Shook, 1999), also have implications on the flexibility of production systems. Detailed below are the performance gains of SMED, JITds and CELLMFG, presented with an evaluation of the investments required for their introduction:

Single Minute Exchange of Die

Simulations results

SMED reduces the setup times and, consequently, the ratio between the value-added operations and the overall cycle time increases. The general improvements we can get from the Single Minute Exchange of Die can be verified by analyzing the different simulations in the Configuration #1 and #2. The increase in production obtained in the case study is about 6-7% (Table 78).

	Production Capacity (Values calculated on 600 Days sample)	
	Config#1 – As-Is	Config#2 – SMED
1# - 100%; Random	Avg 10.22 (Std Dev 0.02)	Avg 10.99 (Std Dev 0.02)
2# - 100%; 2 Batches	Avg 13.98 (Std Dev 0.02)	Avg 14.82 (Std Dev 0.02)

Table 78 - Production Level: As-Is vs SMED

In connection with the flexibility indicators available in literature and presented in paragraph 2.2.1 Introduction to Manufacturing Flexibility, SMED can be considered suitable for the flexibility enhancement of ALPHA's production system:

- An increase of production capacity of about 6-7%, positively related to VOLF (Parker & Wirth, 1999), is shown in Table 78.
- The reduction of setup time, measure of MIXF (Bateman, 1999), is an intrinsic deliverable of SMED

Table 78 shows also that the difference in productivity between a low-mix and a high-mix scenario drops from 37% of the basic arrangement to 35% of the SMED configuration. This suggests that the introduction of SMED is particularly recommended when a high VOLF is required and, at the same time, the demand mix is not homogeneous.

Typical investment required

The analysis of the return on investment is fundamental to motivate and manage the SMED introduction. In literature, we can find examples that show different level of investments in this technique: in some cases, the introduction of SMED consist in purchasing of spare tools and entails less than 10 K€ (Gallego & Moon, 1995); in others, the replacement of complex equipment requires hundreds K€ (Trovinger & Bohn, 1997). Considering the typical budget limitations, the investment order of magnitude for SMEs is in the middle-low part of this possible range.

Just-in-Time delivery by Suppliers

Simulations results

JITds is commonly used for a general reduction of the inventory at supplier end. The analysis of the company concerned shows that a daily supply of raw materials produces a high stock level. Simulating an advanced replenishing logic (JITds), the stock levels drop significantly, as shown in Table 79.

	WIP Inventory (Values calculated on 600 Days sample)	
	Config#1 – As-Is	Config#3 – JITds
1# - 100%; Random	1138 (Std Dev 105)	783 (Std Dev 33)
3# - 50%; Random	462 (Std Dev 18)	333 (Std Dev 12)

Table 79 - Production Level: As-Is vs JITds

Considering the knowledge available in literature (Bartezzaghi & Turco, 1989), the reduction in inventory contributes to the overall flexibility enhancement of a company:

- Wastages associated with a high level of inlet inventory, including maintenance, obsolescence and double inlet control of raw material, could impact the base costs of ALPHA. Thus, the firm could use JITds for improving VOLF (Parker & Wirth, 1999).

- Low inventory levels are considered linked with high MIXF (Bartezzaghi & Turco, 1989), hence, considering the results presented in Table 79, JITds could be adopted by ALPHA to improve this type of flexibility.

The reduction in inventory is more pronounced when the level of production, and therefore the daily storage of raw materials, is high.

Typical investment required

Regarding the investments required for JITds introduction, in literature we can find case studies where the cash flow related to this Lean upgrade are analyzed. Mejabi (Mejabi, 2003), in his evaluation of a small company, provides an indication of the costs expected to implement this technique. The use of a consultant and other tools can be associated with an expected cost of about 15K€ per year for a period of about 5 years.

Cellular Manufacturing

Simulations results

CELLMFG is a production strategy that consists in a division of the plant into self-sufficient units aimed to facilitate operations. This method, often associated with an increased sharing of tasks and responsibilities, allows a better use of resources.

	Production Capacity (Values calculated on 600 Days sample)	
	Config#1 – As-Is (13 Res)	Config#5 – CELLMFG (12 Res)
1# - 100%; Random	Avg 10.22 (Std Dev 0.02)	Avg 9.85 (Std Dev 0.02)
2# - 100%; 2 Batches	Avg 13.98 (Std Dev 0.02)	Avg 13.39 (Std Dev 0.02)

Table 80 - Production Level: As-Is vs CELLMFG

The simulations indicate that the reorganization of production in cell would allow almost the same level of production with less resources (one less, see Table 80). Table 81 clearly shows the impact of Cellular Manufacturing on the use of resources.

	Utilization Response (Values calculated on 600 Days sample)	
	Config#1 – As-Is (13 Res)	Config#5 – CELLMFG (12 Res)
1# - 100%; Random	Avg 62.53% (Std Dev 0.81%)	Avg 66.13% (Std Dev 0.69%)
3# - 50%; Random	Avg 41.62% (Std Dev 0.75%)	Avg 66.17% (Std Dev 0.89%)

Table 81 - Utilization Response: As-Is vs CELLMFG

The changes in terms of inventory levels predicted for the introduction of CELLMFG are reported in Table 82:

	WIP Inventory (Values calculated on 600 Days sample)	
	Config#1 – As-Is	Config#5 – CELLMFG (12 Res)
1# - 100%; Random	1138 (Std Dev 105)	955 (Std Dev 32)
3# - 50%; Random	462 (Std Dev 18)	463 (Std Dev 21)

Table 82 - Production Level: As-Is vs JITds

The simulations indicate that the reorganization of production in cell would allow almost the same level of production with less resources (one less, see Table 81). On the basis of the results of simulations, the gain in flexibility achievable for ALPHA by introducing CELLMFG are described below:

- The use of CELLMFG is advisable for ALPHA, since the company would be able to operate with less resources at the same maximum capacity. In addition, CELLMFG would permit a variable use of resources in case of down turn, disabling production units without affecting the utilization. These two aspects would impact the base cost of the company enhancing the VOLF (Parker & Wirth, 1999).
- Maximum inventory level, related to the case of 100% capacity/random production list, can be reduced by CELLMFG. The effect is negligible for low production rates, as shown in Table 82. Since the inventory level is considered linked with high MIXF (Bartezzaghi & Turco, 1989), CELLMFG could be adopted by ALPHA to improve this type of flexibility, even if other techniques, such as JITds, could better perform in that direction.

Typical investment required

The introduction of CELLMFG typically requires the re-arrangement of the system layout and the removal of part of the equipment. A study on the financial aspects of a company which is carrying out the introduction of CELLMFG is presented by Sullivan (Sullivan et al., 2002), in his article. This type of improvement, similarly with the SMED, typically requires an initial investment of hundreds K€ and is highly related to the specific case.

5.2.2.2 HOW are Lean Manufacturing and Manufacturing Flexibility connected in the SME context?

In the previous paragraph, the impact of LM techniques on flexibility has been evaluated considering the changes in operational performances. In this section, the evaluation on MIXF and VOLF is deepened using the flexibility indicators introduced in paragraph 5.1.1. Assumptions and Statistical Objectives:

Capacity	$\frac{(Production\ at\ Low\ Mix - Production\ at\ High\ Mix)}{Max\ Capacity}$
Inventory	$\frac{\text{WIP}\ at\ 100\%\ \text{Capacity} - \text{WIP}\ at\ 50\%\ \text{Capacity}}{Max\ Capacity}$
Utilization	$\frac{Resources\ Utilization\ at\ 50\%\ Capacity}{Resources\ Utilization\ at\ 100\%\ Capacity}$

Table 83 - Flexibility indicators summary

The effect of SMED, JITds and CELLMFG on the responses have been calculated through the joined use of factorial DOE and of the 5-step method presented in paragraph 5.1.1. Assumptions and Statistical Objectives.

	Capacity Response		Inventory Response		Utilization Response	
	Avg	StdDev	Avg	StdDev	Avg	StdDev
SMED	(1.6%)	0.3%	(19.85)	29.73	(0.2%)	1.2%
JITds	(0.1%)	0.0%	(31.19)	10.94	(0.0%)	1.1%
CELLMFG	(1.0%)	0.1%	(58.60)	19.42	(33.1%)	1.2%

Table 84 – Effects of Factors on Responses

Lean is considered a good strategy to increase flexibility, as it contributes to equalize the system performances under varying boundary conditions (production mix or volume). Detailed below are some considerations of the data presented above in Table 84:

Single Minute Exchange of Die
Effects on responses SMED successfully impacts the Capacity Response. Considering the data presented in Table 78, this implies that SMED helps flattering the maximum capacity of the system at a high level,

regardless the fluctuation in demand mix. Thus, the introduction of this technique is confirmed as a valid practice for VOLF improvement, especially when MIXF is also required. The effects of this technique on Inventory Response and Utilization Response are not statistically relevant.

Just-in-Time delivery by Suppliers

Effects on responses

JITds has a positive effect on Inventory Response. This means that the significant reduction in stocks level, achievable through this tool as shown in Table 79, is more pronounced when the production is high. Considering that inventory is leveled at a low value, JITds is confirmed as a valuable method for MIXF enhancement (Bartezzaghi & Turco, 1989). The effects of this technique on Capacity Response and Utilization Response are not statistically relevant.

Cellular Manufacturing

Effects on responses

CELLMFG has positive influence on each of the three responses. The impact on Capacity Response and Utilization Response detonates its capability to profitably operate both at high or at reduced production flows. With reference also to the data of Table 80 and Table 81, simulations show the possibility to reduce the factory headcount fix costs, with almost the same performance; this would result in a higher VOLF for ALPHA. Regarding the Inventory Response, this technique helps stabilizing the stock levels at a low level. Despite this, with reference to Table 82, the reduction in inventory appears significant only when the production level is close to the maximum flowrate.

The factorial DOE grants the possibility to verify the eventual interactions between the factors producing effects on responses. That kind of analysis helps in the identification of synergies and is useful to suggest or discourage the joint introduction of different factors.

	Capacity Response		Inventory Response		Utilization Response	
	Avg	StdDev	Avg	StdDev	Avg	StdDev
SMED & JITds	0.0%	0.1%	(4.67)	13.22	(0.2%)	1.1%
JITds & CELLMFG	0.1%	0.0%	4.93	13.69	0.3%	1.1%
CELLMFG & SMED	(0.7%)	0.2%	20.62	23.17	0.4%	1.7%

Table 85 - Interaction of Factors

The data relevant to this work are presented in Table 85 and their interpretation is provided hereafter:

Capacity Response
Interaction of Factors The combined effect of SMED and CELLMFG is sensible in the Capacity Response column, hence the joint introduction of these tools is profitable. Other interactions are judged statistically not significant.

Inventory Response
Interaction of Factors Given the high values of the standard deviations related to fluctuations in levels of inventory, the interactions of factors for the Inventory Response are not statistically evaluable.

Utilization Response
Interaction of Factors Analyzing the last 2 columns of Table 84 and Table 85, it is clear to see that the impact generated by CELLMFG is not comparable with the other ones. For this reason, the analysis on interactions related to Utilization Response is not significant.

5.2.3 Conclusions

This study investigates the connections between Lean Manufacturing and Manufacturing Flexibility within the Small-Medium Enterprise context. Case Research is used to fill the need for experiential evidences about Lean introduction into small companies (Bakås et al., 2011) (Moeuf et al., 2016). In that regard, the cause effect relationship between lean techniques and flexibility enhancement is explored in an uncommon field. A single case approach is leveraged to obtain a detailed analysis and a better view on this topic (Burgess, 1993) (Crotty, 1998) (Voss et al., 2002).

On this basis, the first novel contribution of this research is the gathering of empirical data about the use of Lean for Flexibility improvement in a small firm. The present work focuses on two types of flexibility that are commonly deemed the most important (Hallgren & Olhager, 2009a) (Metternich et al., 2013): MIXF and VOLF. On the basis of the available literature about the above mentioned flexibilities (Parker & Wirth, 1999) (Bateman, 1999) (Mendonça Tachizawa & Giménez Thomsen, 2007) (A. Sohal et al., 1989) (Bartezzaghi & Turco, 1989), the following KPIs have been selected for their measurement: Production Capability, Inventory Level and Resource Utilization. Single Minute Exchange of Die, Just in Time delivery by Suppliers and Cellular Manufacturing are the Lean techniques focused upon this PhD Thesis. The flexibility gains for the company have been evaluated by simulations. Single Minute Exchange of Die produces an improved and stable Production Capability, which entails an enhancement of VOLF; this benefit is particularly remarkable when a high product mix is also needed. Just in Time delivery by Suppliers reduces the Inventory Level, improving the MIXF. Cellular Manufacturing generates a positive effect on Resource Utilization, producing lower fixed costs; this enhances the VOLF, and, indirectly, has a positive effect on the MIXF by harmonizing the inventory levels. Although specific benefits vary from case to case, it can be said that the operational process of Lean Thinking contributes to the competitiveness of the firm under examination.

The second novel contribution of this work is related to the extension of a combined use of Case Research and Computer Simulation to a new field within the operation management. Building on the factorial DoE, a new 5-step method has been developed to apprise the benefits of Lean techniques for Manufacturing Flexibility. The method is designed for a carrying time of one year and permits managers to apprise the deliverables of Lean techniques. The preliminary assessment of achievable benefits is a critical step for the financing of Lean introduction (Sullivan et al., 2002). Building on this, the managerial implications of this research mostly concern the development of an efficient decision making tool. The relative simplicity and cheapness of this instrument are aligned with the typical budget constraints of small-medium companies. Furthermore, the requirements for its use are not demanding in terms of base knowledge on these fields, i.e. Lean Manufacturing (in particular on Value Stream mapping), Software simulations and factorial design of experiment.

The principal limitation of this study is the low generalizability of the results which are related to a single case study. In spite of the solidity of this limitation, one of the deliverables of the work is a method for the collection of additional experimental evidences. In this regard, the next possible step of this work should be a comparison between additional samples, that would also allow the optimization of the system and its full automation in a dedicated software tool. Considering this, an in-depth study with other case researches would be desirable for the further extension of the operation management research field.

6 References

In this paragraph, it is possible to find a list of reference papers and books, mentioned within this PhD research.

Abdulmalek, F. A., & Rajgopal, J. (2007). Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics*.

Abernethy, M. A., & Lillis, A. M. (1995). The impact of manufacturing flexibility on management control system design. *Accounting, Organizations and Society*.

Alagumurthi, N., Palaniradja, K., & Soundararajan, V. (2006). Optimization of grinding process through design of experiment (DOE)—A comparative study. *Materials and Manufacturing Processes*.

Alsmadi, M., Almani, A., & Jerisat, R. (2012). A comparative analysis of Lean practices and performance in the UK manufacturing and service sector firms. *Total Quality Management & Business Excellence*.

Alves, A. S., & Tenera, A. (2009). *Improving SMED in the Automotive Industry: A case study.* Paper presented at the POMS 20th Annual Conference Orlando, Florid USA, May1 to May.

Ansari, A., & Modarress, B. (1988). JIT purchasing as a quality and productivity centre. *International Journal of Production Research*.

Bakås, O., Govaert, T., & Van Landeghem, H. (2011). Challenges and success factors for implementation of lean manufacturing in european SMEs. *International conference on the Modern Information Technology in the Innovation Processes of the Industrial Enterprise*.

Barandolini, A., & Bugamelli, M. (2009). Rapporto sulle tendenze nel sistema produttivo italiano. *Questioni di economia e di finanza*.

Bartezzaghi, E., & Turco, F. (1989). The impact of just-in-time on production system performance: an analytical framework. *International Journal of Operations & Production Management*.

Bateman, N. (1999). Measuring the mix response flexibility of manufacturing systems. *International Journal of Production Research*.

Belhadi, A., & Touriki, F. E. (2016). Road Map for the Implementation of Lean production tools in SMEs. *International Conference on Industrial Engineering and Operations Management*.

Bernards, J., van Engelen, G., Schrauwen, C., Cramer, H., & Luitjens, S. (1990). Simulation of the recording process with a VSM on Co-Cr

and Co-Ni-O layers deposited at oblique incidence. *IEEE Transactions on Magnetics*.
Bessant, J., Caffyn, S., Gilbert, J., Harding, R., & Webb, S. (1994). Rediscovering continuous improvement. *Technovation*.
Bhasin, S., & Burcher, P. (2006). Lean viewed as a philosophy. *Journal of Manufacturing Technology Management*.
Bhuiyan, N., & Baghel, A. (2005). An overview of continuous improvement: from the past to the present. *Management Decision*.
Bonfiglioli, R. (2004). Pensare snello. Lean-thinking alla maniera italiana.
Bortolotti, T., Boscari, S., & Danese, P. (2015). Successful lean implementation: Organizational culture and soft lean practices. *International Journal of Production Economics*.
Bouma, G. D., & Ling, R. (2004). *The research process*.
Boyer, K. K. (1996). An assessment of managerial commitment to lean production. *International Journal of Operations & Production Management*.
Boyer, K. K., Leong, G. K., Ward, P. T., & Krajewski, L. J. (1997). Unlocking the potential of advanced manufacturing technologies. *Journal of Operations Management*.
Boyle, T. A., & Scherrer-Rathje, M. (2009). An empirical examination of the best practices to ensure manufacturing flexibility: Lean alignment. *Journal of Manufacturing Technology Management*.
Braglia, M., Carmignani, G., & Zammori, F. (2006). A new value stream mapping approach for complex production systems. *International Journal of Production Research*.
Browne, J., Dubois, D., Rathmill, K., Sethi, S. P., & Stecke, K. E. (1984). Classification of flexible manufacturing systems. *The FMS magazine*.
Burgess, R. G. (1993). *Research methods*.
Buzacott, J. A., & Mandelbaum, M. (1985). Flexibility and productivity in manufacturing systems. *Flexibility and productivity in manufacturing systems*.
Cagliano, R., Blackmon, K., & Voss, C. (2001). Small firms under MICROSCOPE: international differences in production/operations management practices and performance. *Integrated Manufacturing Systems*.

Carpinetti, L. C. R., Gerólamo, M. C., & Dorta, M. (2000). A conceptual framework for deployment of strategy-related continuous improvements. *The TQM Magazine*.
Cassell, C., Worley, J., & Doolen, T. (2006). The role of communication and management support in a lean manufacturing implementation. *Management Decision*.
Chang, S.-C., Lin, R.-J., Chen, J.-H., & Huang, L.-H. (2005). Manufacturing flexibility and manufacturing proactiveness: empirical evidence from the motherboard industry. *Industrial Management & Data Systems*.
Chang, S.-C., Yang, C.-L., Cheng, H.-C., & Sheu, C. (2003). Manufacturing flexibility and business strategy: An empirical study of small and medium sized firms. *International Journal of Production Economics*.
Chen, J. C., Li, Y., & Shady, B. D. (2010). From value stream mapping toward a lean/sigma continuous improvement process: an industrial case study. *International Journal of Production Research*.
Chitturi, R., Glew, D., & Paulls, A. (2007). Value stream mapping in a jobshop. *IET*.
Chryssolouris, G., & Lee, M. (1992). An assessment of flexibility in manufacturing systems. *Manufacturing Review*.
Clegg, B., Pepper, M., & Spedding, T. (2010). The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*.
Commission, E. (2003). EU recommendation 2003/361.
Condra, L. (2001). *Reliability Improvement With Design of Experiment*.
Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*.
da Silva, G. G., & Tubino, D. F. (2013). Lean Manufacturing Implementation in Small and Medium Enterprises (SME): Strengths and Weaknesses. *Enterprise Interoperability: I-ESA'12 Proceedings*.
Dangayach, G., & Deshmukh, S. (2001). Manufacturing strategy: literature review and some issues. *International Journal of Operations & Production Management*.
Dave, Y., & Sohani, N. (2012). Single Minute Exchange of Dies: Literature Review. *International Journal of Lean Thinking*.

Davies, A. J., & Kochhar, A. K. (2002). Manufacturing best practice and performance studies: a critique. *International Journal of Operations & Production Management*.
Detty, R. B., & Yingling, J. C. (2000). Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *International Journal of Production Research*.
Dorota Rymaszewska, A. (2014). The challenges of lean manufacturing implementation in SMEs. *Benchmarking: An International Journal*.
Drew, J., McCallum, B., & Roggenhofer, S. (2016). *Journey to lean: making operational change stick*.
Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of management journal*.
Emiliani, M., & Stec, D. (2005). Leaders lost in transformation. *Leadership & Organization Development Journal*.
Feld, W. M. (2000). Lean Manufacturing: Tools, Techniques, and How To Use Them.
Flynn, B. B., Sakakibara, S., Schroeder, R. G., Bates, K. A., & Flynn, E. J. (1990). Empirical research methods in operations management. *Journal of Operations Management*.
Gallego, G., & Moon, I. (1995). Strategic investment to reduce setup times in the economic lot scheduling problem. *Naval research logistics*.
Garengo, P., Biazzo, S., & Bititci, U. S. (2005). Performance measurement systems in SMEs: A review for a research agenda. *International journal of management reviews*.
Gerwin, D. (1993). Manufacturing Flexibility: A Strategic Perspective. *Management Science*.
Gregor, M., Štefánik, A., & Hromada, J. (2008). Lean Manufacturing Systems Optimisation Supported by Metamodelling.
Grewal, C. (2008). An initiative to implement lean manufacturing using value stream mapping in a small company. *International Journal of Manufacturing Technology and Management*.
Gupta, M., & Cawthon, G. (1996). Managerial implications of flexible manufacturing for small medium-sized enterprises. *Technovation*.
Gupta, Y. P., & Goyal, S. (1989). Flexibility of Manufacturing Systems: Concepts and Measurements. *European journal of operational research*.

Gurumurthy, A., & Kodali, R. (2011). Design of lean manufacturing systems using value stream mapping with simulation: a case study. *Journal of Manufacturing Technology Management*.
Hallgren, M., & Olhager, J. (2009a). Flexibility configurations: Empirical analysis of volume and product mix flexibility. *Omega*.
Hallgren, M., & Olhager, J. (2009b). Lean and agile manufacturing: external and internal drivers and performance outcomes. *International Journal of Operations & Production Management*.
Hammann, J. E., & Markovitch, N. A. (1995). *Introduction to Arena [simulation software].* Paper presented at the Simulation Conference Proceedings.
Ichniowski, C., Shaw, K., & Prennushi, G. (1997). The effects of human resource management practices on productivity: A study of steel finishing lines. *The American Economic Review*.
Imai, M. (1986). *Kaizen: The Key To Japan's Competitive Success*.
Julie Yazici, H. (2005). Influence of flexibilities on manufacturing cells for faster delivery using simulation. *Journal of Manufacturing Technology Management*.
Kackar, R. N. (1989). Off-line quality control, parameter design, and the Taguchi method *Quality Control, Robust Design, and the Taguchi Method*.
Kaplan, R. S. (1986). Must CIM be justified by faith alone? *Harvard Business Review*.
Kelton, W. D. (2002). *Simulation with ARENA*.
Ketokivi, M. (2006). Elaborating the contingency theory of organizations: The case of manufacturing flexibility strategies. *Production and Operations Management*.
Koste, L. L., & Malhotra, M. K. (1999). A theoretical framework for analyzing the dimensions of manufacturing flexibility. *Journal of Operations Management*.
Lage Junior, M., & Godinho Filho, M. (2010). Variations of the kanban system: Literature review and classification. *International Journal of Production Economics*.
Law, A., & Kelton, D. (1982). Simulation Modeling and Analysis.
Lee, S. M., & Ebrahimpour, M. (1984). Just-in-time production system: some requirements for implementation. *International Journal of Operations & Production Management*.

Lewis, M. W. (1998). Iterative triangulation: a theory development process using existing case studies. *Journal of Operations Management*.
Lian, Y.-H., & Van Landeghem, H. (2002). An application of simulation and value stream mapping in lean manufacturing. *Proceedings 14th European Simulation Symposium*.
Lian, Y.-H., & Van Landeghem, H. (2007). Analysing the effects of Lean manufacturing using a value stream mapping-based simulation generator. *International Journal of Production Research*.
Lillrank, P. M., & Kanō, N. (1989). *Continuous improvement: quality control circles in Japanese industry*.
MacDuffie, J. P. (1995). Human resource bundles and manufacturing performance: Organizational logic and flexible production systems in the world auto industry. *ILR Review*.
Marodin, G. A., Saurin, T. A., Tortorella, G. L., & Denicol, J. (2015). How context factors influence lean production practices in manufacturing cells. *The International Journal of Advanced Manufacturing Technology*.
Mascarenhas, B. (1981). Planning for flexibility. *Long Range Planning*.
McAuley, J. (1972). Machine grouping for efficient production. *Production Engineer*.
McDonald, T., Van Aken, E. M., & Rentes, A. F. (2002). Utilizing simulation to enhance value stream mapping: a manufacturing case application. *International Journal of Logistics*.
McIntosh, R., Culley, S., Mileham, A., & Owen, G. (2000). A critical evaluation of Shingo's' SMED'(Single Minute Exchange of Die) methodology. *International Journal of Production Research*.
Mejabi, O. O. (2003). Framework for a Lean Manufacturing Planning System. *International Journal of Manufacturing Technology and Management*.
Mendonça Tachizawa, E., & Giménez Thomsen, C. (2007). Drivers and sources of supply flexibility: an exploratory study. *International Journal of Operations & Production Management*.
Metternich, J., Böllhoff, J., Seifermann, S., & Beck, S. (2013). Volume and mix flexibility evaluation of lean production systems. *Procedia CIRP*.
Ministero dello Sviluppo Economico Direzione Generale per la Politica Industriale, l. C. e. l. P. e. M. I. (2016). Small Business Act Le iniziative a sostegno delle micro, piccole e medie imprese

adottate in Italia nel secondo semestre 2015 e nel primo semestre 2016.
Moeuf, A., Tamayo, S., Lamouri, S., Pellerin, R., & Lelievre, A. (2016). Strengths and weaknesses of small and medium sized enterprises regarding the implementation of lean manufacturing. *IFAC-PapersOnLine*.
Monden, Y. (1998). Toyota Production System - An Integrated Approach to Just-In-Time.
Muller, P., Devnani, S., Julius, J., Gagliardi, D., & Marzocchi, C. (2016). Annual report on European SMEs 2015/2016 SME recovery continues.
Mungwattana, A. (2000). Design of cellular manufacturing systems for dynamic and uncertain production requirements with presence of routing flexibility.
Nahmias, S. (2001). Production and Operations Analysis.
Narasimhan, J., Parthasarathy, L., & Narayan, P. S. (2007). *Increasing the effectiveness of value stream mapping using simulation tools in engine test operations.* Paper presented at the International Conference on Modeling and Simulation.
Narasimhan, R., & Das, A. (1999). An empirical investigation of the contribution of strategic sourcing to manufacturing flexibilities and performance. *Decision Sciences*.
Nemetz, P. L., & Fry, L. W. (1988). Flexible Manufacturing Organizations: Implications for Strategy Formulation and Organization Design. *The Academy of Management Review*.
Osterman, P. (1994). How common is workplace transformation and who adopts it? *ILR Review*.
Padgett, A. (2004). Why lean implementations fail: Have you created a continuous change culture?
Parker, R. P., & Wirth, A. (1999). Manufacturing flexibility: measures and relationships. *European journal of operational research*.
Pattanaik, L. N., & Sharma, B. P. (2009). Implementing lean manufacturing with cellular layout: a case study. *The International Journal of Advanced Manufacturing Technology*.
Petroni, A., & Bevilacqua, M. (2002). Identifying manufacturing flexibility best practices in small and medium enterprises. *International Journal of Operations & Production Management*.
Prajogo, D., & Olhager, J. (2012). Supply chain integration and performance: The effects of long-term relationships, information

technology and sharing, and logistics integration. *International Journal of Production Economics*.
Rosenzweig, E. D., & Roth, A. V. (2004). Towards a theory of competitive progression: evidence from high-tech manufacturing. *Production and Operations Management*.
Rother, M., & Shook, J. (1999). Learning to See: Value Stream Mapping to Add Value and Eliminate Muda.
Rowlands, H., Antony, J., & Knowles, G. (2000). An application of experimental design for process optimisation. *The TQM Magazine*.
Saad, S., Perera, T., Achanga, P., Shehab, E., Roy, R., & Nelder, G. (2006). Critical success factors for lean implementation within SMEs. *Journal of Manufacturing Technology Management*.
Sakakibara, S., Flynn, B. B., & Schroeder, R. G. (1993). A framework and measurement instrument for just-in-time manufacturing. *Production and Operations Management*.
Sandanayake, Y. G., Oduoza, C. F., & Proverbs, D. G. (2008). A systematic modelling and simulation approach for JIT performance optimisation.
Seidel, H., & von Garrel, J. (2010). Flexible Produktionssysteme innovativ managen. *Wandlungsfähige Produktionssysteme*.
Serrano Lasa, I., Ochoa Laburu, C., & de Castro Vila, R. (2008). An evaluation of the value stream mapping tool. *Business process management journal*.
Seth *, D., & Gupta, V. (2005). Application of value stream mapping for lean operations and cycle time reduction: an Indian case study. *Production Planning and Control*.
Shah, R., & Ward, P. T. (2003). Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management*.
Shah, R., & Ward, P. T. (2007). Defining and developing measures of lean production. *Journal of Operations Management*.
Singh, B., Garg, S., & Sharma, S. (2009). Lean can be a survival strategy during recessionary times. *International journal of productivity and performance management*.
Singh, B., & Sharma, S. (2009). Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm. *Measuring Business Excellence*.

Singh, R. K., Garg, S. K., & Deshmukh, S. G. (2008). Strategy development by SMEs for competitiveness: a review. *Benchmarking: An International Journal*.
Sohal, A., Keller, A., & Fouad, R. (1989). A review of literature relating to JIT. *International Journal of Operations & Production Management*.
Sohal, A. S., & Egglestone, A. (1994). Lean production: experience among Australian organizations. *International Journal of Operations & Production Management*.
Soy, S. K. (1997). The Case Study as a Research Method.
Suarez, F. F., Cusumano, M. A., & Fine, C. H. (1996). An Empirical Study of Manufacturing Flexibility in Printed Circuit Board Assembly. *Operations Research*.
Sugimori, Y., Kusunoki, K., Cho, F., & Uchikawa, S. (1977). Toyota production system and kanban system materialization of just-in-time and respect-for-human system. *International Journal of Production Research*.
Sullivan, W. G., McDonald, T. N., & Van Aken, E. M. (2002). Equipment replacement decisions and lean manufacturing. *Robotics and Computer-Integrated Manufacturing*.
Swink, M., Narasimhan, R., & Kim, S. W. (2005). Manufacturing practices and strategy integration: effects on cost efficiency, flexibility, and market-based performance. *Decision Sciences*.
Thomas, A., Barton, R., & Chuke-Okafor, C. (2008). Applying lean six sigma in a small engineering company – a model for change. *Journal of Manufacturing Technology Management*.
Torrès, O. (1999). *les PME*.
Trovinger, S. C., & Bohn, R. E. (1997). Setup time reduction for electronics assembly: Combining simple (SMED) and sophisticated methods.
Tsoukas, H. (2009). Craving for generality and small-N studies: A Wittgensteinian approach towards the epistemology of the particular in organization and management studies.
UE, D. E. f. (2012). Small Business Act (SBA) Fact Sheets.
Ulewicz, R., & Kucęba, R. (2016). Identification of problems of implementation of Lean concept in the SME sector. *Ekonomia i Zarzadzanie*.

Vinodh, S., & Joy, D. (2012). Structural equation modelling of lean manufacturing practices. *International Journal of Production Research*.
Vokurka, R. J., & O'Leary-Kelly, S. W. (2000). A review of empirical research on manufacturing flexibility. *Journal of Operations Management*.
Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management*.
Wang, T., Guinet, A., Belaidi, A., & Besombes, B. (2009). Modelling and simulation of emergency services with ARIS and Arena. Case study: the emergency department of Saint Joseph and Saint Luc Hospital. *Production Planning and Control*.
Wee, H., & Wu, S. (2009). Lean supply chain and its effect on product cost and quality: a case study on Ford Motor Company. *Supply Chain Management: An International Journal*.
Womack, J. P., & Jones, D. T. (1996). Lean Thinking - Banish Waste and Create Wealth in your Corporation.
Womack, J. P., & Jones, D. T. (2005). Lean Solutions: How Companies and Customers Can Create Value and Wealth Together.
Womack, J. P., Jones, D. T., & Ross, D. (1990). The Machine that Changed the World.
Yang pingyu, A., & Yu yu, B. (2010). The Barriers to SMEs' Implementation of Lean Production and Counter measures. *International Journal of Innovation, Management and Technology*.
Yin, R. K. (2009). Case Study Research: design and methods.
Yücesan, E., & Fowler, J. W. (2000). Simulation analysis of manufacturing and logistics systems: Springer.
Zhou, B. (2016). Lean principles, practices, and impacts: a study on small and medium-sized enterprises (SMEs). *Annals of Operations Research*.

APPENDIX A – Item codes field records

This Appendix presents the complete list of records gathered during field measurement in the ALPHA manufacturing department.

1 *Item Codes*

The next paragraphs show the items catalogue segregated by product type. These codes have been used as samples during the field data gathering.

Item Code:

E	###	§§§	$

###	Identification code of the DECORATION
§§§	Identification code of the RAW BASE
$	Identification code of the RAW SIZE

1.1 Small Glass

<u>Small Glass</u>

Dimensions: Height 6-11 cm Diameter 3.5-5 cm

Batch Quantity: 180 Items

Raw Items: 5

BASE	SIZE
702	0
603	5
709	0
535	3
653	5

SMALL GLASS	
E4777020	E5316035
E4837020	E5146035
E4947020	E5306035
E4967020	E4846035
E5317020	E4906035
E5147020	E5317090
E5307020	E5147090
E5327020	E5307090
E5337020	E5327090
E4847020	E5337090
E4907020	E4775353
E4776035	E4835353
E4836035	E4845353
E4946035	E4905353
E4946035	E4966535

1.2 Glass

Glass

Dimensions: Height 9-16 cm Diameter 7-9 cm

Batch Quantity: 180 Items

Raw Items: 4

BASE	SIZE
912	4
912	7
695	4
695	7

GLASS	
E4779124	E5146954
E4839124	E5306954
E5339124	E5326954
E4849124	E4946957
E4909124	E4966957
E5339127	E5316957
E4946954	E5146957
E4966954	E5306957
E5316954	E5326957

1.3 Bottle

Bottle

BASE	SIZE
135	0
356	0
667	0

Dimensions: Height 8-15 cm Diameter 25-40 cm
Batch Quantity: 50 Items
Raw Items: 3

BOTTLE	
E5311350	E4833560
E5141350	E4943560
E5331350	E4963560
E4841350	E5303560
E4901350	E5323560
E4773560	E4966670

1.4 Small Bowl

<u>Small Bowl</u>

BASE	SIZE
655	1

Dimensions: Height 12.5 cm Diameter 21 cm
Batch Quantity: 50 Items
Raw Items: 1

SMALL BOWL	
E4776551	E5306551
E4946551	E5326551
E5316551	E4846551
E5146551	E4906551

1.5 Bowl

<u>Bowl</u>

BASE	SIZE
655	0

Dimensions: Height 20 cm Diameter 21 cm
Batch Quantity: 50 Items
Raw Items: 1

BOWL	
E4776550	E5306550
E4836550	E5326550
E4946550	E5336550
E5316550	E4846550
E5146550	E4906550

1.6 Small Plate

Small Plate

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 120 Items
Raw Items: 3

BASE	SIZE
851	1
851	4
851	5

SMALL PLATE	
E4778511	E5318515
E4908511	E5148515
E4948514	E5308515
E4838515	E5328515
E4948515	E5338515
E4968515	E4848515

1.7 Plate

Plate

Dimensions: Height 2 cm Diameter 31-35 cm
Batch Quantity: 60 Items
Raw Items: 9

BASE	SIZE
000	2
000	3
000	4
000	5
911	3
851	0
851	6
863	0
693	0

PLATE	
E4770002	E5308510
E5140002	E5328510
E5300002	E5338510
E5320002	E4848510
E5330002	E4908510
E4770003	E4778516
E5140003	E5148516
E5300003	E5338516
E5320003	E5318630
E5330003	E5148630
E5350004	E5308630
E5340004	E4946930
E5320005	E4966930
E5330005	E5316930
E5339113	E5146930
E4778510	E5306930
E4838510	E5326930
E4948510	E5336930
E4968510	E4846930
E5318510	E4906930
E5148510	

1.8 Box

Box

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 50 Items
Raw Items: 4

BASE	SIZE
545	0
545	1
694	1
694	2

BOX	
E4775450	E5336941
E4945450	E4846941
E5145450	E4906941
E5305450	E4776942
E4775451	E4836942
E5145451	E4946942
E5305451	E4966942
E4776941	E5316942
E4836941	E5146942
E4946941	E5326942
E4966941	E5336942
E5316941	E4846942
E5146941	E4906942
E5326941	

1.9 Cylindrical Vase

Cylindrical Vase

Dimensions: Height 2 cm Diameter 31-35 cm
Batch Quantity: 60 Items
Raw Items: 9

BASE	SIZE
700	0
600	1
848	1
049	0
557	1
557	2
869	0
869	1

CYLINDRIC VASE	
E4837000	E5305571
E4846001	E5325571
E4848481	E5335571
E4770490	E4845571
E4830490	E4905571
E4940490	E4775572
E4960490	E4835572
E5310490	E4945572
E5300490	E4965572
E5330490	E5315572
E4840490	E5145572
E4900490	E5305572
E4775571	E5325572
E4835571	E5335572
E4945571	E4845572
E4965571	E4905572
E5315571	E4948690
E5145571	E4948691

1.10 Conic Vase

Conic Vase

Dimensions: Height 2 cm Diameter 21-30 cm
Batch Quantity: 50 Items
Raw Items: 6

BASE	SIZE
536	0
552	1
553	1
379	1
280	2
692	0

CONIC VASE	
E4775360	E5325532
E4835360	E5335532
E4775521	E4845532
E4835521	E4905532
E4945521	E4943791
E4965521	E4773802
E5315521	E4833802
E5305521	E4943802
E5325521	E4963802
E5335521	E5143802
E4905521	E5303802
E4775532	E5323802
E4835532	E5333802
E4945532	E4843802
E4965532	E4903802
E5315532	E4776920
E5145532	E5326920
E5305532	E4856920

2 *Parameters Evaluation by Field Measurement*

The next paragraphs present the complete database of field measurements carried out during the case study to evaluate the times required to complete production activities. Those values are the input parameters for the model simulation and are divided by 3 categories:

1) Fixed Parameters (Independent by Raw Material and Item Code)
2) Parameters based on Raw Material
3) Parameters based on Item Code

2.1 Fixed Parameters

Item Code	**Product Type**	**Q. ty**	**Setup Cell [sec]**	**Setup Frame [sec]**
E5325571	Cylindrical Vase	50	1380	840
E5325572	Cylindrical Vase	50	1500	480
E5325521	Conic Vase	50	900	720
E5325532	Conic Vase	50	1440	840
E5323802	Conic Vase	50	1380	960
E5326920	Conic Vase	50	1140	900
E5326551	Small Bowl	50	1440	900
E5326550	Bowl	50	1560	720
E5326941	Box	50	1200	840
E5326942	Box	50	1140	840
E5326930	Plate	50	1140	900
E5328510	Plate	90	1080	660
E5328515	Small Plate	120	1080	900
E5326954	Glass	180	1200	900
E5326957	Glass	180	1500	900
E5327020	Small Glass	180	1740	960
E5323560	Bottle	50	1200	900
E5327090	Small Glass	180	1500	600
E5320003	Plate	60	1260	1020
E5320002	Plate	60	1320	720
E5335572	Cylindrical Vase	60	1740	900
E5336942	Box	60	1440	780
E5318515	Small Plate	60	1020	1140
E4776942	Box	60	1140	780
E5335571	Cylindrical Vase	50	1200	900

E5335572	Cylindrical Vase	50	720	780
E5330490	Cylindrical Vase	50	1260	600
E5335521	Conic Vase	50	1500	720
E5335532	Conic Vase	50	960	1080
E5333802	Conic Vase	50	1260	780
E5336550	Bowl	50	960	960
E5336941	Box	50	1140	1020
E5336942	Box	50	1080	720
E5331350	Bottle	50	1140	660
E5339127	Glass	180	1440	660
E5339124	Glass	180	1500	780
E5337020	Small Glass	180	1200	660
E5336930	Plate	50	720	840
E5339113	Plate	50	1440	840
E5338516	Plate	50	1620	840
E5337090	Small Glass	180	1620	960
E5338510	Plate	90	1320	960
E5338515	Small Plate	90	1020	840
E5305521	Conic Vase	60	1680	720
E4773560	Bottle	60	1380	1020
E5335572	Cylindrical Vase	60	1320	540
E4906550	Bowl	60	1440	720
E5325521	Conic Vase	60	1680	720
E5330003	Plate	60	1500	900
E4945450	Box	60	1140	1020

2.2 Parameters based on Raw Material

Item Code	**Product Type**	**Control [sec]**	**Cleaning [sec]**	**Packaging [sec]**
		E5326954		
E5326954	Glass	12	11	27
E5326954	Glass	15	12	20
E5326954	Glass	14	12	30
E5326954	Glass	14	12	24
E5326954	Glass	14	16	24
E5326954	Glass	9	13	19
E5326954	Glass	15	11	24
E5326954	Glass	13	13	24

E5326954	Glass	14	12	27
E5326954	Glass	12	14	27
E5326954	Glass	14	12	25
E5326954	Glass	13	9	27
E5326954	Glass	16	12	25
E5326954	Glass	16	15	22
E5326954	Glass	13	13	27
E5326954	Glass	17	15	23
E5326954	Glass	14	10	24
E5326954	Glass	12	13	23
E5326954	Glass	15	13	22
E5326954	Glass	16	13	29
E5326954	Glass	11	13	29
E5326954	Glass	17	8	24
E5326954	Glass	12	11	24
E5326954	Glass	9	12	31
E5326954	Glass	20	12	24
E5326954	Glass	11	11	26
E5326954	Glass	14	12	27
E5326954	Glass	14	10	24
E5326954	Glass	11	10	28
E5326954	Glass	16	11	26
E5326954	Glass	11	13	26
E5326954	Glass	12	14	24
E5326954	Glass	14	14	24
E5326954	Glass	16	12	27
E5326954	Glass	11	13	21
E5326954	Glass	15	13	26
E5326954	Glass	14	12	26
E5326954	Glass	15	10	26
E5326954	Glass	10	13	27
E5326954	Glass	13	15	28
E5326954	Glass	15	10	23
E5326954	Glass	10	14	27
E5326954	Glass	11	12	20
E5326954	Glass	11	13	26
E5326954	Glass	12	13	26
E5326954	Glass	14	12	26
E5326954	Glass	11	12	23
E5326954	Glass	12	12	28

E5326954	Glass	15	14	27
E5326954	Glass	11	12	27
E5146957				
E5146957	Glass	15	13	27
E5146957	Glass	14	14	23
E5146957	Glass	18	12	25
E5146957	Glass	16	11	25
E5146957	Glass	12	13	22
E5146957	Glass	15	13	27
E5146957	Glass	15	12	23
E5146957	Glass	12	13	28
E5146957	Glass	11	9	27
E5146957	Glass	17	14	24
E5146957	Glass	11	12	25
E5146957	Glass	9	13	22
E5146957	Glass	11	11	25
E5146957	Glass	16	12	26
E5146957	Glass	17	13	24
E5146957	Glass	12	14	22
E5146957	Glass	13	13	25
E5146957	Glass	13	11	26
E5146957	Glass	17	13	24
E5146957	Glass	15	13	28
E5146957	Glass	10	12	24
E5146957	Glass	13	13	22
E5146957	Glass	10	12	25
E5146957	Glass	13	14	24
E5146957	Glass	13	11	22
E5146957	Glass	15	12	21
E5146957	Glass	11	10	24
E5146957	Glass	14	13	25
E5146957	Glass	13	11	24
E5146957	Glass	15	14	24
E5146957	Glass	14	11	26
E5146957	Glass	9	12	20
E5146957	Glass	16	13	21
E5146957	Glass	18	14	26
E5146957	Glass	9	12	24
E5146957	Glass	11	13	27
E5146957	Glass	15	12	25

E5146957	Glass	15	12	27
E5146957	Glass	12	14	26
E5146957	Glass	10	11	27
E5146957	Glass	12	14	26
E5146957	Glass	16	15	27
E5146957	Glass	10	12	28
E5146957	Glass	11	11	27
E5146957	Glass	11	13	26
E5146957	Glass	16	13	23
E5146957	Glass	9	12	23
E5146957	Glass	10	12	24
E5146957	Glass	16	11	21
E5146957	Glass	15	13	30
E4835353				
E4835353	Small Glass	5	9	18
E4835353	Small Glass	7	9	17
E4835353	Small Glass	5	8	23
E4835353	Small Glass	5	9	18
E4835353	Small Glass	5	9	20
E4835353	Small Glass	6	9	19
E4835353	Small Glass	9	10	16
E4835353	Small Glass	5	10	25
E4835353	Small Glass	7	9	19
E4835353	Small Glass	8	9	19
E4835353	Small Glass	7	10	18
E4835353	Small Glass	6	9	14
E4835353	Small Glass	5	10	22
E4835353	Small Glass	6	9	20
E4835353	Small Glass	5	8	19
E4835353	Small Glass	5	8	17
E4835353	Small Glass	5	11	19
E4835353	Small Glass	9	13	23
E4835353	Small Glass	5	9	19
E4835353	Small Glass	5	8	20
E4835353	Small Glass	7	8	22
E4835353	Small Glass	5	9	22
E4835353	Small Glass	7	9	21
E4835353	Small Glass	5	9	21
E4835353	Small Glass	6	9	16
E4835353	Small Glass	7	10	18

E4835353	Small Glass	7	10	19
E4835353	Small Glass	7	10	20
E4835353	Small Glass	9	9	21
E4835353	Small Glass	7	11	20
E4835353	Small Glass	9	8	23
E4835353	Small Glass	5	10	18
E4835353	Small Glass	7	11	21
E4835353	Small Glass	6	10	18
E4835353	Small Glass	5	10	19
E4835353	Small Glass	7	10	21
E4835353	Small Glass	9	11	18
E4835353	Small Glass	6	8	19
E4835353	Small Glass	8	9	20
E4835353	Small Glass	5	10	20
E4835353	Small Glass	7	8	22
E4835353	Small Glass	9	9	22
E4835353	Small Glass	8	9	18
E4835353	Small Glass	7	10	25
E4835353	Small Glass	7	9	17
E4835353	Small Glass	5	10	21
E4835353	Small Glass	7	8	22
E4835353	Small Glass	7	11	21
E4835353	Small Glass	7	9	19
E4835353	Small Glass	9	8	24
E4966535				
E4966535	Small Glass	7	10	17
E4966535	Small Glass	6	10	16
E4966535	Small Glass	7	10	23
E4966535	Small Glass	5	8	21
E4966535	Small Glass	5	9	23
E4966535	Small Glass	7	11	23
E4966535	Small Glass	5	9	20
E4966535	Small Glass	5	9	18
E4966535	Small Glass	9	9	21
E4966535	Small Glass	7	9	22
E4966535	Small Glass	6	11	22
E4966535	Small Glass	6	10	23
E4966535	Small Glass	5	9	21
E4966535	Small Glass	7	11	15
E4966535	Small Glass	6	9	24

E4966535	Small Glass	5	9	19
E4966535	Small Glass	10	10	19
E4966535	Small Glass	7	11	16
E4966535	Small Glass	7	11	15
E4966535	Small Glass	5	10	20
E4966535	Small Glass	8	9	18
E4966535	Small Glass	7	9	23
E4966535	Small Glass	8	10	20
E4966535	Small Glass	5	10	20
E4966535	Small Glass	6	11	23
E4966535	Small Glass	7	9	18
E4966535	Small Glass	6	8	24
E4966535	Small Glass	6	11	20
E4966535	Small Glass	6	8	20
E4966535	Small Glass	7	10	23
E4966535	Small Glass	7	10	24
E4966535	Small Glass	9	9	14
E4966535	Small Glass	8	9	15
E4966535	Small Glass	6	10	22
E4966535	Small Glass	6	10	20
E4966535	Small Glass	5	10	18
E4966535	Small Glass	5	10	23
E4966535	Small Glass	6	8	20
E4966535	Small Glass	7	8	23
E4966535	Small Glass	7	8	19
E4966535	Small Glass	7	9	21
E4966535	Small Glass	6	10	24
E4966535	Small Glass	6	8	23
E4966535	Small Glass	8	8	21
E4966535	Small Glass	7	9	24
E4966535	Small Glass	6	10	17
E4966535	Small Glass	5	9	20
E4966535	Small Glass	6	9	20
E4966535	Small Glass	5	10	17
E4966535	Small Glass	5	10	22
E5311350				
E5311350	Bottle	46	18	66
E5311350	Bottle	45	22	76
E5311350	Bottle	32	17	66
E5311350	Bottle	30	19	78

E5311350	Bottle	40	18	79
E5311350	Bottle	56	16	81
E5311350	Bottle	39	18	91
E5311350	Bottle	39	18	86
E5311350	Bottle	31	18	78
E5311350	Bottle	43	21	90
E5311350	Bottle	48	17	77
E5311350	Bottle	42	16	93
E5311350	Bottle	65	20	63
E5311350	Bottle	41	19	85
E5311350	Bottle	43	18	68
E5311350	Bottle	31	19	80
E5311350	Bottle	28	20	72
E5311350	Bottle	45	16	87
E5311350	Bottle	50	17	92
E5311350	Bottle	50	19	71
E5311350	Bottle	40	19	69
E5311350	Bottle	49	17	80
E5311350	Bottle	49	18	84
E5311350	Bottle	55	17	73
E5311350	Bottle	51	19	82
E5311350	Bottle	40	17	73
E5311350	Bottle	24	19	79
E5311350	Bottle	55	16	76
E5311350	Bottle	50	18	86
E5311350	Bottle	31	18	78
E5311350	Bottle	50	18	64
E5311350	Bottle	35	16	68
E5311350	Bottle	48	20	76
E5311350	Bottle	49	18	67
E5311350	Bottle	38	18	62
E5311350	Bottle	54	19	85
E5311350	Bottle	52	19	72
E5311350	Bottle	39	20	84
E5311350	Bottle	52	19	90
E5311350	Bottle	40	19	83
E5311350	Bottle	38	19	78
E5311350	Bottle	47	19	67
E5311350	Bottle	48	20	80
E5311350	Bottle	52	18	78

E5311350	Bottle	48	21	81
E5311350	Bottle	47	19	71
E5311350	Bottle	44	18	78
E5311350	Bottle	44	20	85
E5311350	Bottle	55	19	78
E5311350	Bottle	40	18	81
E4963560				
E4963560	Bottle	45	17	90
E4963560	Bottle	38	21	79
E4963560	Bottle	47	19	85
E4963560	Bottle	49	20	83
E4963560	Bottle	36	17	83
E4963560	Bottle	49	17	90
E4963560	Bottle	50	17	72
E4963560	Bottle	50	19	75
E4963560	Bottle	48	20	76
E4963560	Bottle	40	21	75
E4963560	Bottle	53	17	68
E4963560	Bottle	57	20	79
E4963560	Bottle	33	19	71
E4963560	Bottle	37	19	85
E4963560	Bottle	47	18	91
E4963560	Bottle	47	17	76
E4963560	Bottle	33	18	82
E4963560	Bottle	47	16	93
E4963560	Bottle	46	20	82
E4963560	Bottle	35	19	78
E4963560	Bottle	53	17	66
E4963560	Bottle	35	18	72
E4963560	Bottle	52	18	80
E4963560	Bottle	38	22	72
E4963560	Bottle	48	18	66
E4963560	Bottle	32	19	67
E4963560	Bottle	39	16	63
E4963560	Bottle	51	20	76
E4963560	Bottle	53	20	71
E4963560	Bottle	64	19	95
E4963560	Bottle	55	18	74
E4963560	Bottle	54	19	95
E4963560	Bottle	56	18	85

E4963560	Bottle	51	22	86
E4963560	Bottle	40	17	75
E4963560	Bottle	52	18	83
E4963560	Bottle	45	20	87
E4963560	Bottle	39	15	71
E4963560	Bottle	26	20	81
E4963560	Bottle	47	20	84
E4963560	Bottle	53	21	82
E4963560	Bottle	43	21	85
E4963560	Bottle	65	18	70
E4963560	Bottle	52	17	69
E4963560	Bottle	51	18	77
E4963560	Bottle	50	20	71
E4963560	Bottle	42	16	93
E4963560	Bottle	53	20	80
E4963560	Bottle	45	19	74
E4963560	Bottle	54	21	89
E4906550				
E4906550	Bowl	46	26	125
E4906550	Bowl	37	30	117
E4906550	Bowl	44	27	107
E4906550	Bowl	33	28	106
E4906550	Bowl	38	29	116
E4906550	Bowl	44	27	114
E4906550	Bowl	28	25	128
E4906550	Bowl	37	25	103
E4906550	Bowl	37	25	121
E4906550	Bowl	42	24	110
E4906550	Bowl	41	29	108
E4906550	Bowl	34	25	126
E4906550	Bowl	34	25	108
E4906550	Bowl	26	26	106
E4906550	Bowl	29	27	116
E4906550	Bowl	36	29	126
E4906550	Bowl	40	29	112
E4906550	Bowl	29	26	111
E4906550	Bowl	29	27	121
E4906550	Bowl	36	28	116
E4906550	Bowl	28	27	127
E4906550	Bowl	37	28	110

E4906550	Bowl	26	26	112
E4906550	Bowl	36	27	110
E4906550	Bowl	36	28	109
E4906550	Bowl	30	25	111
E4906550	Bowl	38	25	106
E4906550	Bowl	42	28	111
E4906550	Bowl	31	26	106
E4906550	Bowl	36	31	130
E4906550	Bowl	38	24	136
E4906550	Bowl	34	28	121
E4906550	Bowl	43	30	110
E4906550	Bowl	35	25	105
E4906550	Bowl	38	25	103
E4906550	Bowl	45	29	104
E4906550	Bowl	31	24	121
E4906550	Bowl	41	29	124
E4906550	Bowl	29	26	126
E4906550	Bowl	46	26	115
E4906550	Bowl	43	26	118
E4906550	Bowl	39	28	126
E4906550	Bowl	34	29	126
E4906550	Bowl	29	25	110
E4906550	Bowl	43	23	123
E4906550	Bowl	27	25	145
E4906550	Bowl	37	23	125
E4906550	Bowl	34	26	114
E4906550	Bowl	28	28	110
E4906550	Bowl	47	24	105
E4906551				
E4906551	Small Bowl	47	24	62
E4906551	Small Bowl	26	25	67
E4906551	Small Bowl	49	25	59
E4906551	Small Bowl	43	25	56
E4906551	Small Bowl	44	26	63
E4906551	Small Bowl	37	26	76
E4906551	Small Bowl	41	25	64
E4906551	Small Bowl	35	23	58
E4906551	Small Bowl	38	26	48
E4906551	Small Bowl	35	27	70
E4906551	Small Bowl	34	26	77

E4906551	Small Bowl	44	24	67
E4906551	Small Bowl	39	25	71
E4906551	Small Bowl	33	26	60
E4906551	Small Bowl	37	22	61
E4906551	Small Bowl	40	22	65
E4906551	Small Bowl	27	28	65
E4906551	Small Bowl	23	25	71
E4906551	Small Bowl	39	23	71
E4906551	Small Bowl	38	29	43
E4906551	Small Bowl	35	26	67
E4906551	Small Bowl	37	25	65
E4906551	Small Bowl	46	26	67
E4906551	Small Bowl	46	24	61
E4906551	Small Bowl	38	27	76
E4906551	Small Bowl	42	27	77
E4906551	Small Bowl	38	25	61
E4906551	Small Bowl	27	26	84
E4906551	Small Bowl	48	27	58
E4906551	Small Bowl	36	26	55
E4906551	Small Bowl	37	24	67
E4906551	Small Bowl	39	28	60
E4906551	Small Bowl	39	28	59
E4906551	Small Bowl	40	27	60
E4906551	Small Bowl	38	25	73
E4906551	Small Bowl	42	25	78
E4906551	Small Bowl	33	25	52
E4906551	Small Bowl	44	28	58
E4906551	Small Bowl	39	26	77
E4906551	Small Bowl	47	26	73
E4906551	Small Bowl	33	28	70
E4906551	Small Bowl	30	25	56
E4906551	Small Bowl	36	25	71
E4906551	Small Bowl	37	25	78
E4906551	Small Bowl	27	26	67
E4906551	Small Bowl	32	26	59
E4906551	Small Bowl	42	24	65
E4906551	Small Bowl	39	26	66
E4906551	Small Bowl	38	29	59
E4906551	Small Bowl	54	28	68
E5338515				

E5338515	Small Plate	22	16	43
E5338515	Small Plate	23	11	42
E5338515	Small Plate	20	11	29
E5338515	Small Plate	21	12	34
E5338515	Small Plate	17	10	41
E5338515	Small Plate	22	13	40
E5338515	Small Plate	15	11	40
E5338515	Small Plate	18	11	38
E5338515	Small Plate	15	15	36
E5338515	Small Plate	20	11	36
E5338515	Small Plate	14	14	37
E5338515	Small Plate	18	10	44
E5338515	Small Plate	20	15	46
E5338515	Small Plate	15	12	43
E5338515	Small Plate	13	11	50
E5338515	Small Plate	13	12	35
E5338515	Small Plate	17	12	31
E5338515	Small Plate	16	13	32
E5338515	Small Plate	20	11	41
E5338515	Small Plate	22	12	39
E5338515	Small Plate	17	12	32
E5338515	Small Plate	17	13	42
E5338515	Small Plate	20	13	32
E5338515	Small Plate	10	13	41
E5338515	Small Plate	13	11	37
E5338515	Small Plate	18	13	34
E5338515	Small Plate	22	13	32
E5338515	Small Plate	17	16	35
E5338515	Small Plate	21	12	36
E5338515	Small Plate	23	12	39
E5338515	Small Plate	18	12	41
E5338515	Small Plate	22	11	33
E5338515	Small Plate	17	10	38
E5338515	Small Plate	17	13	40
E5338515	Small Plate	20	15	37
E5338515	Small Plate	12	12	33
E5338515	Small Plate	13	12	42
E5338515	Small Plate	20	11	37
E5338515	Small Plate	17	11	41
E5338515	Small Plate	24	14	40

E5338515	Small Plate	11	12	45
E5338515	Small Plate	19	15	39
E5338515	Small Plate	14	11	44
E5338515	Small Plate	10	13	34
E5338515	Small Plate	16	13	42
E5338515	Small Plate	25	12	38
E5338515	Small Plate	23	12	37
E5338515	Small Plate	9	11	32
E5338515	Small Plate	20	12	35
E5338515	Small Plate	18	11	30
E5320003				
E5320003	Plate	82	54	243
E5320003	Plate	70	55	224
E5320003	Plate	41	49	211
E5320003	Plate	73	53	197
E5320003	Plate	62	53	224
E5320003	Plate	52	49	197
E5320003	Plate	72	49	223
E5320003	Plate	77	50	181
E5320003	Plate	67	46	251
E5320003	Plate	64	47	222
E5320003	Plate	74	60	229
E5320003	Plate	73	55	220
E5320003	Plate	78	56	235
E5320003	Plate	54	55	211
E5320003	Plate	64	49	223
E5320003	Plate	59	51	234
E5320003	Plate	60	51	184
E5320003	Plate	48	53	213
E5320003	Plate	65	55	195
E5320003	Plate	54	54	187
E5320003	Plate	71	49	217
E5320003	Plate	50	55	206
E5320003	Plate	65	46	241
E5320003	Plate	87	54	219
E5320003	Plate	52	50	230
E5320003	Plate	82	52	209
E5320003	Plate	57	52	232
E5320003	Plate	65	51	171
E5320003	Plate	90	53	236

E5320003	Plate	45	56	204
E5320003	Plate	84	46	226
E5320003	Plate	68	54	217
E5320003	Plate	74	51	180
E5320003	Plate	47	51	199
E5320003	Plate	62	51	246
E5320003	Plate	69	48	213
E5320003	Plate	67	50	220
E5320003	Plate	67	50	231
E5320003	Plate	57	46	215
E5320003	Plate	64	52	234
E5320003	Plate	74	51	211
E5320003	Plate	67	54	228
E5320003	Plate	74	54	213
E5320003	Plate	62	49	184
E5320003	Plate	68	45	221
E5320003	Plate	60	52	223
E5320003	Plate	68	57	216
E5320003	Plate	50	50	212
E5320003	Plate	66	54	182
E5320003	Plate	75	52	216
E5336930				
E5336930	Plate	21	16	73
E5336930	Plate	24	17	79
E5336930	Plate	21	17	71
E5336930	Plate	21	17	68
E5336930	Plate	23	16	63
E5336930	Plate	16	17	73
E5336930	Plate	19	17	59
E5336930	Plate	19	18	75
E5336930	Plate	21	16	73
E5336930	Plate	20	15	79
E5336930	Plate	23	15	68
E5336930	Plate	19	18	50
E5336930	Plate	16	18	74
E5336930	Plate	18	17	73
E5336930	Plate	24	17	66
E5336930	Plate	25	16	76
E5336930	Plate	23	17	68
E5336930	Plate	21	15	72

E5336930	Plate	19	18	73
E5336930	Plate	22	15	83
E5336930	Plate	22	14	76
E5336930	Plate	18	17	73
E5336930	Plate	21	16	79
E5336930	Plate	23	17	75
E5336930	Plate	24	16	65
E5336930	Plate	19	17	68
E5336930	Plate	22	15	68
E5336930	Plate	24	17	68
E5336930	Plate	26	16	73
E5336930	Plate	26	18	72
E5336930	Plate	24	16	63
E5336930	Plate	27	16	78
E5336930	Plate	26	17	59
E5336930	Plate	18	14	62
E5336930	Plate	30	18	77
E5336930	Plate	19	17	66
E5336930	Plate	21	15	76
E5336930	Plate	16	18	82
E5336930	Plate	26	18	70
E5336930	Plate	19	17	75
E5336930	Plate	15	17	68
E5336930	Plate	18	16	67
E5336930	Plate	22	17	70
E5336930	Plate	23	15	78
E5336930	Plate	26	18	69
E5336930	Plate	25	16	71
E5336930	Plate	23	15	74
E5336930	Plate	19	16	70
E5336930	Plate	21	17	67
E5336930	Plate	18	20	75
E4966941				
E4966941	Box	32	19	85
E4966941	Box	24	18	79
E4966941	Box	44	17	94
E4966941	Box	34	19	97
E4966941	Box	34	14	75
E4966941	Box	33	14	85
E4966941	Box	37	17	89

E4966941	Box	37	19	81
E4966941	Box	33	14	84
E4966941	Box	32	15	77
E4966941	Box	32	18	74
E4966941	Box	29	19	80
E4966941	Box	39	16	81
E4966941	Box	58	18	73
E4966941	Box	30	19	69
E4966941	Box	35	14	83
E4966941	Box	32	19	71
E4966941	Box	41	18	77
E4966941	Box	36	18	92
E4966941	Box	39	17	81
E4966941	Box	38	15	77
E4966941	Box	44	17	97
E4966941	Box	32	20	82
E4966941	Box	41	20	93
E4966941	Box	34	18	79
E4966941	Box	37	18	82
E4966941	Box	45	17	93
E4966941	Box	39	17	94
E4966941	Box	30	16	77
E4966941	Box	36	19	92
E4966941	Box	34	17	81
E4966941	Box	33	18	89
E4966941	Box	47	21	87
E4966941	Box	39	16	76
E4966941	Box	27	17	84
E4966941	Box	43	18	82
E4966941	Box	25	18	84
E4966941	Box	41	16	76
E4966941	Box	41	16	89
E4966941	Box	42	17	78
E4966941	Box	43	12	83
E4966941	Box	27	18	83
E4966941	Box	33	18	69
E4966941	Box	39	18	85
E4966941	Box	38	19	83
E4966941	Box	26	16	92
E4966941	Box	32	16	80

E4966941	Box	41	21	86
E4966941	Box	40	18	71
E4966941	Box	32	19	80
E4846942				
E4846942	Box	39	17	83
E4846942	Box	34	17	84
E4846942	Box	31	14	86
E4846942	Box	40	18	76
E4846942	Box	35	16	68
E4846942	Box	36	18	88
E4846942	Box	28	15	88
E4846942	Box	25	21	90
E4846942	Box	29	19	76
E4846942	Box	25	18	88
E4846942	Box	33	18	85
E4846942	Box	42	16	94
E4846942	Box	31	19	86
E4846942	Box	46	14	86
E4846942	Box	29	14	79
E4846942	Box	41	18	89
E4846942	Box	37	19	87
E4846942	Box	42	18	89
E4846942	Box	37	18	89
E4846942	Box	29	20	72
E4846942	Box	47	17	87
E4846942	Box	33	17	83
E4846942	Box	41	19	76
E4846942	Box	42	18	75
E4846942	Box	31	17	79
E4846942	Box	33	19	83
E4846942	Box	19	17	81
E4846942	Box	35	16	77
E4846942	Box	34	14	80
E4846942	Box	39	18	76
E4846942	Box	22	20	85
E4846942	Box	41	16	81
E4846942	Box	46	15	84
E4846942	Box	34	16	71
E4846942	Box	37	18	76
E4846942	Box	36	18	78

E4846942	Box	48	20	83
E4846942	Box	35	18	87
E4846942	Box	36	20	88
E4846942	Box	38	16	95
E4846942	Box	26	13	76
E4846942	Box	39	18	85
E4846942	Box	41	19	96
E4846942	Box	46	16	82
E4846942	Box	27	18	80
E4846942	Box	43	15	81
E4846942	Box	23	17	85
E4846942	Box	33	15	85
E4846942	Box	29	18	84
E4846942	Box	36	15	75
E5310490				
E5310490	Cylindrical Vase	26	25	62
E5310490	Cylindrical Vase	34	21	57
E5310490	Cylindrical Vase	26	22	49
E5310490	Cylindrical Vase	30	20	61
E5310490	Cylindrical Vase	28	20	62
E5310490	Cylindrical Vase	38	21	60
E5310490	Cylindrical Vase	35	21	63
E5310490	Cylindrical Vase	30	23	62
E5310490	Cylindrical Vase	25	23	58
E5310490	Cylindrical Vase	33	22	52
E5310490	Cylindrical Vase	29	24	54
E5310490	Cylindrical Vase	24	18	54
E5310490	Cylindrical Vase	29	23	50
E5310490	Cylindrical Vase	31	20	60
E5310490	Cylindrical Vase	28	25	56
E5310490	Cylindrical Vase	29	19	56
E5310490	Cylindrical Vase	25	18	59
E5310490	Cylindrical Vase	29	22	52
E5310490	Cylindrical Vase	31	21	57
E5310490	Cylindrical Vase	20	22	61
E5310490	Cylindrical Vase	26	18	48
E5310490	Cylindrical Vase	28	23	59
E5310490	Cylindrical Vase	41	22	54
E5310490	Cylindrical Vase	23	19	58
E5310490	Cylindrical Vase	31	23	57

E5310490	Cylindrical Vase	29	20	60
E5310490	Cylindrical Vase	23	22	51
E5310490	Cylindrical Vase	27	20	62
E5310490	Cylindrical Vase	19	19	65
E5310490	Cylindrical Vase	21	23	67
E5310490	Cylindrical Vase	34	23	61
E5310490	Cylindrical Vase	31	20	66
E5310490	Cylindrical Vase	39	22	58
E5310490	Cylindrical Vase	20	22	65
E5310490	Cylindrical Vase	20	20	60
E5310490	Cylindrical Vase	32	18	68
E5310490	Cylindrical Vase	27	25	52
E5310490	Cylindrical Vase	19	21	54
E5310490	Cylindrical Vase	27	24	67
E5310490	Cylindrical Vase	30	23	63
E5310490	Cylindrical Vase	30	23	58
E5310490	Cylindrical Vase	28	24	54
E5310490	Cylindrical Vase	30	21	54
E5310490	Cylindrical Vase	28	24	63
E5310490	Cylindrical Vase	33	16	55
E5310490	Cylindrical Vase	29	24	67
E5310490	Cylindrical Vase	32	24	57
E5310490	Cylindrical Vase	30	23	58
E5310490	Cylindrical Vase	32	20	55
E5310490	Cylindrical Vase	32	22	59
		E5325571		
E5325571	Cylindrical Vase	28	21	50
E5325571	Cylindrical Vase	29	18	61
E5325571	Cylindrical Vase	23	20	60
E5325571	Cylindrical Vase	29	22	56
E5325571	Cylindrical Vase	21	24	61
E5325571	Cylindrical Vase	26	20	70
E5325571	Cylindrical Vase	28	22	66
E5325571	Cylindrical Vase	28	21	60
E5325571	Cylindrical Vase	19	20	57
E5325571	Cylindrical Vase	20	22	61
E5325571	Cylindrical Vase	24	20	58
E5325571	Cylindrical Vase	27	21	56
E5325571	Cylindrical Vase	27	22	42
E5325571	Cylindrical Vase	19	23	52

E5325571	Cylindrical Vase	28	24	53
E5325571	Cylindrical Vase	30	22	56
E5325571	Cylindrical Vase	30	21	52
E5325571	Cylindrical Vase	34	22	54
E5325571	Cylindrical Vase	25	21	51
E5325571	Cylindrical Vase	29	24	59
E5325571	Cylindrical Vase	20	21	61
E5325571	Cylindrical Vase	21	22	63
E5325571	Cylindrical Vase	35	21	61
E5325571	Cylindrical Vase	36	21	69
E5325571	Cylindrical Vase	26	21	68
E5325571	Cylindrical Vase	32	23	55
E5325571	Cylindrical Vase	31	19	64
E5325571	Cylindrical Vase	28	22	54
E5325571	Cylindrical Vase	25	18	58
E5325571	Cylindrical Vase	22	23	56
E5325571	Cylindrical Vase	31	21	61
E5325571	Cylindrical Vase	20	23	52
E5325571	Cylindrical Vase	26	23	58
E5325571	Cylindrical Vase	21	24	62
E5325571	Cylindrical Vase	32	22	59
E5325571	Cylindrical Vase	25	24	52
E5325571	Cylindrical Vase	30	24	60
E5325571	Cylindrical Vase	22	20	51
E5325571	Cylindrical Vase	39	18	54
E5325571	Cylindrical Vase	17	24	55
E5325571	Cylindrical Vase	22	21	50
E5325571	Cylindrical Vase	24	22	63
E5325571	Cylindrical Vase	24	24	66
E5325571	Cylindrical Vase	30	22	50
E5325571	Cylindrical Vase	36	19	53
E5325571	Cylindrical Vase	33	24	48
E5325571	Cylindrical Vase	20	21	57
E5325571	Cylindrical Vase	32	22	61
E5325571	Cylindrical Vase	30	21	55
E5325571	Cylindrical Vase	18	20	54
E5143802				
E5143802	Conic Vase	39	20	68
E5143802	Conic Vase	22	25	67
E5143802	Conic Vase	28	24	72

E5143802	Conic Vase	23	26	75
E5143802	Conic Vase	35	30	77
E5143802	Conic Vase	30	26	81
E5143802	Conic Vase	43	23	81
E5143802	Conic Vase	37	30	70
E5143802	Conic Vase	28	23	67
E5143802	Conic Vase	22	25	81
E5143802	Conic Vase	40	21	62
E5143802	Conic Vase	29	27	56
E5143802	Conic Vase	41	28	73
E5143802	Conic Vase	42	26	76
E5143802	Conic Vase	24	24	85
E5143802	Conic Vase	26	29	69
E5143802	Conic Vase	14	20	63
E5143802	Conic Vase	29	29	69
E5143802	Conic Vase	34	25	60
E5143802	Conic Vase	46	29	72
E5143802	Conic Vase	25	26	58
E5143802	Conic Vase	33	28	72
E5143802	Conic Vase	21	28	68
E5143802	Conic Vase	24	26	76
E5143802	Conic Vase	43	23	78
E5143802	Conic Vase	24	21	68
E5143802	Conic Vase	37	22	74
E5143802	Conic Vase	35	25	81
E5143802	Conic Vase	45	23	63
E5143802	Conic Vase	45	30	75
E5143802	Conic Vase	36	21	75
E5143802	Conic Vase	37	30	59
E5143802	Conic Vase	17	27	62
E5143802	Conic Vase	47	28	72
E5143802	Conic Vase	46	25	74
E5143802	Conic Vase	30	25	75
E5143802	Conic Vase	45	20	66
E5143802	Conic Vase	27	24	73
E5143802	Conic Vase	37	31	80
E5143802	Conic Vase	31	26	64
E5143802	Conic Vase	34	29	70
E5143802	Conic Vase	34	29	70
E5143802	Conic Vase	27	25	84

E5143802	Conic Vase	29	25	78
E5143802	Conic Vase	31	25	68
E5143802	Conic Vase	42	26	68
E5143802	Conic Vase	37	25	91
E5143802	Conic Vase	32	27	67
E5143802	Conic Vase	44	26	66
E5143802	Conic Vase	30	21	76
E4776920				
E4776920	Conic Vase	35	23	63
E4776920	Conic Vase	27	29	76
E4776920	Conic Vase	35	23	78
E4776920	Conic Vase	20	25	79
E4776920	Conic Vase	23	24	76
E4776920	Conic Vase	44	23	67
E4776920	Conic Vase	36	19	76
E4776920	Conic Vase	30	25	67
E4776920	Conic Vase	28	24	63
E4776920	Conic Vase	32	24	73
E4776920	Conic Vase	49	26	68
E4776920	Conic Vase	30	25	64
E4776920	Conic Vase	24	22	71
E4776920	Conic Vase	49	22	71
E4776920	Conic Vase	43	28	69
E4776920	Conic Vase	38	27	69
E4776920	Conic Vase	21	24	70
E4776920	Conic Vase	27	27	62
E4776920	Conic Vase	35	23	64
E4776920	Conic Vase	26	22	75
E4776920	Conic Vase	42	29	69
E4776920	Conic Vase	30	24	58
E4776920	Conic Vase	27	27	65
E4776920	Conic Vase	24	26	77
E4776920	Conic Vase	37	28	60
E4776920	Conic Vase	38	29	69
E4776920	Conic Vase	33	27	67
E4776920	Conic Vase	42	27	76
E4776920	Conic Vase	29	19	68
E4776920	Conic Vase	36	24	73
E4776920	Conic Vase	26	26	67
E4776920	Conic Vase	30	24	69

E4776920	Conic Vase	29	28	66
E4776920	Conic Vase	38	26	60
E4776920	Conic Vase	26	29	78
E4776920	Conic Vase	43	26	74
E4776920	Conic Vase	37	28	73
E4776920	Conic Vase	34	25	63
E4776920	Conic Vase	23	26	86
E4776920	Conic Vase	30	19	64
E4776920	Conic Vase	26	25	85
E4776920	Conic Vase	19	28	66
E4776920	Conic Vase	36	29	54
E4776920	Conic Vase	31	26	61
E4776920	Conic Vase	43	25	93
E4776920	Conic Vase	31	25	67
E4776920	Conic Vase	19	24	68
E4776920	Conic Vase	19	27	64
E4776920	Conic Vase	42	20	79
E4776920	Conic Vase	28	24	51

2.3 Parameters based on Item Code

Item Code	**Product Type**	**Printing [sec]**
	E4966942	
E4966942	Box	55
E4966942	Box	61
E4966942	Box	59
E4966942	Box	61
E4966942	Box	56
E4966942	Box	59
E4966942	Box	57
E4966942	Box	63
E4966942	Box	64
E4966942	Box	57
E4966942	Box	56
E4966942	Box	58
E4966942	Box	60
E4966942	Box	53
E4966942	Box	59

E4966942	Box	59
E4966942	Box	57
E4966942	Box	51
E4966942	Box	57
E4966942	Box	62
E4966942	Box	63
E4966942	Box	55
E4966942	Box	57
E4966942	Box	56
E4966942	Box	60
E4966942	Box	58
E4966942	Box	62
E4966942	Box	56
E4966942	Box	55
E4966942	Box	60
E4966942	Box	57
E4966942	Box	64
E4966942	Box	54
E4966942	Box	58
E4966942	Box	60
E4966942	Box	61
E4966942	Box	57
E4966942	Box	57
E4966942	Box	57
E4966942	Box	56
E4966942	Box	63
E4966942	Box	60
E4966942	Box	58
E4966942	Box	58
E4966942	Box	62
E4966942	Box	61
E4966942	Box	56
E4966942	Box	53
E4966942	Box	58
E4966942	Box	60
	E4905521	
E4905521	Conic Vase	114
E4905521	Conic Vase	127
E4905521	Conic Vase	120
E4905521	Conic Vase	120

E4905521	Conic Vase	120
E4905521	Conic Vase	119
E4905521	Conic Vase	115
E4905521	Conic Vase	117
E4905521	Conic Vase	119
E4905521	Conic Vase	125
E4905521	Conic Vase	114
E4905521	Conic Vase	108
E4905521	Conic Vase	116
E4905521	Conic Vase	116
E4905521	Conic Vase	111
E4905521	Conic Vase	119
E4905521	Conic Vase	112
E4905521	Conic Vase	118
E4905521	Conic Vase	110
E4905521	Conic Vase	113
E4905521	Conic Vase	113
E4905521	Conic Vase	118
E4905521	Conic Vase	117
E4905521	Conic Vase	113
E4905521	Conic Vase	115
E4905521	Conic Vase	116
E4905521	Conic Vase	118
E4905521	Conic Vase	116
E4905521	Conic Vase	104
E4905521	Conic Vase	123
E4905521	Conic Vase	125
E4905521	Conic Vase	119
E4905521	Conic Vase	120
E4905521	Conic Vase	115
E4905521	Conic Vase	111
E4905521	Conic Vase	123
E4905521	Conic Vase	117
E4905521	Conic Vase	104
E4905521	Conic Vase	110
E4905521	Conic Vase	123
E4905521	Conic Vase	114
E4905521	Conic Vase	110
E4905521	Conic Vase	111
E4905521	Conic Vase	117

E4905521	Conic Vase	120
E4905521	Conic Vase	121
E4905521	Conic Vase	108
E4905521	Conic Vase	118
E4905521	Conic Vase	121
E4905521	Conic Vase	111
	E5337090	
E5337090	Small Glass	39
E5337090	Small Glass	36
E5337090	Small Glass	38
E5337090	Small Glass	39
E5337090	Small Glass	39
E5337090	Small Glass	37
E5337090	Small Glass	40
E5337090	Small Glass	36
E5337090	Small Glass	37
E5337090	Small Glass	39
E5337090	Small Glass	36
E5337090	Small Glass	39
E5337090	Small Glass	39
E5337090	Small Glass	38
E5337090	Small Glass	39
E5337090	Small Glass	37
E5337090	Small Glass	37
E5337090	Small Glass	39
E5337090	Small Glass	38
E5337090	Small Glass	41
E5337090	Small Glass	36
E5337090	Small Glass	39
E5337090	Small Glass	36
E5337090	Small Glass	34
E5337090	Small Glass	35
E5337090	Small Glass	37
E5337090	Small Glass	37
E5337090	Small Glass	39
E5337090	Small Glass	36
E5337090	Small Glass	36
E5337090	Small Glass	37
E5337090	Small Glass	36
E5337090	Small Glass	43

E5337090	Small Glass	35
E5337090	Small Glass	37
E5337090	Small Glass	38
E5337090	Small Glass	37
E5337090	Small Glass	37
E5337090	Small Glass	36
E5337090	Small Glass	36
E5337090	Small Glass	37
E5337090	Small Glass	37
E5337090	Small Glass	38
E5337090	Small Glass	35
E5337090	Small Glass	38
E5337090	Small Glass	42
E5337090	Small Glass	36
E5337090	Small Glass	35
E5337090	Small Glass	42
E5337090	Small Glass	35
	E4776550	
E4776550	Bowl	95
E4776550	Bowl	101
E4776550	Bowl	107
E4776550	Bowl	95
E4776550	Bowl	94
E4776550	Bowl	95
E4776550	Bowl	93
E4776550	Bowl	107
E4776550	Bowl	96
E4776550	Bowl	97
E4776550	Bowl	102
E4776550	Bowl	98
E4776550	Bowl	95
E4776550	Bowl	101
E4776550	Bowl	97
E4776550	Bowl	97
E4776550	Bowl	97
E4776550	Bowl	97
E4776550	Bowl	100
E4776550	Bowl	98
E4776550	Bowl	95
E4776550	Bowl	102

E4776550	Bowl	93
E4776550	Bowl	101
E4776550	Bowl	100
E4776550	Bowl	106
E4776550	Bowl	101
E4776550	Bowl	95
E4776550	Bowl	101
E4776550	Bowl	101
E4776550	Bowl	103
E4776550	Bowl	100
E4776550	Bowl	101
E4776550	Bowl	100
E4776550	Bowl	95
E4776550	Bowl	95
E4776550	Bowl	94
E4776550	Bowl	100
E4776550	Bowl	100
E4776550	Bowl	97
E4776550	Bowl	101
E4776550	Bowl	99
E4776550	Bowl	99
E4776550	Bowl	95
E4776550	Bowl	98
E4776550	Bowl	90
E4776550	Bowl	88
E4776550	Bowl	96
E4776550	Bowl	99
E4776550	Bowl	98
	E4830490	
E4830490	Cylindrical Vase	50
E4830490	Cylindrical Vase	49
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	50
E4830490	Cylindrical Vase	56

E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	50
E4830490	Cylindrical Vase	51
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	52
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	56
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	57
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	51
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	51
E4830490	Cylindrical Vase	53
E4830490	Cylindrical Vase	49
E4830490	Cylindrical Vase	48
E4830490	Cylindrical Vase	58
E4830490	Cylindrical Vase	52
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	52
E4830490	Cylindrical Vase	50
E4830490	Cylindrical Vase	56
E4830490	Cylindrical Vase	51
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	54
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	50
E4830490	Cylindrical Vase	59
E4830490	Cylindrical Vase	55
E4830490	Cylindrical Vase	53

E4835360

E4835360	Conic Vase	80
E4835360	Conic Vase	77
E4835360	Conic Vase	84
E4835360	Conic Vase	78
E4835360	Conic Vase	83
E4835360	Conic Vase	82
E4835360	Conic Vase	89
E4835360	Conic Vase	81
E4835360	Conic Vase	72
E4835360	Conic Vase	79
E4835360	Conic Vase	79
E4835360	Conic Vase	84
E4835360	Conic Vase	78
E4835360	Conic Vase	85
E4835360	Conic Vase	76
E4835360	Conic Vase	81
E4835360	Conic Vase	83
E4835360	Conic Vase	87
E4835360	Conic Vase	77
E4835360	Conic Vase	85
E4835360	Conic Vase	86
E4835360	Conic Vase	83
E4835360	Conic Vase	82
E4835360	Conic Vase	83
E4835360	Conic Vase	84
E4835360	Conic Vase	80
E4835360	Conic Vase	76
E4835360	Conic Vase	81
E4835360	Conic Vase	81
E4835360	Conic Vase	86
E4835360	Conic Vase	82
E4835360	Conic Vase	79
E4835360	Conic Vase	79
E4835360	Conic Vase	80
E4835360	Conic Vase	78
E4835360	Conic Vase	80
E4835360	Conic Vase	87
E4835360	Conic Vase	92
E4835360	Conic Vase	82
E4835360	Conic Vase	81

E4835360	Conic Vase	74
E4835360	Conic Vase	79
E4835360	Conic Vase	73
E4835360	Conic Vase	87
E4835360	Conic Vase	86
E4835360	Conic Vase	77
E4835360	Conic Vase	84
E4835360	Conic Vase	79
E4835360	Conic Vase	79
E4835360	Conic Vase	80
	E4776920	
E4776920	Conic Vase	142
E4776920	Conic Vase	151
E4776920	Conic Vase	147
E4776920	Conic Vase	150
E4776920	Conic Vase	146
E4776920	Conic Vase	144
E4776920	Conic Vase	153
E4776920	Conic Vase	141
E4776920	Conic Vase	149
E4776920	Conic Vase	128
E4776920	Conic Vase	139
E4776920	Conic Vase	153
E4776920	Conic Vase	152
E4776920	Conic Vase	150
E4776920	Conic Vase	144
E4776920	Conic Vase	142
E4776920	Conic Vase	147
E4776920	Conic Vase	153
E4776920	Conic Vase	155
E4776920	Conic Vase	141
E4776920	Conic Vase	142
E4776920	Conic Vase	158
E4776920	Conic Vase	143
E4776920	Conic Vase	137
E4776920	Conic Vase	144
E4776920	Conic Vase	139
E4776920	Conic Vase	139
E4776920	Conic Vase	151
E4776920	Conic Vase	152

E4776920	Conic Vase	152
E4776920	Conic Vase	157
E4776920	Conic Vase	145
E4776920	Conic Vase	154
E4776920	Conic Vase	146
E4776920	Conic Vase	146
E4776920	Conic Vase	140
E4776920	Conic Vase	146
E4776920	Conic Vase	152
E4776920	Conic Vase	140
E4776920	Conic Vase	150
E4776920	Conic Vase	147
E4776920	Conic Vase	148
E4776920	Conic Vase	156
E4776920	Conic Vase	146
E4776920	Conic Vase	146
E4776920	Conic Vase	155
E4776920	Conic Vase	139
E4776920	Conic Vase	145
E4776920	Conic Vase	144
E4776920	Conic Vase	155
	E5325571	
E5325571	Cylindrical Vase	66
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	66
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	61
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	61
E5325571	Cylindrical Vase	60
E5325571	Cylindrical Vase	67
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	68
E5325571	Cylindrical Vase	66

E5325571	Cylindrical Vase	60
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	67
E5325571	Cylindrical Vase	62
E5325571	Cylindrical Vase	68
E5325571	Cylindrical Vase	69
E5325571	Cylindrical Vase	69
E5325571	Cylindrical Vase	60
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	67
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	62
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	69
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	60
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	70
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	63
E5325571	Cylindrical Vase	65
E5325571	Cylindrical Vase	66
E5325571	Cylindrical Vase	58
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	64
E5325571	Cylindrical Vase	67
E5325571	Cylindrical Vase	65
	E5306954	
E5306954	Glass	44
E5306954	Glass	48
E5306954	Glass	41
E5306954	Glass	52
E5306954	Glass	46
E5306954	Glass	48
E5306954	Glass	47

E5306954	Glass	45
E5306954	Glass	49
E5306954	Glass	47
E5306954	Glass	48
E5306954	Glass	45
E5306954	Glass	47
E5306954	Glass	45
E5306954	Glass	47
E5306954	Glass	48
E5306954	Glass	45
E5306954	Glass	44
E5306954	Glass	47
E5306954	Glass	49
E5306954	Glass	49
E5306954	Glass	46
E5306954	Glass	50
E5306954	Glass	46
E5306954	Glass	45
E5306954	Glass	47
E5306954	Glass	43
E5306954	Glass	46
E5306954	Glass	47
E5306954	Glass	46
E5306954	Glass	47
E5306954	Glass	44
E5306954	Glass	44
E5306954	Glass	50
E5306954	Glass	44
E5306954	Glass	46
E5306954	Glass	45
E5306954	Glass	46
E5306954	Glass	51
E5306954	Glass	46
E5306954	Glass	48
E5306954	Glass	42
E5306954	Glass	46
E5306954	Glass	47
E5306954	Glass	46
E5306954	Glass	42
E5306954	Glass	47

E5306954	Glass	49
E5306954	Glass	45
E5306954	Glass	45
	E5318630	
E5318630	Plate	23
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	21
E5318630	Plate	20
E5318630	Plate	22
E5318630	Plate	20
E5318630	Plate	23
E5318630	Plate	21
E5318630	Plate	24
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	22
E5318630	Plate	23
E5318630	Plate	22
E5318630	Plate	22
E5318630	Plate	22
E5318630	Plate	20
E5318630	Plate	20
E5318630	Plate	23
E5318630	Plate	20
E5318630	Plate	24
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	21
E5318630	Plate	24
E5318630	Plate	22
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	22
E5318630	Plate	22
E5318630	Plate	23
E5318630	Plate	20
E5318630	Plate	22

E5318630	Plate	21
E5318630	Plate	23
E5318630	Plate	22
E5318630	Plate	22
E5318630	Plate	20
E5318630	Plate	21
E5318630	Plate	23
E5318630	Plate	23
E5318630	Plate	21
E5318630	Plate	22
E5318630	Plate	20
E5318630	Plate	22
E5318630	Plate	21
E5318630	Plate	22