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Lean and Assembly: process improvement using Lean Tools in an Italian manufacturer

TESI DI LAUREA MAGISTRALE IN

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Abstract (English version)

In present days companies put in place different strategies to sustain competitive advantage over their competitors: one of them is manufacturing cost reduction. To achieve this ambitious strategic objective, one of the most successful approaches is the adoption of Lean Manufacturing and, as a tactical action, the implementation of Continuous Improvement Program based on Lean Manufacturing Tools.

This work presents a practical application to an improvement process in an Italian manufacturing company: the objective is to provide a real successful case study to support the methodological framework already present in the scientific literature.

After a brief review of the existent methodologies and frameworks, the case study is presented. The improvement project is selected and a description of the actual process is provided with major inefficiencies and wastes. The target is set, based on relevant KPIs, and the gap is determined: the analysis of root causes is carried out to design the most effective solutions to problems. A rough implementation with is delivered to the area: a close monitoring of the selected KPIs is put in place, in order to evaluate the results of the project.

Key-words: Lean, Assembly, Kaizen, Improvement, Make to Order, Case study.

Abstract (versione italiana)

Al giorno d'oggi, le aziende mettono in pratica differenti strategie per sostenere il vantaggio competitivo rispetto ai loro competitor: one di queste è la riduzione dei costi di produzione. Per ottenere questo ambizioso obiettivo strategico, uno degli approcci di maggior successo è l'adozione della Lean Manufacturing e, come azione tattica, l'implementazione di un Programma per il Miglioramento Continuo, basato sulle tecniche Lean.

Questo lavoro presenta un approccio pratico ad un progetto di miglioramento in un'azienda italiana: l'obiettivo è di fornire un caso di successo reale per supportare le metodologie che già sono esistenti nella letteratura scientifica.

Dopo una breve revisione delle esistenti metodologie, il caso studio viene presentato. In primis, il progetto viene selezionato e una descrizione dello stato attuale del processo è fornita, distinguendo i maggiori sprechi e inefficienze. L'obiettivo è definito, basato su KPIs rilevanti, e il gap è determinato: attraverso l'analisi delle cause radici le soluzioni sono progettate. L'area è quindi trasformata con una prima implementazione e i KPIs sono monitorati per valutare i risultati del progetto.

Parole chiave: Lean, Assemblaggio, Kaizen, Miglioramento, Make to Order, Caso studio.

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1 Introduction

In present days companies put in place different strategies to sustain competitive advantage over their competitors: one of them is manufacturing cost reduction.

To achieve this ambitious strategic objective, one of the most successful approaches is the adoption of Lean Manufacturing and, as a tactical action, the implementation of Continuous Improvement Program based on Lean Manufacturing Tools.

Typically, with these Continuous Improvement Programs, companies select areas and processes to improve and then the improvement process based on analysis and Lean tools is delivered to the area.

This work presents a practical application of an improvement process in an Italian manufacturing company: the objective is to provide a real successful case study to support the methodological framework already present in the scientific literature.

Indeed, in the second chapter a brief review of the existent methodologies and frameworks is presented. The research is focused on methodologies correlated with practical applications in assembly processes: these are reported in the chapter, with cases from several industries.

The third chapter describes the methodology and the case study tackled in the company. Once the context has been cleared out and the improvement project has been selected, a description of the actual process is provided with major inefficiencies and wastes: the relevant KPIs is evaluated on the percentage of Non Value Added activities performed by the operator during the shift.

Based on the KPI, the target is set and the gap is determined: the analysis of root causes is carried out to design the most effective solutions to problems.

A rough implementation with Kaizen events, “Rapid improvements”, is then brought to the assembly area: a close monitoring of the selected KPIs is put in place, in order to evaluate the effectiveness of each implemented solution. The second chapter ends with a discussion of the results.

In the fourth chapter a reflection about the experience is presented, with a discussion of possible future improvements. Moreover, the methodology and the results are compared with the one contained in the literature review.

2 Literature review

The main content of the work presented in this paper is an application of well-known techniques and frameworks to an industrial case study: for this reason, this introductory chapter has the objective of presenting some of the frameworks used by researchers and their application in other industrial cases.

The focus of the paper is toward the application of Lean concepts and tools: as mentioned before, Lean concepts are well-known, so in this chapter only a small resume of the fundamentals is reported.

2.1. Lean Manufacturing and Kaizen

The basic concept that a Lean company has to pursue in order to maximize the profit, is to deliver in the more efficient and effective way value to the customer. Efficiency is reached by eliminating waste in the processes through a continuous improvement process, called Kaizen. For what concerns manufacturing process improvement, it must happen on the field, the Gemba, with great involvement of the workforce.

Nowadays Lean Manufacturing and the Kaizen Methodology are more and more recognized as fundamental concepts and practices that companies use to achieve and sustain a competitive advantage in the global industrial context. As said before, manufacturing companies typically put in place Lean Manufacturing to look for strategical cost reduction and process optimization in the short and in the long term. Lean manufacturing is also important as a transitory step in the successful implementation of the Industry 4.0 paradigm, that today and for the next years is one of the biggest challenges that manufacturing companies will have to face off.

For this reason and thanks to the great results achieved in the past years, the implementation of Lean and Kaizen is constantly increasing "*enlarging frontiers of kaizen implementation in new industry sectors that are still unexplored*" (Rossini et al. 2019) . New manufacturing sectors are a field of interest for researchers, that are willing to understand all the potentialities of Lean and Kaizen implementation. These sectors are, for example, make-to-order companies featured with high-mix and low-volume production. Both Rossini (2019) and Cannas (2018), in their work, refers to these industrial context, as a proof of the current importance of the theme.

Another key concept mentioned before is the Kaizen concept, also called Continuous Improvement, is *"an endless effort to ameliorate organizations"* (Rossini et al. 2019) that has to directly involve people and proceed with constant, progressive changes. The application must be performed on the field: indeed, according to Cannas (2018), mathematical models are *"still too complicated and a model capable to intercept the variety and the complexity has not be developed by researches. The application of these models to complex industrial problems is still far to be performed"*.

Characteristics of Kaizen events have been listed by Hamel (2009): the approach has to involve the employees, be based on standard work, be enabled by a person in the organization who leads the change and, last but not least, has to be aligned with the strategy of the company. Also Rossini (2019) stressed out the importance of standardization in Kaizen application, as a tool to track and transmit knowledge inside the company.

Another application of Kaizen events in process improvements is reported by Ortiz (2006): its study demonstrates a successful application of Kaizen concepts when performing Assembly Line Balancing, which is a method to optimize the performances of assembly lines. Moreover, he stressed the fundamental importance of people involvement to allow the organization in achieving best results.

Lean manufacturing proved to be very successful in improving the value delivered to customers for industrial contexts where stable conditions for demand and supply have been established: as a matter of fact, stability is a prerequisite for Lean implementation.

However, recently, the focus of researchers moved toward different application fields in order to enlarging the frontiers of proven effectiveness of Lean application.

Examples of this trend are the already cited works of Rossini (2019) and Cannas (2018): the former provided a framework with a successful industrial implementation in a Make-To-Order company producing air compressor, while the latter studied and tested a methodology for the balancing of an assembly line using Lean Tools in a chocolatier company where the line manages high number of parts and finished products. Finally, Schulze (2021), explored the application of Lean in the Engineering-To-Order industry, highlighting the existing barriers in the organization, management, know-how and culture. However, the research is interesting for the novelty of the application field that provides highly customizable goods.

2.2. Frameworks for Lean Implementation

Another key topic when talking about Lean is the implementation, which is the most important part and the one responsible for the real change in the organization.

Researchers reported several approaches to Lean implementation, changing according to the context of application: "*companies lack on having a structured guide for their continuous improvement journey and strive on looking for a kaizen framework that fits well with their systems*" (Rossini et al. 2019).

Timans et al. (2016) proposed a framework for Lean and Six Sigma implementation in Small and Medium Enterprises: their work has a broader perspective over the implementation of Lean, talking about not only of the improvement of a manufacturing system but also, with a wider breath, about how a company can achieve and sustain a culture dedicated to Lean and Continuous Improvement. Below it is reported a schema of the framework Timans et al. (2016) provided in their work.

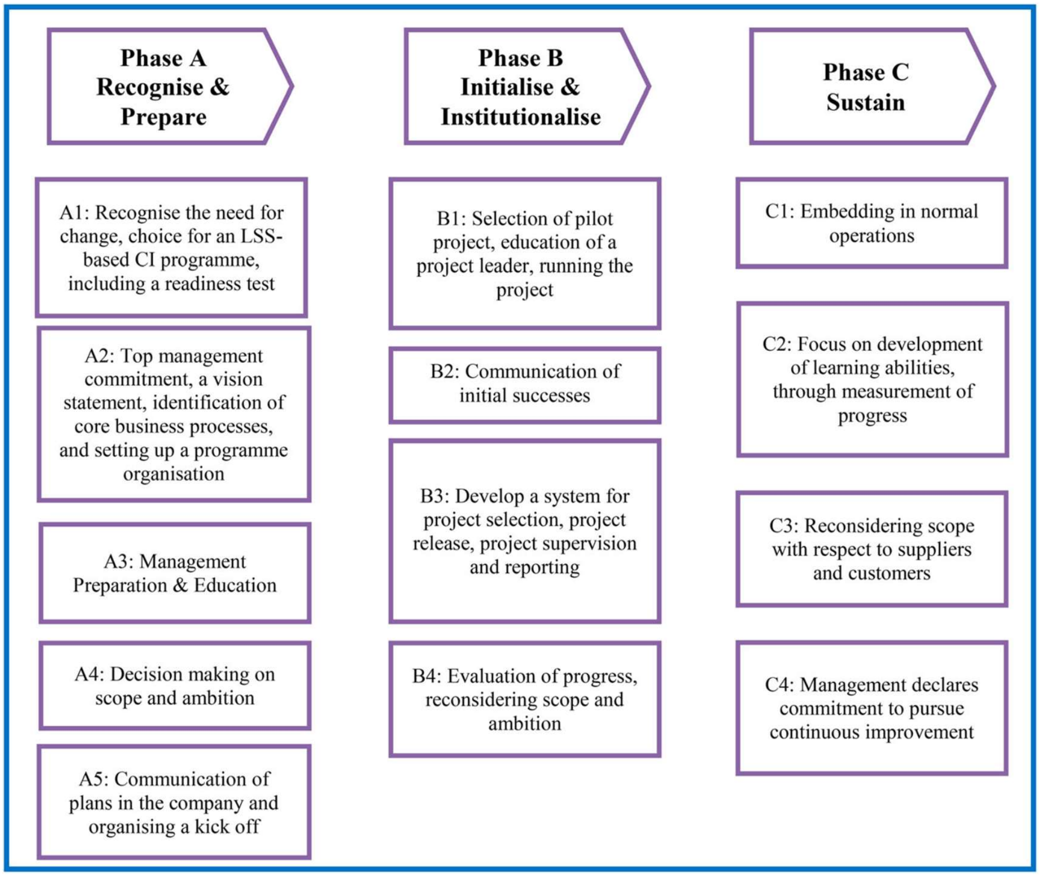


Figure 1 Framework for Lean Implementation in SMEs (Source: Timans el al., 2016)

Other researchers focuses on developing frameworks for the implementation of Lean where the production happens. Despite a lot of different approaches, some commonalities emerged: these are the orientation toward an analytical and structured analysis of the production processes, with different tools used according to the application context, a team-based approach, enhanced by a clear role assignment, and implementation using the Kaizen concept explained in the previous part of this chapter.

Álvarez et al. (2009) proposed a methodology to improve processes in an assembly line, which is based on Lean Tools and Kaizen methodology. The most important tool used is Value Stream Mapping, as a mean to analyze processes and inventories.

Design and implementation of solution have been done with a Kaizen Continuous Improvement approach, with a continuous cycle of measure, analyze, design and test. They tested the methodology with a practical application: measured results are a reduction of inventory, material flow improvements, reduction of Non-Value-Added activities and finally a reduction of cycle times.

Prashar (2014) studied the application of Lean Manufacturing in an Indian company, with the objective of illustrating how the application of Value Stream Mapping and Kaizen events can drastically improve the performance of an assembly line. Researchers stressed out the importance of studying the initial state of a process, identify areas of improvement and the reason behind the need for them, and finally the implementation in the field through Kaizen events. Results of their study are: reduction of inventory levels, improvements of quality and reduction in the number of resources needed for production.

Correia et al. (2018) performed a study to improve the performances of an assembly line of electronical devices: this application of Lean Tools is interesting due to the complexity of the products that are featured with different configurations and produced in small batches. Correia carried out a successful application of Value Stream Mapping and, to optimize the performance of the assembly line, an implementation of assembly line balancing through Lean concept. Results have been improvements in productivity, an increase of quality of products. Moreover, the project improved the effectiveness of the working conditions, reducing non value added activities and improving ergonomics.

In the work of Dinesh et al. (2019), the researchers proposed a structured framework to tackle the problem of increasing the production capacity of an assembly line. In the image below the proposed framework is reported: the most important tool is Value Stream Mapping, used as guideline to find improvements in the system.

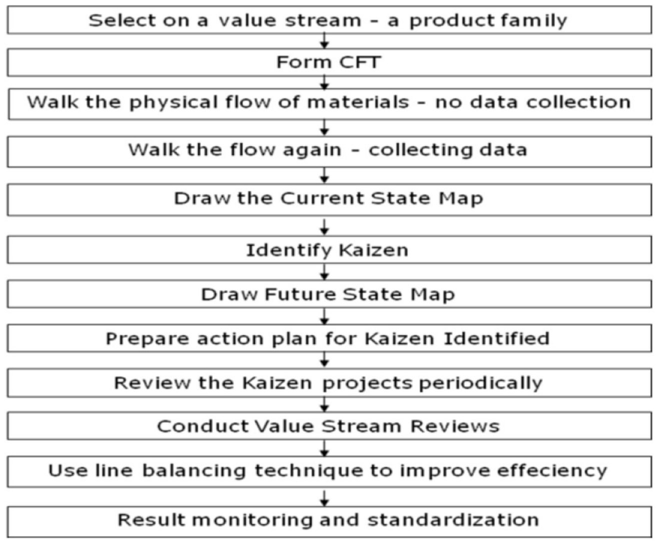


Figure 2 Schema for assembly line improvement through Value Stream Mapping (Source: Dinesh et al., 2019)

However, the researchers find also extremely important, when talking about an assembly line, to perform events for line balancing; moreover, Kaizen events have been conducted in order to transform the assembly line through small steps. Obtained results affected the assembly line over these performances: increase in production capacity, reduction of manpower, increase of productivity and improved overall efficiency of the assembly line.

Rane et al. (2015) used a different approach respect to the other presented before, to the topic of performance improvement. The research was conducted in a vehicle assembly line. They, at first, tried to develop a mathematical model to describe the production system, in order to perform optimization through exact algorithms: however, this approach was not able to capture all the complexities of a real production system. For this reason they shifted to an approach based on Lean tools, to develop solutions, and on simulation, to evaluate the impact of every solution before to implement them. The results obtained on the performance of the vehicle assembly line were: reduced cycle time and increased production capacity, increase in quality and the diffusion of Lean culture, which was positively accepted by people in the company.

Lam et al. (2016) worked on a framework for assembly line optimization. They first analyzed the assembly line in terms of assembly processes, workstation layout and cycle time. The Takt Time required by the market is computed and bottleneck analysis is performed to identify improvements. Root causes have been identified using typical problem solving tools, such as Ishikawa diagram, and different solutions have been developed: the central solution is to reduce bottlenecks by reviewing the balancing of the assembly line.

Results have been an increase of efficiency of the assembly line in term of productivity and usage of resources, with a decrease of 25%.

Nee et al. (2012) operated in the context of Small and Medium Enterprises, with the objective of developing a framework for process improvements. The methodology is divided into 5 phases: definition of the scope of the process, measure the process, analysis and initial identification for opportunities, identification of definitive solution and implementation with monitoring. In the image below, the schema of the methodology is reported.

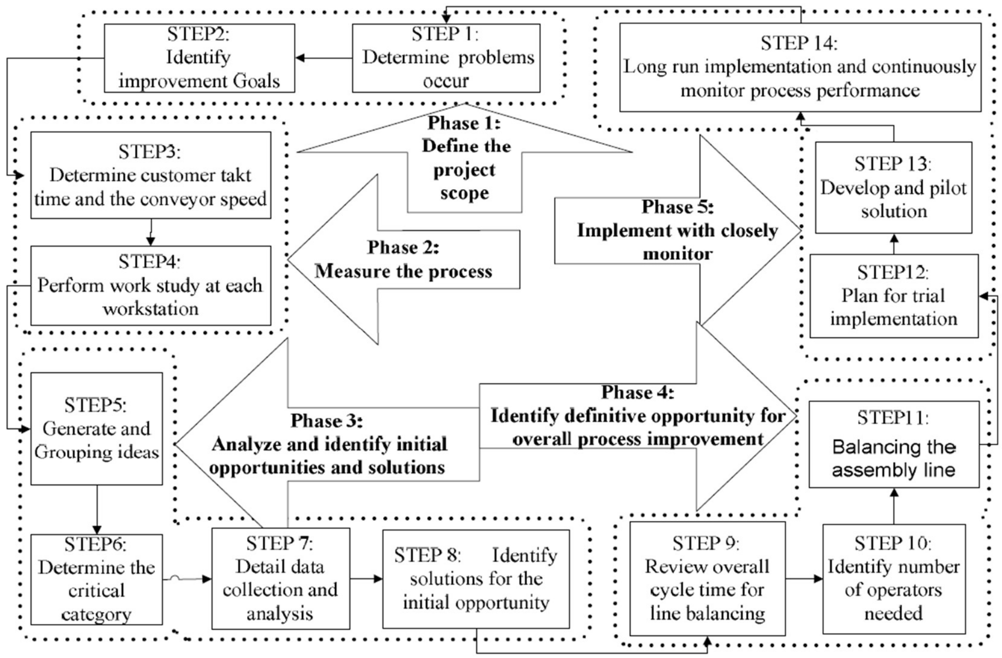


Figure 3 Process improvement framework (Source: Nee et al., 2012)

The framework has been tested with a case study in a manufacturing company: Lean tools such as definition of Takt Time, bottleneck analysis and waste elimination, line balancing and people involvement were at the basis of the case study.

Results obtained in the case study are an overall improvements of the assembly line, with lower manpower, lower cycle time and increase balance between workstations.

In the paper of Borgave & Sapkal (2020), researchers addressed the application of Lean Manufacturing to the assembly line of a company producing compressors. The methodology they present is based on the following steps: at first data about the processes are collected, measuring value added and non-value added activities. The desired takt time of the assembly line is computed and bottleneck stations are identified. The following step is the implementation of Lean Tools: researchers selected FMEA analysis, as a prioritization tools to rank the causes of the bottlenecks and to develop solutions; solution has been implemented through Kaizen events. Results achieved are positive: reduction of cycle time, reduction of the space available for the production and a reduction of the distance travelled by operators.

Cannas et al. (2018) aimed at providing a framework to guide practitioners in the implementation of the Assembly Line Balancing concept, in order to ease the application of the technique: "*performing kaizen events for every product and redesigning the layout of the manufacturing plant every time a new product is launched would require too much time and too many investments*" (Cannas et al. 2018), since in the design of an assembly Line the most important problem to be solved is the Assembly Line Balancing. The methods mostly applied in the literature, according to Battaïa and Dolgui (2013), consist in the application of the mathematical models mainly used for the combinatorial optimization.

The methodology proposed by the researchers is composed by two steps: at first, the complexity of the production system has to be reduced by acting on finished products, materials and components. After that, Assembly Line Balancing is performed with empirical and practical tools, with an easier approach to the topic rather than with mathematical concepts.

Complexity can be managed and reduced by applying different strategies both at the product level and at the process level (Brun and Pero, 2012): in this case, complexity reduction has the objective of identifying a representative product. The selection is based on the analysis of the bill of materials to identify commonalities between the components; then, to each of the clusters is assigned a set of task and an assembly macro cycle is estimated. The representative macro cycle is selected by looking at the set with the highest planned working hours. This step is mandatory to perform the second step in an efficient and effective way: indeed, the number of kaizen events depends on the quality of the analysis performed.

Kaizen events are directly conducted on the field with involvement of the operators: in each event only one problem of unfulfilled performance should be tackled, with the objective of eliminating the gap. The suggested methodology is the following: data gathering, standardization with the application of 5S and standard sheets and the, line balancing.

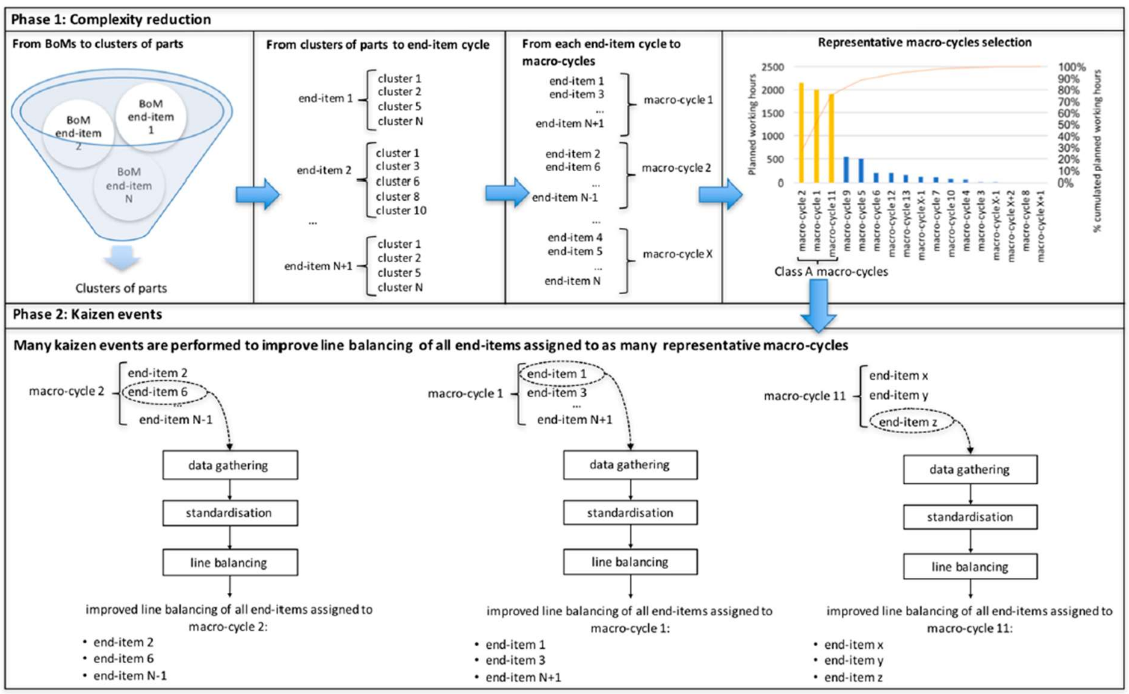


Figure 4 Schema of the methodology (Source: Cannas et al. 2018)

The case study has been delivered in an Italian chocolatier company where the assembly line has to cope with a large varieties of different parts and end-item. The application of the methodology reported an overall improvements of the assembly line performances; however, researchers established the largest improvements in the process of Assembly Line Balancing that, due to the preparatory work of complexity reduction and the novel application through empirical tools, took few time and allowed for assembly improvements too.

Rossini et al. (2019) studied a framework for Lean and Kaizen implementation in an high-mix low-volume production context: their idea is to develop a successful methodology in order to lead practitioners in the application of Lean manufacturing concepts.

The framework is structured on the basis of the A3 methodology, with a structured approach to problem solving and guiding the team through the project phases. One of the most important aspects of the A3 template is processes and data visualization, which is useful to spread information and to keep the project going. Fundamental is the creation of the team, that has to involve people from different company functions and has to be structured with a clear division of role and responsibilities.

Phases of the framework are reported in the image below.

Box 1: Reason for action	Box 4: Gap analysis	Box 7: Completion plan
Box 2: Initial state	Box 5: Solution approach	Box 8: Confirmed state
Box 3: Target state	Box 6: Rapid experiments	Box 9: Insights

Figure 5 Framework for kaizen implementation – (Source: Rossini et al. 2019)

In *Reason for action* the project is selected and a clear and concise statement, representing the problem, is defined. Afterwards, in the *Initial state*, the present state has to be mapped: measurement is fundamental to guide the improvement and, for this reason, KPIs must be identified and measured using analytical tools such as Value Stream Mapping. The third phase, *Target state*, has the objective of defining a clear target for the project, that has to be based upon the KPIs used in the *Initial state* phase.

Gap analysis is at the base of *Solution approach:* indeed, the task is to understand the reasons behind the gap between the present and the target state. The use of analytical tools for problem solving, such as 5Whys analysis and Ishikawa diagram, is suggested to approach the problem. After, *Solution approach* and *Rapid experiments* are the steps dedicated to the develop and test the solution with the highest priority: so the use of prioritization tools, such as Cost-Benefit analysis, is suggested. In *Rapid experiments*, the time horizon has to be compressed: researches explain the need of dedicated resources to complete the project in the most efficient and effective way. The *Completion plan* has to track the realization of the activities in order to get to the *Confirmed state* respecting the timing: the confirmed state has to be measured, in order to let the company analyze the results and the overall development of the project in the last phase of the *Insights.*

The framework has been tested with a case study in a manufacturing company characterized by high-mix low-volume. Analytical tools such as Value Stream Mapping, SIPOC analysis, RACI matrix for role allocation, interviews with data collection, Ishikawa diagram, cost impact matrix and Yamazumi chart were applied. The application was successful from all the points of view, with these results: reduction of cycle time, increase in planning accuracy, reduction of lead time and a reduction of the area occupied.

Among all the selected papers, two of them are very representative regard to the application context of the case study further presented in this paper work. These are the work of Cannas et al. (2018) and Rossini et al. (2019): the methodology applied by these researchers is at the base of the one used in the case study.

3 Case study: assembly process improvement at Giacomini S.p.A.

This chapter of the paper work describes a practical experience I carried out in a in Italian manufacturing company, Giacomini S.p.A.

The experience has the aim of implementing Lean knowledge for process improvement in an assembly area, using a framework to guide the work.

In the next chapters a brief introduction of the Company and the operating context is presented and then the improvement project is explained.

At end the results are clearly shown.

3.1. Description of the company

Giacomini S.p.A. is an Italian excellence, designing, manufacturing and distributing high-end components and integrated systems for the treatment and usage of water.

The history of the company began right after the World War II when, in 1951, the founder Alberto Giacomini started to produce brass components using a simple lathe. From that moment on the company was engaged in a great development and growth path thanks to the boost given by the Economic Boom in the final decades of the 20th century and their natural propension of competing in the international market. Nowadays the company kept a strong relationship with its origin, since the headquarter and main production facilities are still in the original city where Alberto Giacomini lived: a small town in Novara district, San Maurizio d'Opaglio. Giacomini S.p.A counts a total of three production facilities, all located in Italy: two of them are in San Maurizio d'Opaglio while the third one is in Verona district, at Castelnuovo del Garda. A part from that, the company has a very global dimension with established partners and customers in USA, Canada, Brasil, Russia, China and India but also all over Europe.

The dimensions reached by the company, that counts around 1000 employees and 200 million € of Total Revenues, set it as one of the market leaders in the industry of brass and water systems.

The industry the company operates in, is the construction and building industry. By looking in a more detailed way at the product-range offered by Giacomini S.p.A., six main market segments are recognized: energy management, radiant systems, water management, gas distribution, renewable sources, fire protection. In all these segments, the company proposes as products both single components and integrated systems. For example, a customer can decide to buy a single valve or a complete, integrate system for managing, metering and distributing water in a building.

The market is mainly B2B, where the company has a direct contact with customers thanks to commercial branches located in the countries of main interest. Typical customers are distributors, building designers, water systems technicians and fitters. Nowadays the construction and building industry asks for a huge variety of products, changing especially in terms of flexibility and adaptability, according to the different needs of the solutions: the global dimension of the customer base forced Giacomini S.p.A to develop different products to be compliant with the variety of regulations existing in the supplied countries.

In its recent history Giacomini S.p.A. has put in place different strategies to support its competitive advantage: the most important one that regards manufacturing is called "Lean Company" and, as it can be easily understood, it regards a major transformation of production in order to be smoother and more conscious in the usage of resources. A specific team has been formed to sustain this change but, since the novelty of the introduction, the Lean culture is not as widespread within the company. Moreover, the Lean transformation is coupled with the introduction or the conversion of production systems compliant with the of the Industry 4.0 paradigm: Giacomini S.p.A. is preparing itself to meet the challenges of the future, in order to become faster and more flexible in serving customers.

3.2. Methodology

The case study was delivered using a precise and structured methodology, reported in the literature from several authors.

The methodology is based on the well-known A3 framework, which is a standard tool to solve and carry out problems in an analytical way. However, as it will be described soon in the paper-work, the production systems is MTO, with high variety and low volume production: for this reason the A3 framework was integrated with prioritization tools to cope with the particular MTO context.

For what regards the implementation is carried out through the usage of kaizen events, called Rapid Improvements, which was planned by the team in order to try and test the functionality of the solutions.

The steps of the methodology, that are also the next chapters, are reported below:

a. *Context setting and background of the project*
b. *Problem definition*
c. *Target setting*
d. *Gap analysis*
e. *Countermeasures*
f. *Implementation*
g. *Results*

3.3. Context setting and background of the project

In this chapter the introduction at the context of the project is presented.

The objective is to set up the conditions where the project has to be delivered, the reason for the action and the relevant stakeholders.

3.3.1. Reason for action

The aim of the first part of this chapter is to collect information about the reason behind the need for action. This is going to be helpful for the project development, in order to understand in a better way how the project will help the company in achieving its strategy.

During the last years, the company put in place a Continuous Improvement Program, led by the direction of both the Manufacturing Manager and the Lean Manager.

The Continuous Improvement Program created an evolving context: the reason for action is the relocation of the assembly line "Line 21" in another plant of Giacomini S.p.A.. Due to this reason, the company decided to seize the opportunity to improve the production processes of the before mentioned production line.

3.3.2. Background of the project

In the project background a first approach to the problems to be tackled in the project is presented. In addition, the operative context of the production line is introduced.

About the project deployment of the activities, no structured framework was used. However, the project was carried out in a multifunctional team, formed by the Plant

Manager, the Production Manager, the Lean Manager, the Production Line Manager and the Production Line Operators. Direct involvement in the activities was requested from the Lean Manager and the Production Manager, while indirect or on-request involvement from the Production Line Manager and the Production Line Operators. The Plant Manager was the person in charge for the project development.

The production system is now described: it is a Make To Order, characterized by a high number of product variants and a medium to low production volume: the product mix counts 42 products, that are divided in semi-finished products (7) and finished products (35).

The manufacturing process is an assembly process, carried out in a fixed position assembly layout, with components to assembly and assembly to operator method. On average two operators are working in this assembly area; the logistic process between the warehouses and the assembly area is carried out by a dedicated logistic operator.

The first approach to the problem description is a macro analysis of production data. The objective of the analysis is to understand the metrics and the point of view of the Production Managers of the company, in order to start to focus on the problem in a quantitative way. Historical production data were used, supplied by the ERP of the company and referring to years 2018, 2019, 2020.

The extracted data, available for the analysis are:

- *Date*: the day when the production was done, expressed in dd/mm/yyyy
- *Production order number*: the serial number, which is univocal, referring to the production order
- *Material ID*: the code associated to the processed product

- *Operator ID*: the code associated to the worker
- *Process ID*: the code associated to the manufacturing step which was processed
- *Production line ID*: the code associated to the production line
- *Effective production volume*: the quantity produced in the shift
- *Effective production time*: the effective amount of production time in the shift
- *Efficiency*: a performance indicator computed as the effective production time/standard production time

The analysis of the performance of the assembly line, with "Efficiency" taken into account as reference KPI, displayed a low overall performance of the assembly line. According to the Production Manager the average Efficiency, 68%, is way lower than other assembly lines of the company. In addition, we measured the data interval to verify the consistency of this data in a simple way: from the verification it emerged that the performance data were not consistent, for which a more detailed study was necessary. This further study will be addressed in the next chapter.

3.4. Problem definition

This chapter describes the approach toward the definition of the problem.

It is divided into these parts: in the first the Make To Order context of the assembly area is tackled in order to reduce the variability of the processes.

Secondly, a prioritization approach to determine the most relevant projects is carried out and the project is selected.

In the last part, the selected project is investigated and the problem statement is carried out.

3.4.1. Approaching the MTO context: complexity reduction

In the previous chapter we highlighted the necessity of a deeper analysis of the elements composing the production system. In this phase of the project, the products produced in the assembly line and the technological transformation of the production processes are investigated.

The objective of this step of the methodology is twofold: on one side a deeper study of the production mix results in a more precise and comprehensive understanding of the assembly system and, on the other side, it allows to reduce the complexity by highlighting the most relevant components of the production system.

The output of this part is a prioritization matrix.

3.4.1.1. Production data analysis

Also in this case, the starting point of the breakdown of the problem is production data analysis. The objective is to characterize the production system by highlighting the most relevant components. In doing so, historical data are used.

The dataset is the same described in chapter 3.4.

Data are analyzed according to the dimension of “Effective production time”: the idea behind this choice, which was taken in agreement with the other components of the team, is that time is the nearest proxy of the manufacturing costs. Consequently, the effective production time is a relevant parameter to identify the most important products from an optimization perspective.

However, as a secondary KPI, the team decided to take the “Effective production volume” to also get an idea of the volume produced and the complexity of the products: if the volume produced is low but the Effective production time is high, the product is a complex one; on the other hand, if the processing time is low but the production volume is high the product is a simple one.

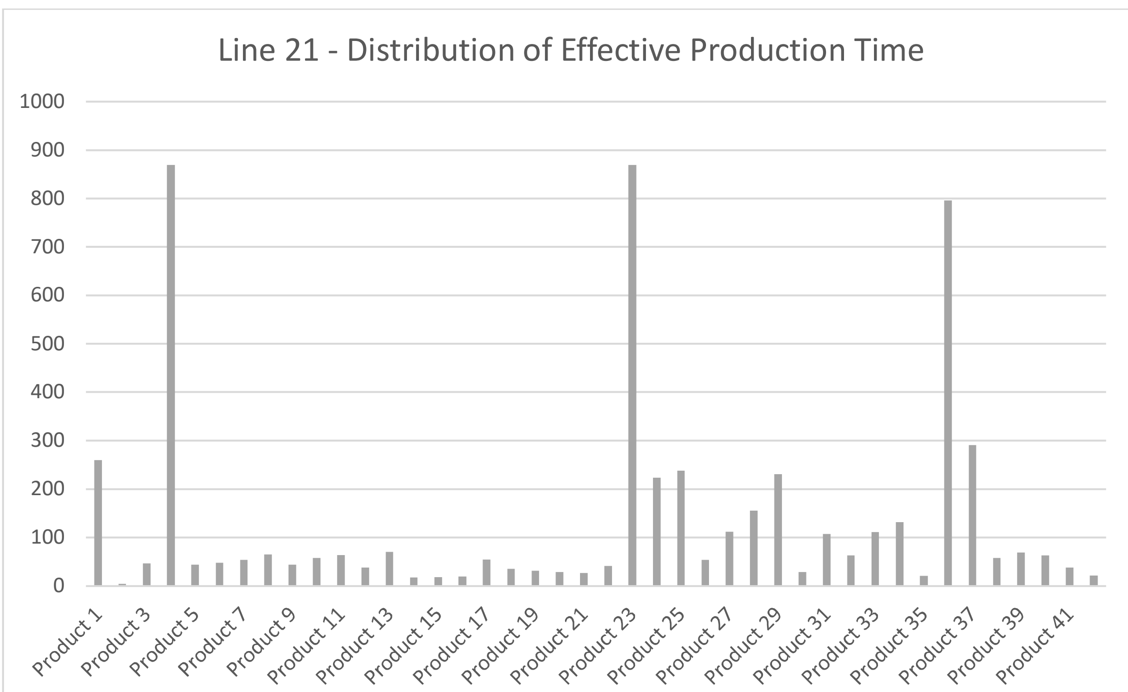


Figure 6 "Line 21" distribution of effective production time

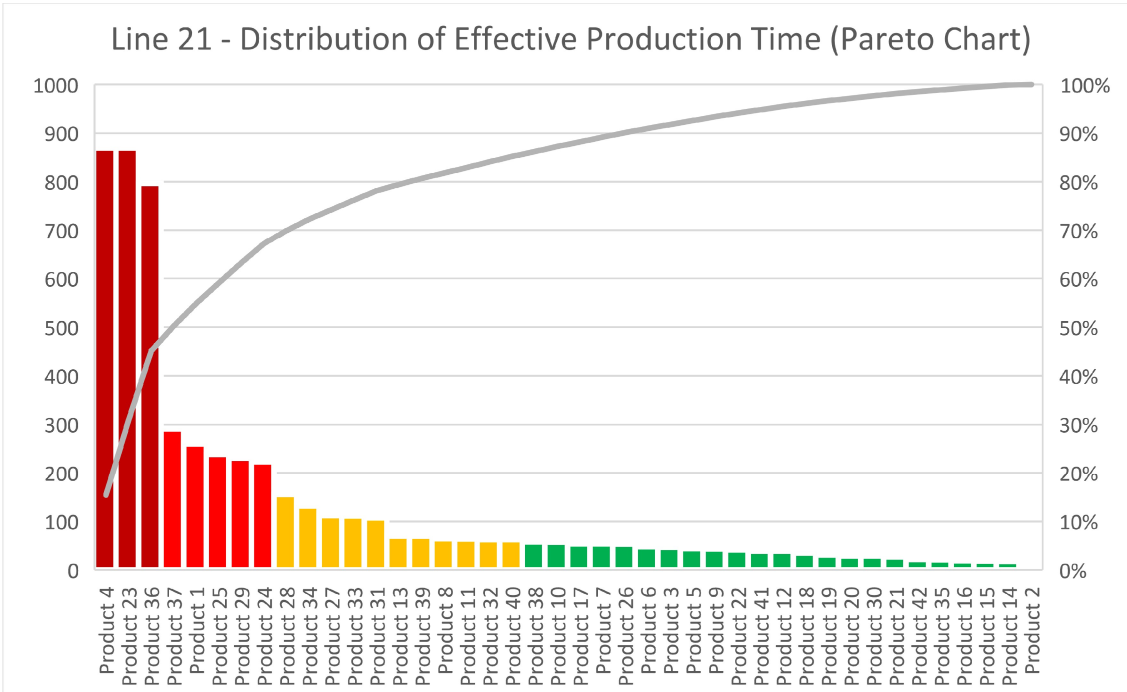


Figure 7 Distribution of effective production time - Pareto chart

The diagram displays which are the most relevant products according to Pareto analysis: the names of the products have been hidden for confidential reasons. As explained before, the reference KPI is the Effective Production Time. Four classes of products can be identified: AA (3 products), A (5 products), B (11 products), C with the remaining products. Although products in class AA have a huge impact on the production time, discussion with the team agreed that a deeper analysis was needed using the product family classification to assess the existence of a more comprehensive prioritization.

3.4.1.2. Product families identification

Once the most relevant products have been identified, the idea is to check if among the products there are similarities.

The methods chosen for the classification are based on well-known practices:

- Technology routing
- Geometrical and components-based classification

Technology routing

The first classification is made through a qualitative analysis of the production processes. Company's staff such as the Plant Manager and the Production Line Manager played a key role as expertise facilitator in this part of the project.

From the Company's ERP data about the standard production processes were extracted and, thanks to the collaboration of the expertise of the company, it was possible to draw the Technology Routing Matrix.

The analyzed data were organized in the following way:

- *Material ID*: the code associated to the processed product
- *Material Name*: the name associated to the processed product
- *Process ID*: the code associated to the manufacturing step
- *Process Name*: the name associated to the manufacturing step
- *Production Line ID*: the code associated to the production line
- *Standard Cycle Time*: the cycle time set as the standard in the system
- *Standard Setup Time*: the setup time set as the standard in the system
- *Workforce Coefficient*: the coefficient represents the number of operators needed to perform the process

The objective of this analysis is to, in a very rough and simple way, identify product families according to the transformation they have to go through.

The manufacturing processes are four:

- *Gluing assembly*: the process of gluing consists in the joining of parts through the usage of glue. It is a completely manual process, with low or none presence of assembly fixtures. This is the most complex part of the process both from a quality and manufacturing lead time point of view: indeed, it is affected from strong technical constraints for the application of the glue that, once the parts are joined, has to polymerize before going on with the other processes.
- *Nut and pipe assembly*: this is a completely manual process with presence of assembly fixtures, that are key to guarantee the repeatability and the accuracy of the process. Parts are positioned inside the fixture and, once the desired position is established by the operator, each nut and pipe is tightened at the established torque.
- *Testing*: the testing process involves a quality control process, where the operator is responsible for establish whether the product is compliant and ready to be sold. The process consists in a visual check of any possible leakage: the product is filled with air and dipped in a tub, where the operator has to check for the formation of air bubbles.
- *Packing*: the packing process is usually the last stage of the manufacturing process. The product is refined and finished with the last parts and then packed in its case. Afterwards the product is transferred to the finished-goods warehouse or directly in the shipping area.

The methodology used to perform the analysis is a grouping algorithm.

	N° products	Gluing assembly	Nut and pipe assembly	Testing	Packing
Macro-Family 1	23	1	1	1	1
Macro-Family 2	19	0	1	0	1

Table 1 Technology routing diagram

From the data reported in the table above, it was possible to distinguish between two macro-families of products: Macro-Family 1 and Macro-Family 2.

The process of Macro-Family 1 is characterized by all the four manufacturing processes described in the previous part of the chapter: the technological routing for the great majority of products (21 out of 35 products, 60%) is composed by gluing assembly, nut and piping assembly, testing and packing.

The process of Macro-Family 2 is simpler (14 out of 35 products, 40%) and the technological routing is composed by nut and piping assembly and packing.

Geometrical and components-based classification

After the identification of Macro-Family 1 and Macro-Family 2, the preliminary analysis continued with a more refined analysis of the products, which were analyzed under the components perspective, by studying the bill of materials.

In each Macro-Family, products were grouped according to geometrical similarities in shape and in their bill of materials. The analysis performed was a comparison between each bill of materials, by looking at the quantities used by each components in every products.

As for the Technology Routing, also in this case the methodology used to derive the product families is the grouping algorithm.

	Product Family	N° products
Macro-Family 1	Product-Family 1	2
	Product-Family 2	10
	Product-Family 3	10
	Product-Family 4	1
Macro-Family 2	Product-Family 5	10
	Product-Family 6	4
	Product-Family 7	5

Table 2 "Line 21" product families

Macro-Family 1 has four different product families: Product-Family 1, Product-Family 2, Product-Family 3 and Product-Family 4. Despite the differences in the components, all these four product-families are similar in shape.

The situation is different for Macro-Family 2: inside the family there are three recognizable product-families (Product-Family 5, Product-Family 6, Product-Family 7), which are very diverse in shape and composition of the bill of materials.

In the table below are summarized the data of the previous analysis: the table displays the cumulative of Effective Production Time and Effective Production Volume of the Product-Families identified in the previous paragraph.

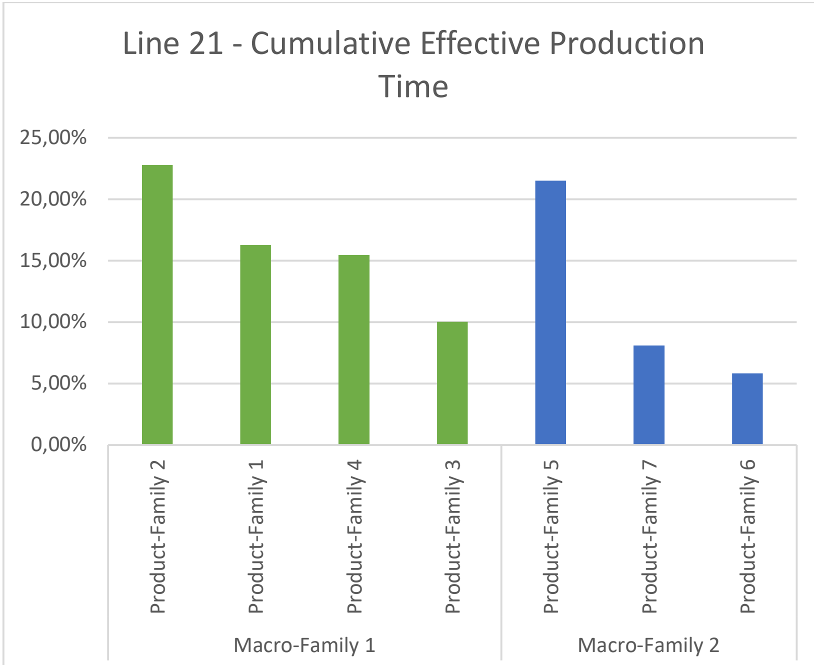


Figure 8 "Line 21" Cumulative effective production time

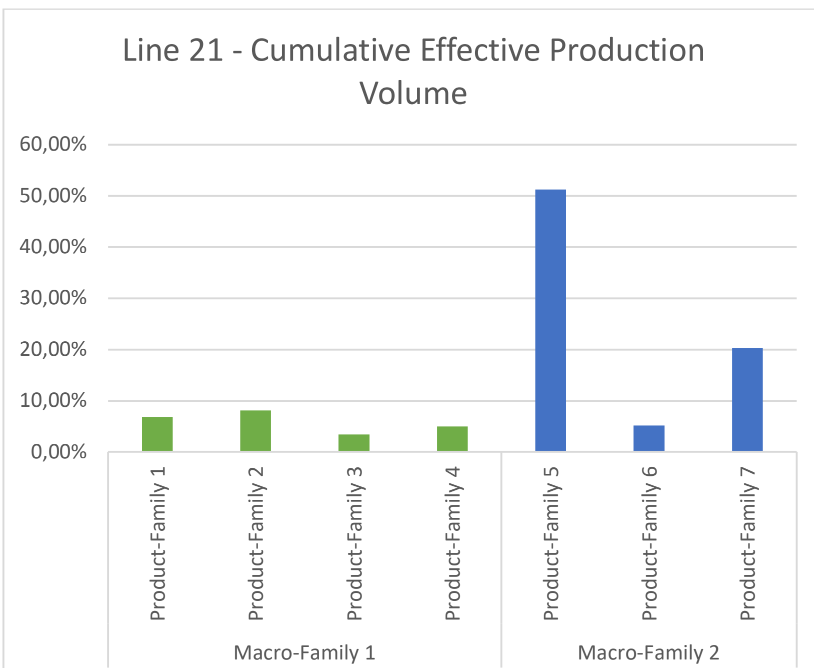


Figure 9 "Line 21" Cumulative effective production volume

The analysis carried out in the previous part of the chapter are important to reduce the complexity of the production system, in order to let the team decide where to put the priority of intervention and then to focus the effort on the most profitable project.

3.4.2. Project selection

This part of the project aims to prioritize intervention to address problems in a more efficient and effective way.

The tool used for the prioritization is a multicriteria decision matrix, which was composed and discussed with the members of the project team. In this phase all the members played a key role by making available their experience about the production system and other improvement projects.

The classification in product-families derived in the previous chapter was the starting point to compute the matrix, according to the Estimated Improvement Effort and the Estimated Improvement Impact.

The Estimated Improvement Effort is the effort that the company has to put in place in order to achieve an improvement on a product family: values that can be assigned are qualitative "Low", "Medium", "High" according to the knowledge about the production process and its complexity; the assumption behind the classification is that if the team has low knowledge about a production process and its complexity is high in number of different stages and technological transformations, then the effort would be high.

On the other hand, Estimated Improvement Impact represents the positive impact that the improvements would have on the organization. It is an estimation since the project team has not established the objectives yet; however, by looking at the data of production volume and effective production time, it is possible to understand if an improvement on a certain product family would generate a greater impact that an improvement on another one. Also in this case the classification has been made with a qualitative point of view, according to three levels "Low", "Medium" or "High".

The discussion within the project team lead to these results:

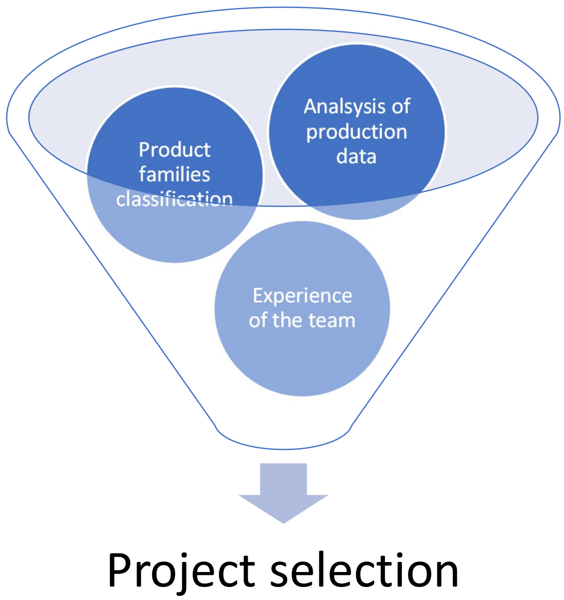
Project Selection Matrix		Estimated Improvement Effort		
		Low	**Medium**	**High**
Estimated Improvement Impact	**High**	Product-Family 5	Product-Family 7	
	Medium	Product-Family 6	Product-Family 1	Product-Family 2
	Low		Product-Family 4	Product-Family 3

Table 3 Project prioritization matrix

The matrix establishes the order to address the projects in the assembly area. The first project to tackle is highlighted in green and it is the one involving Product-Family 5, as it has a low Estimated Improvement Effort and a high Estimated Improvement Impact; the other improvement projects are ranked according to the color, from green to red, thus the order is Product-Family 6, Product-Family 7, Product-Family 1, Product-Family 4, Product-Family 2, Product-Family 3.

This paragraph ends the preventive analysis on the production system, based on data available on the company's ERP. From now on, since the team selected

Product-Family 5 as the most relevant project, the discussion will regard that particular product family.



10 Project selection process

3.4.3. Gemba walk: production process data collection

This chapter intends to show the methodology, based on Lean Tools, used to study the production process related to Product-Family 5.

As explained in the introductory part of the paper-work, Lean Tools are effective if the work is done "on the field": this means, for the first part of the project, to spend time in the production area to look at the effective realization of products.

For this reason, the first part of the chapter will explain how the process is delivered and how data about it were collected. At the end, a Present State Value Stream Map has been drawn and the problem has been defined.

3.4.3.1. Description of the process

To better understand the next parts of the paper work, a brief description of the products entailed in Product-Family 5 is needed. The products have 2 main parts: the primary group, which is responsible for the operation of the product, and the insulation foam shell, that acts as case for the primary group. The primary group is composed by different types of valves and pipes that, according to product variants and specifications, are grouped together.

In order to describe the process in the correct way, data about both the information and the material flow were collected through observation, time and motion study and several interviews to the Assembly Line Manager and the Operators involved in the production process.

The production process is divided into 4 phases:

1. Kitting
2. Nuts and pipes assembly
3. Packing
4. Shipping

The first phase is a pure logistic activity of material preparation: in the company it is called "kitting". The logistics from the components warehouse to the shop floor is managed by a dedicated operator that picks and sorts all the material needed to fulfil the production order. The picking list is manually generated by the Assembly Line Manager, who checks the warehouse location of each material and write it on the production order; the production order works as picking list. Once the picking list has been completed, it is given to the Logistic Operator to perform the picking mission in the warehouse.

The Logistic Operator is able to complete its mission in an average of 1 hour per mission; the data has been extracted by the ERP according to the historical data of the last 3 years. Low volume material is collected into cases which are placed over a pallet, while high volume material is directly delivered in its original case, that is a big carton box placed over a pallet. The material is sorted in an area of the shopfloor near the assembly area (walking distance = 15 meters), and distinguished by the other kit of materials by a paper reporting the production order.

The Assembly Line Manager communicates by voice to the Assembly Operators of Line 21 who has to take care of the production order. Once the communication is completed, the Assembly Operator walks from the production area to the sorting area, search for the right production order and starts the last-mile transportation of the material to the line.

The assembly process is entirely in charge to one operator, who takes care of all the 2 macro processes identified in the previous chapter (nut and pipe assembly, packing). The production begins with the operator placing the material over the workbench; the position of the material is determined according to the experience of the operator working in the assembly line.

The first part of the assembly process is "Nut and pipe assembly": as described in the previous part, the main features of this process are the usage of assembly fixtures and the tightening of nuts and pipes at a predetermined torque.

"Nut and pipe assembly" for Product-Family 5 is a manual process with a medium complexity level of tasks to be accomplished: it can be divided into 2 main sets of tasks. The first is the composition of the insulation foam shell, while the second comprehends the assembly of the primary group.

The assembly sequence is the following:

1. Composition of the lower part of the shell
2. Assembly of the primary group
3. Positioning of the primary group inside the shell
4. Closure of the shell

Once the shell is composed and closed, it is moved to a Work-In-Progress Area (WIP Area 1), which is behind the operator, and placed there to wait until the end of the production batch. On average, the size of the production batch is 20 pieces and it is determined by the operator.

When the "Nut and pipe assembly" batch is completed, the semi-finished material is moved from WIP Area 1 to the workbench beside the workplace, where all the tasks of the "Packing" are performed. The product is finally placed upon a pallet that is moved from the production area to a buffer area where the Logistic Operator takes care of the transportation to the finished products warehouse or to the shipping area.

Below the first part of the Present State Value Stream Map of the process: the diagram is a very simple representation of the production flow of "Line 21". Since the focus are the activities performed inside the plant, they are highlighted in blue in the diagram.

3.4.3.2. Layout of the area

To represent the development of the process from a spatial point of view, describing the layout is fundamental.

There are two separate areas where the products are assembled and sometimes they work as parallel resources. However, as explained in the previous parts of the paper work, the layout of the assembly system is a "fixed position assembly": for this reason, the assembly process of "Nut and pipes assembly" and "Packing" tasks are performed in two precisely distinguishable moments in time. Both operators are able to work in each area. The areas are placed one aside to the other and, from a configuration of the space, are twins.

For this reason, in order to have a more comprehensive representation of the activities performed by the operator, movements of man and material are represented in the layout to get to a spaghetti chart.

The space is divided in the following way:

1. The components are placed behind the operator;
2. When to perform the assembly activities, the operator moves the components the from the area behind him to the workbench;
3. Once the assembly steps 1, 2, 3, 4 are completed, the sub-assemblies are also moved behind the operator and piled up over a pallet in WIP Area 1;
4. When the production batch is completed, semi-finished products are moved back to the workbench to be processed in the steps 5 (packing) and then placed over a pallet behind the operator;
5. Once the pallet is completed, the operator moves it to the top of the assembly area.

All the assembly tools and fixtures are placed over the workbench, in a big case with other assembly tools.

3.4.3.3. Time and motion study

In chapter 3.4 the analysis of production data extracted from the ERP displays an average performance of "Line 21" as 68%. Product-Family 5 contributes to this result with an average performance of 52%, which is stable around this value despite the different configurations of the product and the temporal evolution.

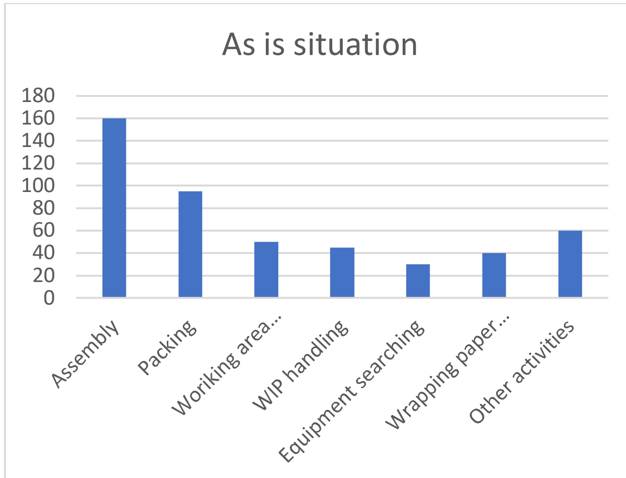
To understand the reason behind this result, a series of observations on the field has been done. The objective is to identify which are the main Non-Value Added activities done by the operator during the daily production, in order to, further in the project, develop the most suitable solutions for the assembly line.

Data were collected through observation of time and methods: the samplings were taken in the Gemba, where I was working as a junior consultant.

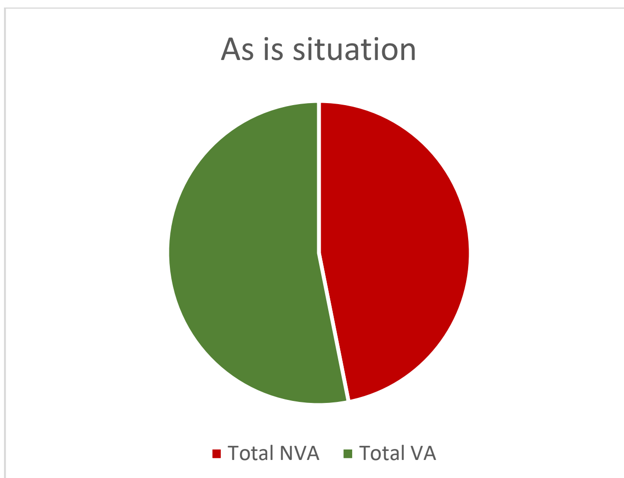
Collected data has been divided into these 7 categories:

1. Assembly: the activities described in chapter 3.5.3.1
2. Packing: the activities described in chapter 3.5.3.1
3. Working area organization: these are the activities done by the operator at the beginning of the day. Examples taken by the Gemba walk are the retrieval of the kitted material from the buffer and the disposition of the material over the workbench.
4. WIP handling: the handling of WIP between the stages of Assembly and Packing
5. Equipment searching: the activities related to the searching, testing and disposition on the workbench of the assembly fixtures
6. Wrapping paper retrieval: when the operator performs the task of preparing the wrapping paper, which is done by a specific machine
7. Other activities

Collected data are showed in the graphs below: total Non-Value Added activities performed by the operator account for the 47% of the available time.



11 As is situation - Data collection



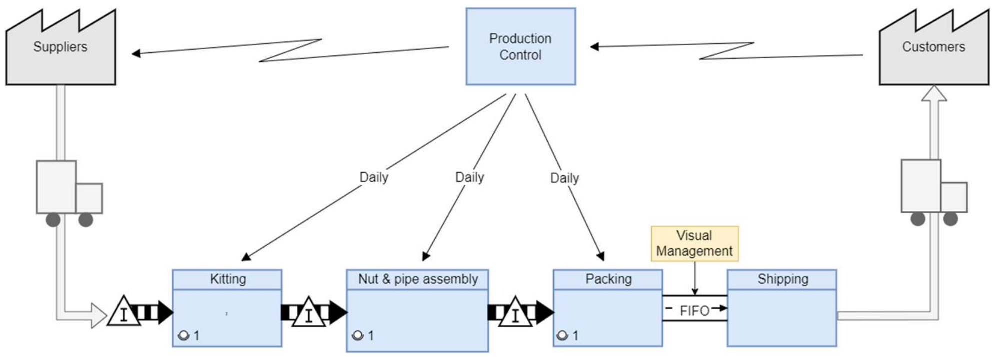
12 As is situation - Distribution of VA and NVA

3.4.3.4. Value stream mapping

The information reported in the previous part of the chapter are collected into the Value Stream Map of the present state.

Data about processing times are neglected on purpose, since are not relevant for the development of the project: from the analysis of the data collected in the previous part, improvements on the processing time of assembly and packing would have low impact, thus data is not taken into consideration.

In the VSM is clearly reported the division between the two transformation stages: this is important for the next part of the project, because it is also a relevant part of the NVA performed by the operator.



13 Current state Value Stream Map

3.4.4. Definition of the problem

In the previous parts of the chapter, the problem to address in the project has been approached in two sequential ways: at first the analysis of the ERP production data aimed at describing the production system, giving a priority of intervention to the Product Families assigned to the production line. Secondly a more focused data collection has been done in the Gemba, with the objective of characterizing the performance of the production system regarding the selected Product Family.

These data collection sessions showed a high percentage of Non Value Added activities done throughout the production time. Since the company wants to improve the performance of the assembly line, in the next parts of the project the team has to solve this issue: to reduce the Non Value Added activities related to the production of Product-Family 5 in the assembly area of Line 21.

3.5. Target setting

This part of the methodology has the aim of defining the target that the improvement activities have to reach in order to satisfy all the stakeholders of the project.

The literature about target setting explains how the definition of the target is crucial for project development: a good target has to be quantitative and measurable to assess the success of the project, and challenging to create commitment and stimulate the team. Then, the target has to be the steering point of the project: its destination.

In this specific case, as reported in the previous parts of the paper work, the object of the problem are Non Value Added activities related to the production process. So, in agreement with the project team, the decision was to set the objective around the percentage of the production time absorbed by these activities.

The table below summarizes evaluations made on the target: the objective is to reduce Total Non-Value Added time from 47% to 31%.

	As is situation		*Objectives*	
Activities	**Time [min]**	**% Time**	**Time [min]**	**% Time**
Total NVA	225	**47%**	150	**31%**
Total VA	255	**53%**	330	**69%**

Table 4 Target definition

3.6. Gap analysis

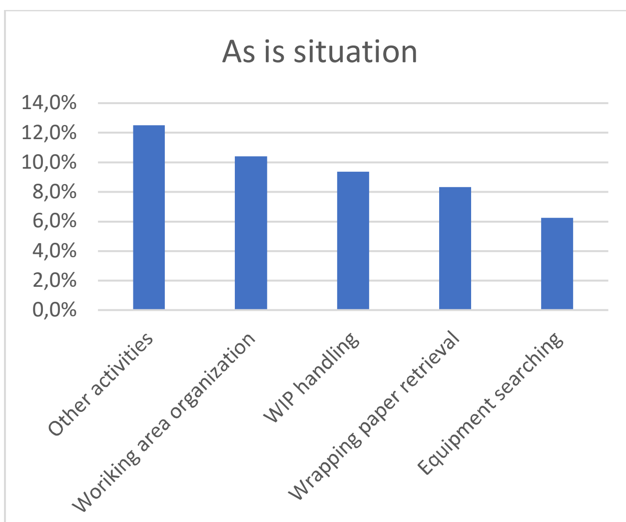
This chapter describes the problem solving analysis done to understand how to cope with the gap between the present situation and the objectives.

The aim of the analysis is to identify which are the root causes behind the gap in order to, further in the project, address them with properly developed solutions. Lean tools for problem solving were applied.

3.6.1. Analysis of the Non Value Added activities

The aim of this first part of the Gap Analysis is to deepen the data collected in the first part of the project work.

The graph below shows the Non Value Added activities ordered by the impact on the overall production activities.



14 Distribution of Non Value Added activities

The sequence to approach is:

1. Working area organization (10,4%)
2. WIP handling (9,4%)
3. Wrapping paper retrieval (8,3%)
4. Equipment searching (6,3%)

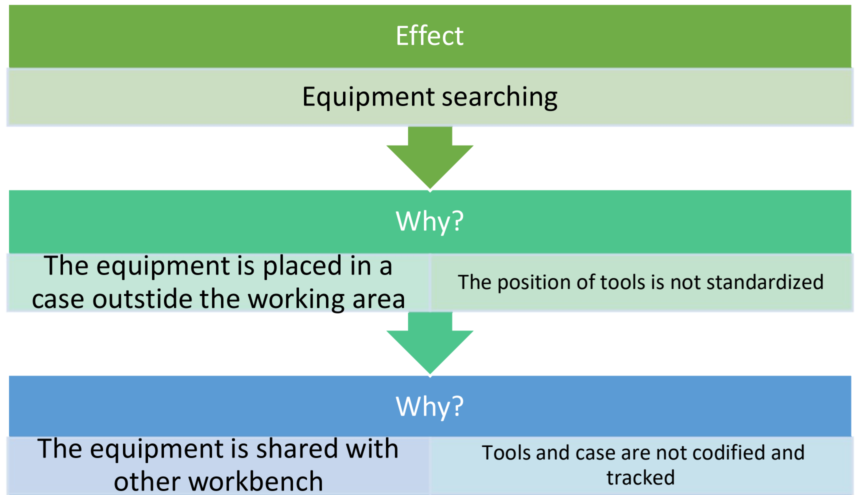
"Other activities", even if it has the highest impact, is selected as not influential: it comprehends activities that are difficult or not possible to eliminate or reduce, such as operator breaks from work.

3.6.1.1. Working area organization and equipment searching

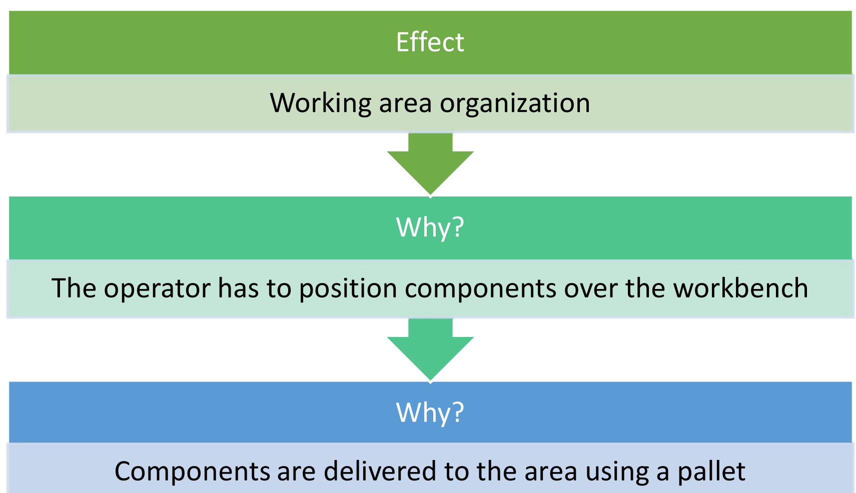
The first couple of Non-Value Added activities to address can be grouped as "organizational activities". Indeed, these are activities performed by the operator at the beginning of the production day or when the necessity to perform a setup emerged.

During data collection, these activities have been divided due to the subject of the organization: for "working area organization" the subject is raw materials and components used by the operator in the production day. Instead, during "equipment searching" the subject is all the tools and fixtures used to assemble the products.

The chosen root cause analysis for this NVA activities is 5Whys analysis, and the logical flow is reported below.



15 5Why analysis - Equipment searching



16 5Why analysis - Working area organization

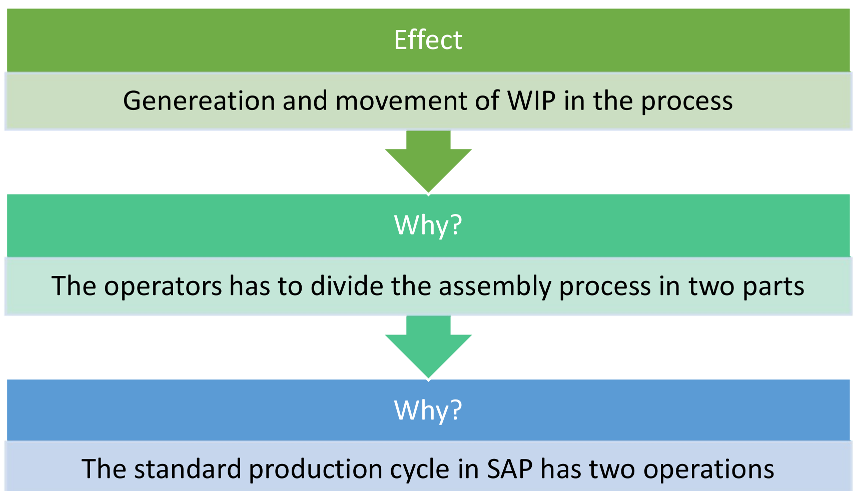
The expected gain in reducing the impact of these NVA over the production time is around 20 minutes per day (4,2%).

3.6.1.2. WIP Handling

As explained in the previous chapter, this activity is related to the movement of Work In Progress pieces from the workbench to the WIP Area and from the WIP

Area to the workbench. The root cause analysis for this Non Value Added activity is pretty simple and it is addressed with 5Whys Analysis.

Several interviews with assembly line operators and assembly line manager highlighted that the necessity of separating activities is forced by the structure of the production order, which is an effect of the production cycle fed into SAP; a schema of the analysis is presented below.



17 5Why analysis - WIP handling

There is no technological constraint, as for example the polymerization time needed to reach a mechanical resistance in a gluing process, so the time spent in the WIP area can be completely removed from the production process.

For this reason, the expected gaining in solving this cause is 9,4% of the production time which is around 45 minutes per day.

3.6.1.3. Wrapping paper retrieval

The activity of wrapping paper retrieval is a production activity performed by the operator outside of the production cycle. The reason behind this activity is to retrieve the necessary wrapping paper to complete the packing process of the products.

By observation of the process these data emerged: the wrapping paper is prepared by an automatic machine which is placed in the middle of the shopfloor and, on average, the operator visits the machine 4 times per day, for a total of 40 minutes per day.

Since the activity is necessary for the production, the waste of production time stays in the way the activity is performed: indeed it is done as an “internal activity”, referring to the terminology used for SMED practices, with the operator waiting for the wrapping machine completing the task.

The activity cannot be completely eliminated, thus the aim is to reduce the impact on the production time: the expected gain is 10 minutes per day.

Below, a short comprehensive schema of the identified root causes is reported.

Non Value Added activities	Root cause
Working area organization	Components are delivered to the area using a pallet
Equipment searching	The equipment is shared with other workbench
	Tools and case are not codified and tracked
Wrapping paper retrieval	The task is performed as an "internal activity"
WIP handling	The standard production cycle in SAP has two operations

Table 5 List of the rootcauses

3.7. Countermeasures

In this chapter the process for solution design is presented.

As reported in the literature review and frequently affirmed by researchers, one of the objectives of the Organization is to overcome waste in the processes by resolving problems at the root cause: solution design begins there, as countermeasure to the root causes identified in the previous chapter.

Each countermeasure is going to be presented and evaluated: at the end of the chapter solutions are evaluated according to the impact on the target and then prioritized for the following part of the project, implementation.

3.7.1. Design of countermeasures

In the table below the list of countermeasures is reported: in the next part of the chapter each countermeasure is going to be discussed.

Non Value Added activities	Root cause	Countermeasure	
Working area organization	Components are delivered to the area using a pallet	(1) New intralogistics equipment	
Equipment searching	The equipment is shared with other workbench	(2a) Redefinition of the working areas	(2) OPF assembly cell design
	Tools and case are not codified and tracked	(2b) 5S and standard sheets	
Wrapping paper retrieval	The task is performed as an "internal activity"	(2c) SMED	
		(2d) New workbench for packing	
WIP handling	The standard production cycle in ERP has two operations	(2e) Redefinition of the standard production cycle	
		(2d) New workbench for packing	

Table 6 List of countermeasures

Countermeasures can be grouped in two main categories: the first is a stand-alone solution, "New intralogistics equipment", while the second, "One Piece Flow assembly cell design", is a group of solutions that are intended to transform the production area in an assembly cell.

3.7.2. New intralogistics equipment

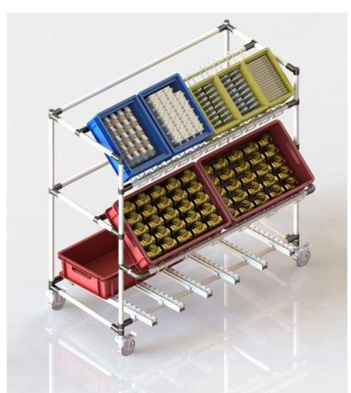
The aim of this solution is to reduce the impact of the "Working area organization" activity.

This solution does not act directly on the production process, however it affects the logistic process and, as a consequence, the production process itself.

As explained in the previous chapters, the logistic process is a key point for the assembly area: there is a logistic operator who is charged to retrieve, prepare all the necessary components for each assembly area; at the end of material preparation the material is delivered to the assembly area in cases placed over a pallet.

The aim of the solution is to replace the usage of pallet with a more flexible cart, where the logistic operator can place the full cases ready to be used by the assembly area.

An example is reported in the image below.



18 Example of intralogistics cart (Source: https://www.flexlogik.it/image/Esempio-Lean-FlexLogik.jpg)

The solution is evaluated as an high-impact and high-cost solution: the impact is high since the Non-Value Added activity of "Working area organization" can be eliminated completely by the activity charged to the assembly operator. However, the high cost is the result of two aspects: the first is the CAPEX necessary to develop the solution, intended as the investments needed to both develop and purchase the intralogistics cart and to review the material preparation area in order to sustain the usage of carts instead of pallets. The second is the organizational change needed to deliver the process in an efficient and effective way.

3.7.3. Assembly cell design

The solution of "Assembly cell design" is formed by a group of solutions: each solution is going to be explained in detail.

3.7.3.1. Redefinition of the working areas

The first solution to design the assembly cell is intended to overcome the issue of shared equipment with other assembly areas.

The reason behind this fact is that the actual assembly system, fixed position assembly, enables the production in multiple areas of the shopfloor: even this is a very flexible production system, it is proven to be not efficient. To overcome the issue, the team selected an area to destinate the production process of the selected Product-Family.

With this choice, it is possible to destinate to the selected area all the tools and equipment to produce Product-Family 5: this action is a low-cost and medium-impact over the Non-Value Added activities.

3.7.3.2. 5S and standard sheets

During data collection one of the evidences was the disorder in the storage of the equipment that generates loss of time during the initial phases of production.

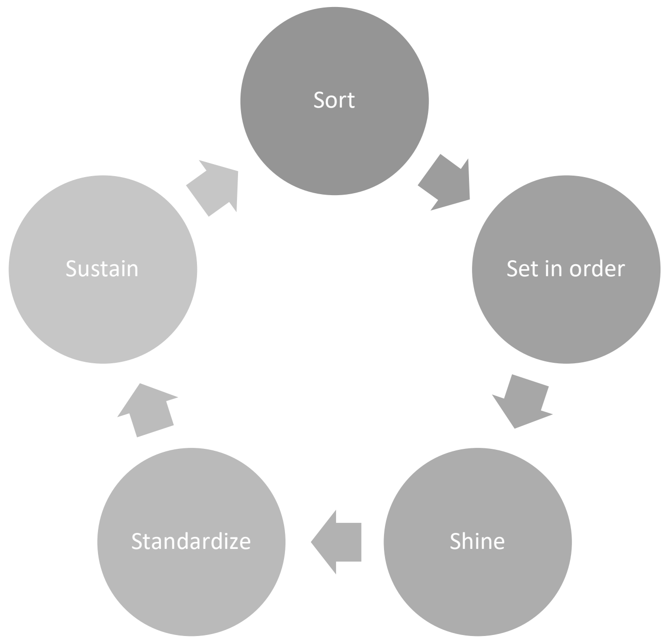
With solution explained in chapter 3.8.3.1, all the equipment is going to be centralized to the selected area: another improvement, related to equipment, is the standardization of both tools and their placement in the assembly area.

To deliver the solution the well-known Lean tools "5S" and the draft of a standard sheet for the equipment are proposed.

5S is basically a framework to guide the organization to the selection and the standardization of equipment and components inside the Gemba, the shopfloor.

Steps are:

1. Sort: the actions aimed at separating what is useful from what it is not; at the of the activity everything not useful is eliminated from the area.
2. Set in order: what is kept in the area is placed in order and where it is needed.
3. Shine: the area must be constantly cleaned and keep tidy in order to highlights any possible inefficiency.
4. Standardize: the actions and methodology intended to develop a tool to keep in a easy way the condition reached. In this case, a standard document to keep track of the tools and their location in the assembly area.
5. Sustain: the actions intended to make the change effective over time.



19 Schema of 5S methodology

This solution is evaluated as low cost, since the area is limited and one assembly operator can take charge of the activity. However, even if it is a simple tool, its effectiveness is proven: for this reason its impact has been evaluated as medium.

3.7.3.3. SMED

SMED is another key tools from the Lean toolbox: in the specific case of the project, the tool is used to review the process of wrapping paper retrieval.

As explained in the previous chapters, the activity of working paper retrieval is performed several times during the day: the machine is automatic and the operator waits for the end of the automatic cycle before to come back to the assembly area.

The idea is an easy application of SMED technique: the activity is concentrated in one moment during the day, by leveraging on the automatic working cycle of the machine. The new procedure suggests to perform the activity at the beginning of the day, during the “organization of the working area”.

This solution has a low cost for development and implementation, with a medium impact.

3.7.3.4. Redefinition of the standard production cycle

The design of this solution affects the production system in two ways: the first leverages on the ERP, as an enabling factor for the second, that is the physical redefinition of the production cycle.

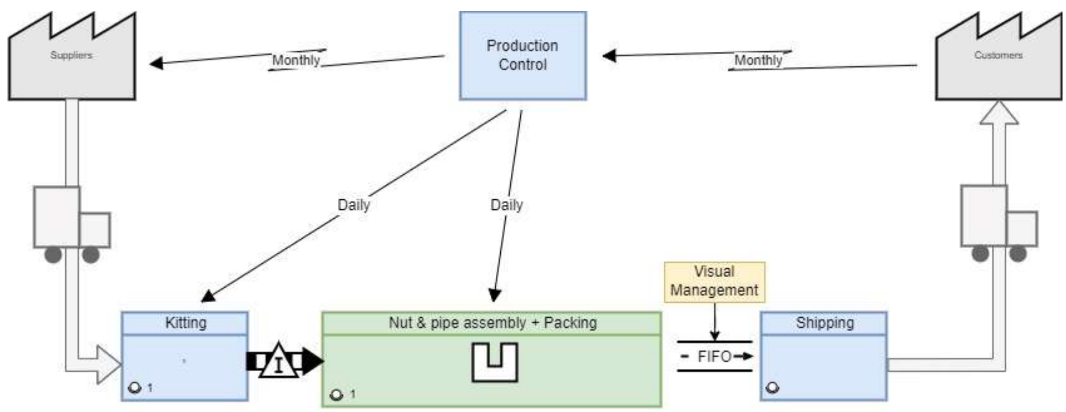
The ERP forces the production to follow what is set a standard production cycle: so if in the ERP a production cycle is divided in two operations, in the shopfloor two separated production orders will be generated. Instead, the adjustment of the ERP with only one operation in the standard production acts as enabling factor for a flow-based production. In this case, the adjustment is the following:

State	Operation ID	Operation description
As is	10	Assembly
As is	20	Packing
To be	10	Assembly + Packing

Table 7 Standard production cycle

As explained before, the adjustment of the ERP allows to modify the physical production cycle in order to eliminate the generation and handling of WIP in the process.

Indeed, WIP is generated in between assembly and packing: since there is no technological reason behind the fact, the production can be easily made as One Piece Flow.



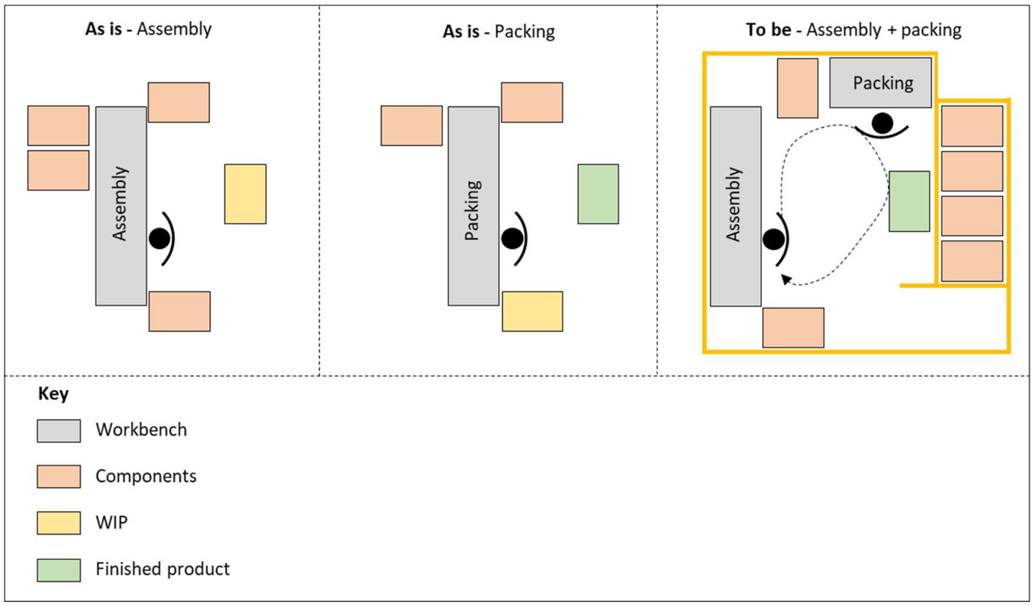
20 Value Stream Map - To be

The solution, coupled with the one explained in the following chapter, will realize the One Piece Flow assembly cell: for this reason it is evaluated as high-impact and medium cost.

3.7.3.5. New workbench for packing

This solution is intended to work on two Non Value Added activities: wrapping paper retrieval and WIP handling: the idea is to design a specialized workbench for the tasks related to packing.

The solution explained in chapter 3.8.3.4 needs an area where the operator can perform the packing activity with the desired One Piece Flow method: the new workbench is placed in the layout in order to minimize the walking distance travelled by the operator. Two scenarios are designed and evaluated: below the layout of the selected scenario is reported.



21 Layout - Comparison between As Is and To Be

Moreover, the design of the workbench proposed to keep inside it and available to the operator everything needed to perform the packing activity. For this reason, a new bigger case for the wrapping paper is integrated into the workbench. Furthermore, a dedicated space for boxes and other components is foreseen into the workbench.

Below, an example of the workbench is reported.

22 Example of workbench for packing (Source: https://www.rk-rose-krieger.com/fileadmin/images/rkrosekrieger/produkte/modultechnik/lean-arbeitstische/Lean-Packtisch.jpg)

The solution is evaluated with medium cost, since it is a CAPEX investment but a low budget, and high impact over the production activities.

3.7.4. Countermeasure evaluation

In the tables below, countermeasure and data about cost and impact are reported.

Evaluation matrix		Cost		
		Low	*Medium*	*High*
Impact	*High*		(2d) (2e)	
	Medium	(2a) (2b) (2c)		
	Low			(1)

Table 8 Evaluation matrix – Countermeasures

Countermeasure	Cost	Impact	Priority
(2a) Redefinition of the working areas	Low	Medium	1
(2b) 5S and standard sheets	Low	Medium	1
(2c) SMED	Low	Medium	1
(2d) New workbench for packing	Medium	High	2
(2e) Redefinition of the standard 58production cycle	Medium	High	2
(1) New intralogistics equipment	High	High	3

Table 9 Priority of implementation

The last table displays the order of implementation of the solutions that is going to be defended in the next chapter.

3.8. Implementation

In this chapter, the plan and the actions the company undertook to implement the solutions are described.

The beginning of the planning process is represented by the prioritization matrix composed in chapter 3.8.4: the sequence of implementation has been defined with an evaluation made with all the components of the team. The table summarizes the sequence.

Countermeasure	Priority	Implementation Sequence
(2a) Redefinition of the working areas	1	1
(2b) 5S and standard sheets	1	2
(2c) SMED	1	3
(2d) New workbench for packing	2	4
(2e) Redefinition of the standard production cycle	2	5
(1) New intralogistics equipment	3	6

Table 10 Implementation sequence

The selected approach for the implementation process is a proven Lean approach, reported also in the literature, made of rapid improvements and based on the Agile methodology of Plan-Do-Check-Act. The idea is to bring to the assembly area improvements based on steps, in order to allow the system to gradually adapt to them. Moreover, an active monitoring of the solutions in the first phases of the implementation is done to check for the proper functioning: the reason is to check if the solution is not reaching the target according to the philosophy of "fail fast to adapt".

The implementation is then divided into three steps:

1. Rapid improvements 1, where solutions (2a), (2b) and (2c) are introduced
2. Rapid improvements 2, where solutions (2d) and (2e) are introduced with "rough and tough solutions"
3. Rapid improvements 3, where solutions (2d) is introduced in its conclusive shape, after the purchase of the new workbench.

The direct involvement of the assembly operators working in the area was key to successfully implement every solution: in particular in Rapid Improvements 1, when solutions of 5S and SMED have been delivered. The operators were led in the application of the techniques described in chapter 3.8: at the end of the activities the assembly area was identified and equipped with the necessary tools selected during 5S. The procedure for "Wrapping paper retrieval" was developed and shared with the members of the team. Moreover the standard sheet was filled and made available in the assembly area.

The description of Rapid Improvements 2 and Rapid Improvements 3 is better-made by looking at picture of the area:

23 Assembly area - As is

24 Packing area - As is

25 Rough implementation of the new workbench

26 Rough implementation of the new layout

27 Final layout of the assembly area

At the end of Rapid Improvements 2 the ERP was updated with the new standard production cycle reported in chapter 3.8.3.4.

3.9. Results

In the final chapter of the case study, results are presented: at the end of the project results have to be measured and discussed in order to critically assess the output of the implementation.

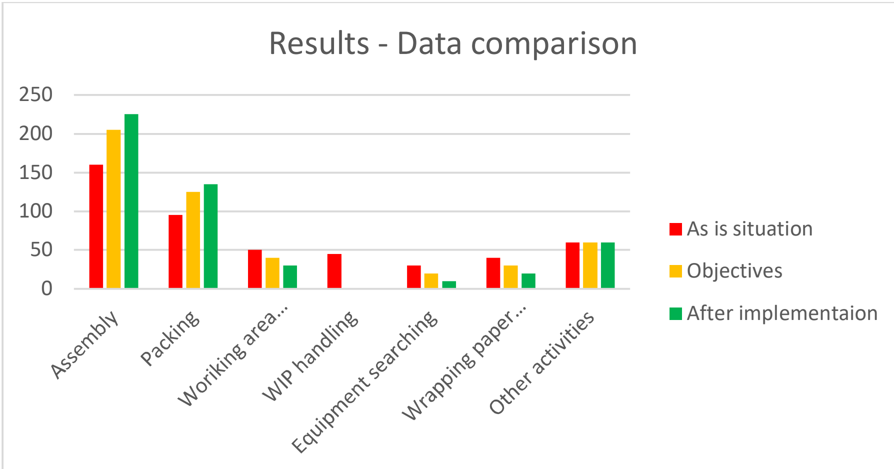
The assessment is going to be made with a comparison between the targets, set in chapter 3.6, and the measurement carried out after the Rapid Improvements.

The table below displays the change over the selected KPIs.

	As is situation		*Objectives*		*After improvements*	
Activities	**Time [min]**	**% Time**	**Time [min]**	**% Time**	**Time [min]**	**% Time**
Total NVA	225	**47%**	150	**31%**	120	**25%**
Total VA	255	**53%**	330	**69%**	360	**75%**

Table 11 Results

The critical assessment of the data from the table shows that the target is fully met, with all the implemented solutions properly working. The improvements in the Total Value Added time after the improvements are due to an higher impact of improvements for "Equipment searching" (-50% respect to Objectives), "Wrapping paper retrieval" (-33% respect to Objectives) and "Working area organization" (-25% respect to Objectives): the reason is that the impact of standardization activities, such as 5S and SMED, was underestimated. Once more this is the proof of how powerful a simple application of standard conditions can be helpful to reduce waste in the process in gross way.



28 Data comparison between As Is, Target, After implementation

From an economical point of view, the improvement project resulted in a gain in revenues, estimated in an average of 1.980.000 €/year, and a reduction in manufacturing costs, estimated as 15.400 €/year.

Moreover, other benefits have been tracked down after the implementation activities:

- Involvement of employees, which were an important part of the project
- Ergonomics, with a reduction of bending movements due to the elimination of WIP handling and the successful implementation of the new packing workbench
- Cleaning and organization of the working area
- Diffusion of Lean culture with a proven and successful implementation

In conclusion, the activity was successful from all the point of view: all the stakeholders were satisfied from the project. In the next future the company can extend the approach not only to the other Product Families reported at the beginning of the project, but alto to other areas of the shopfloor and, as suggest in countermeasure design, deepen the design and implementation of a new logistic process in order to reduce more and more the logistics Non-Value Added activities related to “Working area organization”.

4 Conclusions and future developments

In this chapter, a resume of the obtained results, future developments and an insight about the project are presented.

Moreover, the methodology used to deliver the project is compared with the other presented in the literature

Talking about results, the improvement of the assembly process has been reached under several points of view: at first, the increase of production capacity, thanks to the analysis and consequent reduction of the most impactful sources of waste; consequently the increase of efficiency of the assembly area was confirmed by a performance monitoring performed several months later than the implementation.

Another important aspect are the working conditions: workers reported an improvements in the ergonomics of the working stations, a more clear and ordered area without any unnecessary WIP and lower fatigue. This led to a reduction in the cycle time too.

Last but not least, the direct involvement of operators in the improvement process allowed the diffusion of Lean culture and a more consistent change management: positive feedback was continuously provided by the operator.

Future developments of the area can be seen under three degree of effort: at first, with the lower effort, the other Product-Families should be analyzed and their production process improved. The same methodological approach should be used, since it is proven to be successful.

Further, the improvements should be directed to the logistic process as already suggested in the project. However, this change can have a bigger impact on the organization: for this reason, the analysis should comprehend both the entire assembly area and the warehouses. On the other side, the expected improvements are huge: as taught by researchers, an efficient logistic process can dramatically improve manufacturing performances.

At last, talking about technological infrastructure and Industry 4.0, the introduction of a Manufacturing Execution System with a direct interface on each workstation can help the company in improving the real-time monitoring of the assembly area, in order to reach more and more higher efficiency.

Finally, an insight about the methodology. In the literature review, two articles (Cannas et al. (2018) and Rossini et al. (2019)), have been highlighted as very influential about the work: indeed, by looking in a critical way at the used methodology, it was necessary to limit the variety of the production mix and, subsequently, the improvement project was tackled following the structured A3 methodology proposed by Rossini.

This structured approach was successful because of the simplicity of the framework, that it is easy to explain to each people of the team. Moreover, the preparatory selection of the project or product family allowed a more focalized approach to problems with a quick implementation of corrective solutions.

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