POLITECNICO DI TORINO

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Application of Lean Manufacturing Methodology in Telescopic Fork Assembly Line

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“Quality means doing it right when no one is looking.”

Henry Ford

Table of Contents

List of Figure

List of Table

Abstract

Companies frequently find techniques and tools to enhance productivity and quality for success in the long-term to maximize competitive advantage.
To date, the lean manufacturing principle is one of the successful improvement concepts that have been applied to eliminate waste and non-value-added activities that occur in many companies.

The objective of this research is to examine the existing production line of telescopic fork production unit and apply lean manufacturing principles and other improvement tools and techniques to help the company identify areas of opportunity for waste reduction and improve the efficiency of the production process.

The production line is considered in this thesis belongs to the telescopic fork developed by Eurofork S.p.A, an automated material handling company based in Turin/Italy.

1. Introduction

All companies, every day, ask themselves how a competitive advantage can be created in the market and how, eventually, it can be maintained, given the growing number of companies.
On the other hand, however, it is fundamental how to understand, once the volume of demand has been increased, it is possible to satisfy it all; in fact, it is not always possible and sustainable to increase costs and consequently prices, in a historical moment in which the cost of raw materials is volatile and, above all, overseas competitors enjoy considerable advantages.
Attention to quality therefore becomes fundamental, and of primary importance. Quality not only in the product and in the search for raw materials, but above all quality in the process.
It is important to question whether current business processes are being performed in the best way and to try to apply best practices to bring immediate improvements and benefits.

Lean Production is perhaps the most important and widespread methodology aimed at making improvements to production processes; Lean concepts are mostly evolved from Japanese industries, especially from Toyota. Lean Manufacturing is a waste reduction technique as suggested by many authors, but in practice lean manufacturing maximize the value of the product through minimization of waste. Lean principles define the value of the product/service as perceived by the customer and then making the flow in-line with the customer pull, and striving for perfection through continuous improvement to eliminate waste by sorting out Value Added activity (VA) and Non-Value Added activity (NVA).

This study was carried out at a telescopic fork production unit in Eurofork S.p.A. In the application of Lean principles to the assembly line, it is observed that many sources of waste could be eliminated. Problems encountered in the line are related to unnecessarily movements of the operator and improper organization of the plant layout.
The distances travelled by components and workers throughout the production process are viewed as a cause of production inefficiency. Excessive motion and transportation result in unnecessary expenditures and wasted energy.

Considering these problems, the Lean Manufacturing technique is applied to make the existing layout more efficient and reduce waste. As a first step, the description of the current flow of material and information is done, through the construction of AS-IS Value Stream Mapping. After the description of the situation, the Lean principles have been applied, trying to identify the main source of waste and the cause-effect relationship. This is the most important and effective step of the Lean Manufacturing because this technique based on the idea that all the non-value-added activities must be reduced. Following this, a full dataset has been created to quantitative describe each phase of the process. At the end, the theory described in the research has been applied on the real process through a simulation, to understand where concretely and continuously intervene.
Some best practices and a final layout have been decided, bringing effective benefits to the production time.

2. The Lean Manufacturing Methodology

Lean is a systematic method to reduce waste of all forms in an assembly line in a practical, reliable, and cost-effective way. It identifies waste as anything that adds cost to the product, such as wasted worker hours, excessive movement, or unnecessary steps in the manufacturing process.
These wastes are in general made up of all those activities, carried out during production, which absorb resources without creating value: procedures that are not needed, movement of material and personnel from one place to another without reason, inaccuracies in the production phases that deal with rework, groups of people on the assembly line to await production for the completion of the previous phase.

2.1. Origin: Toyota Production System (TPS)

Lean is widely agreed to have been developed by Toyota Motor Corporation (Toyota) after World War II, to increase efficiency. Since Japan's production capabilities, raw materials, and resources had been extensively damaged by the war, the then-standard manufacturing methods produced products with high prices. Thus, Toyota created a system to continuously improve their factories' productivity, which they called the Toyota Production System (TPS). Implementing TPS helped the company lower its prices to compete with comparatively inexpensive German and American cars. It is from TPS that the principles of Lean Manufacturing Methodology were later derived.

In 2007, MIT researchers found that TPS was much more efficient than traditional mass production in that it represented a “completely new paradigm” and a “radically different approach to production”. After this report, TPS gained substantial popularity and was emulated in the factories of many other companies. Silverline uses a system modeled after the Toyota Production System in their North Brunswick location. Due to TPS' inherent compatibility with Lean principles, implementation of the solutions described in this paper was significantly easier.
To be successful, TPS requires a foundation of “stability,” which is defined as “bringing process variability under control”. Essentially, all activities must be standardized, and every worker should do their job the same way. In a factory, this is both practicable and desirable, because the production process reliably produces quality products. Additionally, a manager can easily adjust a stable production process to meet demand; for example, operating half as many lines will always lead to exactly half as many units produced.
The system itself relies on two pillars, Jidoka and Just-in-Time Inventory.

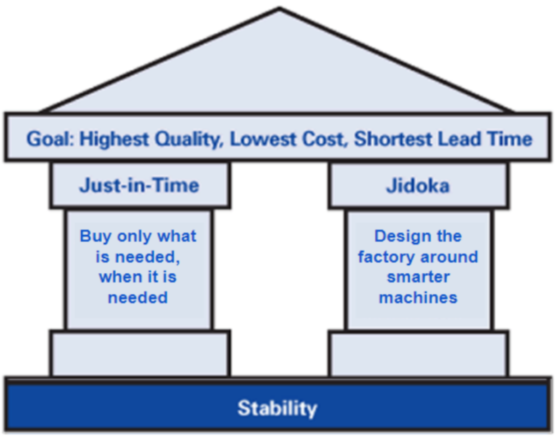

Figure 1. Jidoka and Just-in-Time Inventory

a. *Jidoka:* According to Toyota Global, the Japanese word Jidoka means “automation with a human touch”. It represents the concept of a well-designed machine that can make certain decisions for itself, and thus requires less human supervision. It originates from the automatic loom, which was designed by one of Toyota's engineers to automatically stop when a broken thread was detected. With this type of machine, less human supervision is required since one man can keep track of several looms. This is a crucial pillar of TPS because it dramatically reduces the need for human labor, which helps a firm save on wage costs.
b. *Just-in-Time:* Just-in-time (JIT) inventory is a way to organize production by delivering and receiving materials and parts “right when they are needed”. At Toyota, materials are not only prohibited from being on the production floor until they are required, but also kept away from stations until production is active. This results in decreased inventory, and thus lower storage costs. Beginning the implementation of JIT is a multi-step process. The first step is to assess and document the current inventory. Then, managers use these results to determine what the firm will need in the future. Finally, managers set up JIT in a workplace setting by stocking up on only what is needed and buying new materials only when a particular order from a customer requires it. Since factories have to store fewer materials, logistical costs and inventory waste are reduced. Additionally, a flexible inventory that is based on the orders that customers give allows for customer responsiveness. A drawback, however, is that any delays from the suppliers of a factory's parts can seriously bring down the factory's bottom line. In addition, any fluctuations in the market price of certain parts impact JIT systems more because they are more reliant on other companies and so less on their stock of these parts.

2.2. Lean Thinking principles

The first concept the Toyota system aimed at was cost reduction: profit being the difference between the selling price and the cost incurred, contrary to the common formula of defining a price by adding a margin to the costs incurred.
The basic line established by Taiichi Ono is the reduction of the time from the arrival of the customer's order to when the delivery takes place, and the payment is made. In between, all activities that do not bring value are removed because they are waste.

And the fight against waste thus becomes a principle for achieving lean production. The basic requirements for achieving this goal are just-in-time production and automation under human control: the former is fulfilled by creating a process with a continuous flow, capable of delivering what is required, where required and at the required time; the second is obtained by equipping each operator and each production process with the means for identifying and correcting product or system defects.
The greater efficiency obtained must not be translated into an increase in production as well as the use of production means. The greatest gain comes from cost reduction: from the ability to carry out operations as before, but net of eliminated waste, with a lower cost for the production process. The reduction in costs leads to an increase in the margin on the selling price of the product, maintaining all the characteristics to which the customer attributes value and for which he is willing to pay.
Following the Lean methodology, the systematic elimination of sources of inefficiency is possible only through five actions, called Womack and Jones principles, which are the reference points for the reorganization of the process.
The first action is the definition of value as perceived by the customer. The second action aims to identify the value stream for each product. The third principle states that it is necessary to make a continuous product flow in the remaining value-added steps. The fourth action aspires to a flow that

is "pulled" by the customer, where continuous flow is possible. The last principle aims at the pursuit of perfection (Womack et al., 1996).

2.2.1. Value definition

The starting point for Lean Production is the concept of Value, which must be rethought from the customer's point of view.
Only a small fraction of the actions and total time it takes to produce a specific product add real value to the end customer. It is fundamental to define the value of the product according to the customer's perspective so that all non-value activities or MUDA (waste) can be removed step by step.

2.2.2. Value stream mapping

Once what is precious for the customer has been defined, the second action consists in mapping the value flow, which is made up of all those interconnected activities necessary to transform raw materials into finished products, producing value for the customer (Lovelle, 2001). The analysis of the value stream shows three different possible activities: activities that add value, activities that do not add value, but necessary and therefore must be maintained (or at least minimized or optimized) and activities that do not add value but generate waste, and therefore must be eliminated. Another important aspect of the value stream is that it is analyzed from the point of view of the whole product, without looking at individual departments (Howell, 2013). To map it, Lean thinking suggests for example the visual tool of the flow of values map, which considers AS-IS and TO-BE situation of the flow (Grewal, 2008). This second action aims to understand, within the process, what adds value for the customer, for what they are willing to pay to identify the process time and eliminate all activities that do not add value.

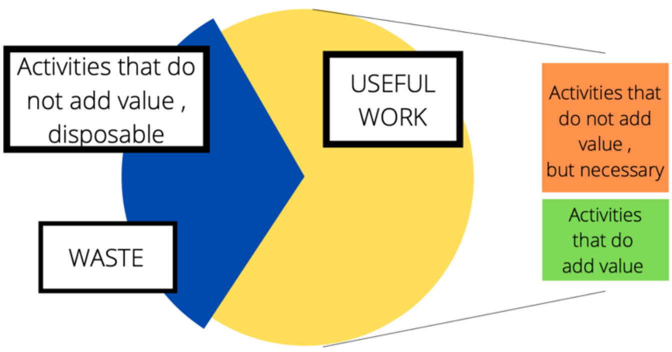

Figure 2. Waste identification and useful work

2.2.3. Continuous flow

Once those activities that do not create value are eliminated, the remaining activities must be organized in a flow: the process must be carried out without obstacles and interference. The ideal flow is what is called one piece flow, although many times this is not feasible due to set-up settings and the need to flow multiple product streams through individual machines or cells.

Anything that blocks the flow is waste, so it must be identified to be removed; it is necessary that the process can proceed without constraints (Krafcik, 1988). Furthermore, each piece must follow the takt-time, which is the expected production rate to deliver the product to the customer or, in other words, the production rate necessary to satisfy the customer's request. It is calculated through the ratio between the total time available to deliver a product and the volume of the product to be delivered. (Myerson, 2012)
A mistake that occurs frequently is to compromise because of the systems available: not wanting to invest in the right technology or system.
When there exists an overall view of the flow of value and each activity is reorganized to generate and make this flow, for all present and future production, then the company can be defined as operating in a lean way.

2.2.4. Pull production

The fourth principle is the most critical and is related to the way production is organized and conducted. Indeed, the warehouse is one of the main rejects and this must be eliminated. Thinking about the traditional metaphor of the boat, inventory hides most of the problems within an organization and causes a lot of other waste (Gupta et al., 2014). Ideally, a system should only produce when the customer places the order: the production must be driven by actual market demand (Spearman et al., 1992). Pull production is done using Kanban and Just in time

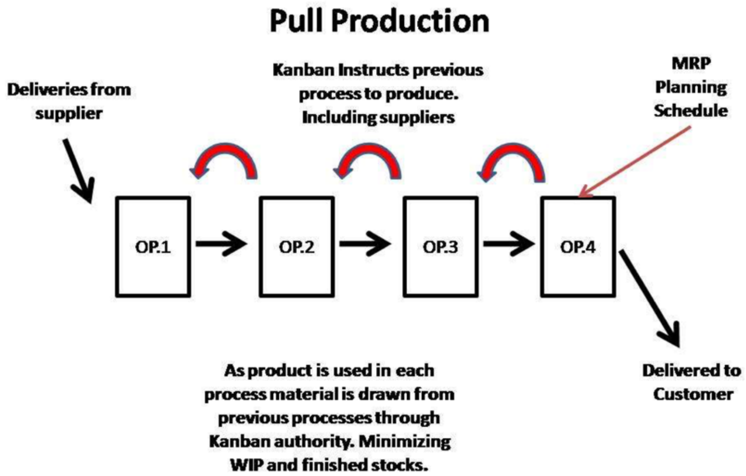

Figure 3. Pull production scheme (http://leanmanufacturingtools.org)

Kanban is a simple and visible tool that allows to reconstitute the required component, obviously called the request from the outside. Only a minimum level of stock is left in the workplace, and before its depletion, education on paper.
Kanban performed by the operator ensures a just-in-time replenishment. Just-in-Time means that in order to ensure smooth pull production and make the right product, it has been needed to have the right pieces, in the right place, at the right time. Through these tools, customer orders can be quickly fulfilled on the spot and components are manufactured from standard ones or taken from a small warehouse, i.e. replenished later in the same way supermarket shelves are filled when customers buy products (Kumar et al., 2007). Obviously, a pull production needs a high degree of visibility on the process, to be reactive when a product is required; in other words, greater visibility supports more effective just-in-time production (Myerson, 2012).

2.2.5. Pursuit of perfection

By implementing the first four actions, it is already possible to prevent a huge amount of waste within organizational processes.
Perfection as a concept is abstract but leads to the definition of a goal to aspire to. From his research derive the inspiration and guidelines that will support the improvement process. Lean focuses its attention on the goal of pursuing continuous perfection through the care of daily operations: the focus must be on the daily journey and not on the destination. Being better than competitors is not enough because the main goal is to provide value to customers, achieving zero waste.
This strong ambition could be interpreted with the term Kaizen; it is made up of two Japanese words: Kai, meaning change, and Zen, meaning perfection, which together are translated into continuous improvement (Bhuiyan et al., 2005). Kaizen is more of an attitude than a simple process of making improvements. In practice, it is the attitude of each member of the organization, which must be guided by the aspiration to improve everyday performance, through an infinite cycle towards perfection. To this end, a collaborative and participatory approach must be established to actively involve each actor in the continuous improvement process, using competences, experiences, skills, and abilities in the field in their own field. It is behavior that is focused on what needs to be done instead of what could be done.
The vision of continuous improvement is achieved one step at a time, day after day, through small but continuous initiatives. This concept is strongly at odds with the purely western idea of innovation and revolution (Yamamoto, 2010). However, Kaizen alone is not useful for pursuing Lean's ambitious goals: what is also needed is Kakushin (discontinuous improvement) and Kaikaku (revolutionary or radical change). Indeed, every firm needs both approaches (radical and incremental) to pursue perfection (Gåsvaer et al., 2012).

2.3. The 5S System

One method of identifying and addressing areas of inefficiency in manufacturing is the 5S system. Originally conceived as part of the Toyota Production System, the 5S system provides multiple benefits to the function of a workplace, including improved performance, better health, and increased safety. Each “S” in 5S represents a step in a process that improves the function of a business. Translated to English, the five “S” roughly stands for Sort, Set in Order, Shine, Standardize, and Sustain. Sorting the inventory of a workspace serves to remove all surplus items from the workstation. This includes putting less-used items in a different area while keeping the more important items in closer proximity. Similarly, Set in Order is devoted to arranging materials most logically, taking into consideration the role of every item in each step of the process. Shine establishes the responsibility of the company and each employee to clean up his or her workspace. After implementing Sort, Set in Order, and Shine, a firm needs to standardize the process so that the workplace does not revert to its original state. Standardization includes assigning regular tasks, creating schedules, and posting instructions to habituate these activities. Sustain, the last step of the 5S system refers to keeping the entire process running smoothly and keeping everyone in the system involved; it cements 5S as a long-term program and not just a short-term fix.
With 5S principles, companies in Hong Kong have successfully increased product quality and employee satisfaction. The implementation of the 5S system has also been shown to allow for easier integration of other management tools. In their studies, Ho and Fung (1994) stated that 5S was one of the strongest tools for enhancing the success factor of Total Quality Management implementation, which is another lean manufacturing principle. 5S has also been shown to be a driver for the successful implementation of other quality tool applications.

2.4. The Seven Types of Waste

As mentioned above, in Lean Manufacturing each of the operations that do not add value can be considered within one of the categories of the following waste classification. Each form of waste is linked to the others: overproduction requires excess means and work, leads to an increase in stocks and the consumption of space, large stocks make it difficult to trace production problems.
The following sections offer a brief explanation of each type of waste, as well as the identification of the most common causes and strategies that mitigate their effects.

2.4.1. Overproduction

Overproduction is the continued manufacturing of an item above the necessary demand for it, and in the process, creating a build-up of unused products. This creates waste as the product accumulates at a faster rate than it is transported out and can generate high storage costs and reduce product quality as quality control checks become more difficult at larger scales.
Among the main causes of overproduction, we can identify inefficient processes, uneven programming, misuse of automation, etc.
The measures that can be taken to eliminate waste associated with overproduction go through the generation of small production batches, leveling programs, and the ability to transform our production system into a "pull" system, producing the quantity needed at the moment. necessary.

2.4.2. Waiting

Waiting is the period when a product is not being transported or undergoing a transformational process. Much of a product's life in an assembly line system is spent waiting to be processed further, contributing to wasted time. Ideally, processes should feed directly into one another so that it flows from one step to another smoothly. There are multiple indicators that show us the presence of pending rejects: the operator waiting for the materials to arrive, an operator waiting for a machine to finish a job or even an operator waiting for other operators to continue. Expectations are attributable to various causes, including unbalanced lines, frequent quality problems, very long set-up times, poor planning. The review of all these activities can lead to ample room for improvement in the lead time of the product.

2.4.3. Transportation

Transportation is an inherently wasteful practice as it requires time, energy, and money to move a product, yet adds nothing to a product's value. Manufacturing processes should be compact such that the product does not need to be transported long distances during or upon the completion of the process. Furthermore, handling and transport create opportunities for damaging and reducing the quality of the product.
To counter these rejects it is possible to make more frequent and smaller deliveries, to carry out studies to optimize the lay-out and to obtain a better flow control.
Handling is estimated as an added value by the consumer only if it brings an advantage in the position or in the delivery times.

2.4.4. Inappropriate processing

Inappropriate processing represents the improper utilization of assets to perform tasks. Tools and machines should be specialized to the necessary task they perform, so when a machine can do far more than what it is being used for it is an example of inefficiency and waste. It is thus preferential to invest in smaller, more specialized equipment, and take advantage of a more powerful machine for appropriately difficult tasks. This form of waste is the most difficult to identify and eliminate, and reducing it involves eliminating unnecessary elements of the work itself. The use of unskilled operators or repeated steps in the production process are the main causes that can lead to over-processing.

2.4.5. Unnecessary inventory

Stock refers to the stock of finished products, semi-finished products or raw materials accumulated by the production system. Both finished products for which there is no destination or a well-defined order and raw materials or semi-finished products produced without having concrete orders for finished products must be considered excess inventory. These stocks, blocked in inventory, generate waste from various points of view: deterioration, depreciation, waste of the value of the goods and of the capital invested.
Perhaps the most serious problem when you want to create a "lean" production system is that the excess of inventories makes it difficult to identify other problems in a transparent way, for example imbalances in production processes, late deliveries, etc.
Among the most effective measures to combat this type of waste is to produce in smaller batches, switch to a production system of the Pull type and to a leveled programming.

2.4.6. Excess motion

These are the movement actions of components and operators that are not necessary for the functioning of the production system. Excessive movement is a waste. Any waste in this aspect consumes time and energy in an inefficient way and has a high cost. A movement is a waste if there is another shorter, simpler and / or less expensive move to perform the same operation or to achieve the same result.
Movement tires, takes up space and takes time. Any simplification is therefore a saving. Only the essential movements must be maintained, inserting the indications in the procedural guides, and introducing special tools to facilitate the work activity (for example, adaptive workstations).
Improving the organization of the workspace and redesigning the plant layout are techniques that help mitigate the effects of these wastes.

2.4.7. Defects

It consists of producing defective parts or manipulating materials improperly. It also includes the waste of having to redo the job again and the loss of productivity associated with interruptions in the continuity of the process. They affect the capacity of the process, add costs and compromise the quality of the final product or service. Inspections upon receipt of material and the presence of rework areas along the production line are indicators of rework waste.
There are multiple causes behind rework waste, including the purchase of uncontrolled materials, inadequate tools, overproduction. Carrying out quality checks on products sent by suppliers, thus avoiding the need for a space in the plant to carry out the checks, reduces the cost of these waste.

3. Lean production in SMEs

The “Lean” business ideology (Bhasin, 2013) is a business method that promotes efficiency and elimination of waste, while also focusing on a high level of awareness of what the customer wants (Bhamu and Singh Sangwan, 2014; Shah and Ward, 2007). Due to this ideology the method has been adopted by many companies to direct their outlooks and exertions to best improve their operations. This shows how Lean is not limited to one type or size of company, but rather all types, sizes and industries that strive to increase their competitive advantages, operations, and profits in the regional and global markets.

To date, the research has mainly focused on larger companies implementing it (Dombrowski et al. 2010), in particular in the automobile industry. However, it should be acknowledged that SMEs can also take advantage of the Lean methodologies as long as they can successfully adapt them to suit their individual situations. Any company, regardless of size, faces challenges and the Lean methods have proven themselves beneficial, especially in the manufacturing industry, over the years. This has been supported by the number of companies adopting the methods and the large number of studies carried out that have supported its success in their results (Hu, Mason, Sharon J. Williams, et al., 2015).

Small And Medium-Sized Enterprises (SMEs) are among the most important economic units in the world. They contribute more than larger organizations, economically, in terms of providing employment, added value and contribution to GDP of the country. For all this, it has become important to think about the ways that will contribute to the improvement of the SME.
Lean's approach as a model, based on the elimination of waste, can play a vital role in the competitive trend to help manufacturers by saving their resources with higher productivity. The recent philosophy facilitates the opportunity to design and direct SMEs to survive in a dynamic market environment.

In the literature it can been found many examples for the implementation of Lean Production in large and medium sized enterprises. Considering the size classes, it can be observed, that Lean Manufacturing concepts are basically realizable by large, medium, and small enterprises. An implementation of Lean Production concepts in micro enterprises with less than 10 persons employed wouldn’t make sense. However, for many small enterprises between 10 and 49 employees the application of Lean Manufacturing could be one important step to increase the productivity and to be more competitive on the market.
Typically, SMEs and especially small enterprises are not only adaptive and innovative in terms of the products but also their manufacturing practices. Recognizing the continuing competitive pressures, small organizations are becoming increasingly proactive in improving their business operations, which is a good starting point for introducing lean methods. Practical examples of real case application have been presented in the following section.

3.1. Practical example (1): Production of exclusive bathroom furnishings

The applied approach for implementation has been considered by a small sized company with 25 persons employed. The firm started in 1995 as a small crafts enterprise processing solid surface material (Corian®) for kitchens and interior design in corporate and public spaces. In course of time the firm focused his activity on the production of exclusive bathroom furnishings in solid surfaces and increased to a small industrial organization with 15 production workers. The Management wants to be prepared to benefit from the predicted upward phase of the market cycle and started a project to improve the productivity rate in manufacturing.

To implement this concept in the illustrated firm with 25 employees it was important to decompose the whole concept into single working packages and to plan them on the time axis. The management decided in close collaboration with an external manufacturing consultant to implement the concept within a period of two years in single steps. Small companies are very flexible and fast in their decision-making, but in account of the limited resources the people in this firm were not able to dedicate too much time to the project. Therefore, it came out, that it is better to realize such a project step by step. The time was a very critical factor in the implementation process. In small enterprises the implementation of single steps presses very often on the shoulders of single persons; in medium or large companies the workload is usually distributed on a team.

The first operative working package consisted in the reorganization of the manufacturing layout introducing work cells and small autonomous teams (to ease the workload of the production manager and to increase productivity).

In every team was named a highly experienced and organizational capable worker as team leader. The team leaders had to start their job with the moderation of CIP-meetings to gather ideas and suggestions to reduce waste and inefficiency. In every team were done 5S-Workshops to clean up the production and to define guidelines for order and tidiness. The teams had also to develop new and more efficient workstations.
An important improvement was realized through the central picking station to prepare and cut the raw material, to pick the semi-finished and purchased components as well as the special Corian®-adhesive. The worker at the picking station must commission all the needed components on a special trolley and to bring this trolley to the single manufacturing cells. The advantage of this reorganization was an incredible increase in productivity of more than 25% over all products, because in the prior situation every worker had to provide the single components oneself. Therefore, times for walking, searching, and handling were enormous. In the new situation every worker in the single cell does not have to leave his cell during the working hours. Also, the specialization in the manufacturing cells helped to reduce manufacturing times.

To ensure a zero-defect approach, every team is now responsible for the quality of the own process steps.
Every team leader had to elaborate standardized working instructions with photos for the different positions to ensure the Knowledge Management and a standardized process. These visual work instructions are also very helpful to train new and foreign workers. In a central point of production was created an Info-Point for Visual Management to show news and production KPIs on a Whiteboard.

3.2. *Practical example (2): Production of paint and surface finish products*

The second company considered was originally established in the 1950s and it is located in Southern Finland. The company's revenue is approximately seven million euros, and it employs roughly twenty people. The company focuses on importing and manufacturing paint and surface finish products. Approximately 20% of the products are manufactured in-house by using make-to-stock principles. Customers are retailers that are mainly located in Finland, and they re- quire very short delivery times. The demand is seasonal; roughly 50% of sales occur between May and September.

The company's key business processes include customer service, marketing and sales, manufacturing, inventory management, and purchasing. Sup- port processes include business planning, competence development, product development, and re- source management. The goal of the 6-month development project analyzed in this study was to create a plan to achieve more productive and efficient production. The main sub-goals included retaining the competitiveness of local manufacturing, creating a profitable product portfolio, achieving continuous flow in production, and improving the workforce's competencies.

Based on the current state analysis, several forms of waste were identified. The main challenges were identified to be a large amount of work-in-process (WIP) production, a large product portfolio, and the production layout. The first issue, the large number of WIP items, resulted in extra intermediate inventory, which caused disorder in the facilities. In addition, quality issues were not identified due to these inventories. The current state analysis also demonstrated that the company's portfolio included over one hundred different products. The large amount of product variants was partly causing large WIP production. In addition, the employees specialized in certain tasks and their absences increased WIP production.

The production flow was not smooth enough. Items were transferred several times between work-stations during the production process. Production setup times were also quite long. This was partly due to disorder in the facilities; a lot of time was spent searching for production tools and in some cases the tools had to be repaired before use. In addition, the utilization rates for some of the machines were very low. The setup times for these machines were long, which led the management to increase the lot sizes. Product lot sizes varied between 3,000 and 10,000 units.

After the current state analysis, the objective state and goals were set for the company's production. The aim was to remove all non-value adding activities from the production process. Value stream mapping and related tools were utilized to standardize activities and improve the production flow, layout, and cycle and setup times. The 5S method and continuous improvement were also identified as important to achieve the objectives that were set. Figure 4 illustrates the case company's objective state and goals.

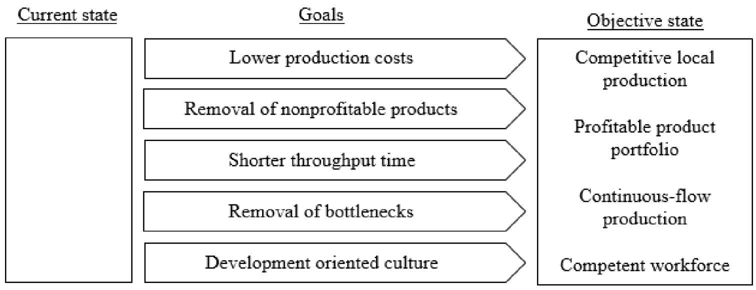

Figure 4.The case company's objective state and goals

The removal of non-value adding activities was identified as a key element in the development of production. Decreasing WIP production was an effective way to tackle some of the problems presented above. Finalizing a production lot before starting the next one results in shorter lead times and smaller intermediate inventories. This, in turn, makes it easier to find items in the production facilities. A renewed layout reduces unnecessary movement and ensures smooth production flow. The discontinuation of nonprofitable products – approximately 50% of the portfolio – improves profitability and enables getting rid of unnecessary machine resources in production (i.e., 40% of the current equipment).
Human resources were also identified as a key area needing development. One of the key issues identified in the current state analysis was the high specialization of the production employees, which made the production process vulnerable, since the absence of one employee could prevent producing certain products. This issue was planned to be tackled with resource reallocation, training, and task rotation. Dis-order in the production facilities would be addressed with 5S implementation. Required tools and their storage locations were defined at each workstation. Finally, a proposal was made to change the packaging materials for the final products from cardboard boxes to plastic bags in cases where the old material was not considered to add any value compared to plastic. This change results in material cost savings and enables automatization.

3.3. Highlights

These real cases of Lean Manufacturing application underline how lean philosophy has proven to be a viable and popular approach for developing production processes and enabling continuous improvement in these companies.

Despite the substantial differences in the production systems of each company, the literature demonstrates how the Lean methodology brings substantial improvements, albeit with different peculiarities in each case. It therefore becomes of primary importance to increase and consolidate specific knowledge on the methodology within each company, so as to be able to gain a competitive advantage in the market.

In line with what has been said and seen so far, the Lean Production methodology has been applied to the Eurofork S.p.A telescopic fork production line.

4. Eurofork S.p.A

4.1. Company overview

Eurofork S.p.A., founded in the year 2000, is an Italian company that produces automatic handling systems. With over 20 years of know-how learned in the handling field, Eurofork today is one of the leading players in the global market concerning the production of telescopic forks, for both the number of units produced and its turnover.
In addition to the division Telescopic forks, the company boasts two other areas: the Service department which deals with after-sales assistance, maintenance, and purchasing of parts sales, and the Esmartshuttle division specialized in design and manufacture of shuttle systems for multi-depth automated warehouses.

4.2. Telescopic Fork

A telescopic fork is a machine composed of a fixed body and superimposed elements that move in a bilateral telescopic way for the translation of loads concerning the center.
Telescopic forks are especially used in automatic warehouses and industrial automation. In automatic warehouses, they are the element that allows the stacker crane to move along the Z-axis, allowing loads to be picked up in the shelving cells. In industrial automation, telescopic forks find various applications such as changing the assembly line of skids in the automotive sector.

Typically, they are used in pairs to give stability to the load or in batteries of several forks connected by Cardan joints. They are used to withstand loads ranging from 50 kg to 25000 kg.
In most cases, telescopic forks are used for handling pallets. The pallets can be stored on racks in first or double depth (hence the types of forks take their name).

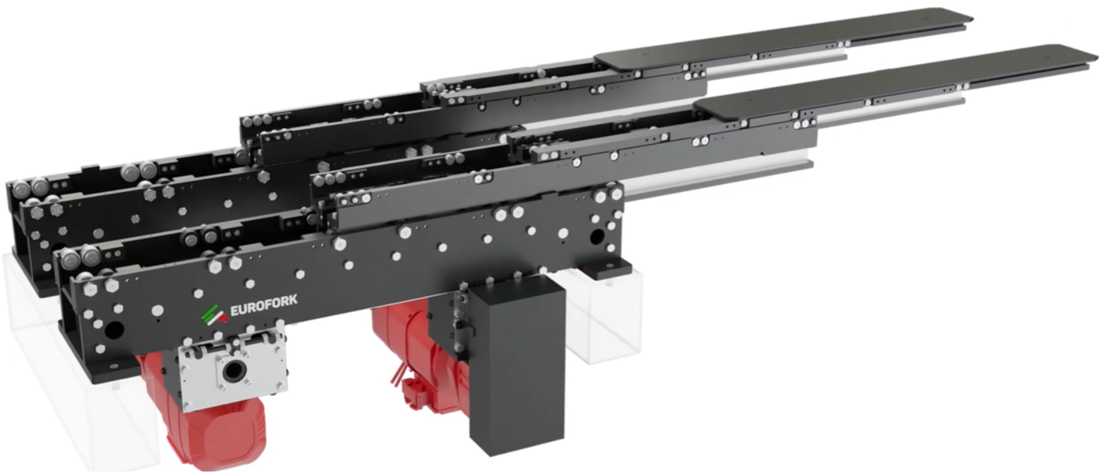

Figure 5. Eurofork telescopic fork

There exist, depending on the number of movable elements, different typologies of telescopic forks:

- Simple depth (two movable elements concerning the fixed body):
  They have two movable elements concerning the fixed body. These forks perform a bilateral movement called "in simple depth”; they can move the loads stored in the shelving in a single line.

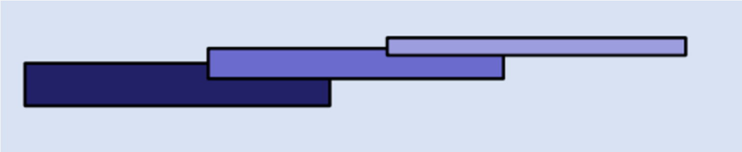

Figure 6. Single depth telescopic fork

- Double depth (three movable elements concerning the fixed body):
  They have three movable elements concerning the fixed body. These forks perform a bilateral movement called "double depth”; they can move the loads stored in the shelving on two lines. Forks with three extensions can reach high stroke/fork length ratios: this means that with them it is possible to obtain longer strokes than those achievable with simple depth forks or it is possible to handle heavier loads by reducing the maximum stroke.

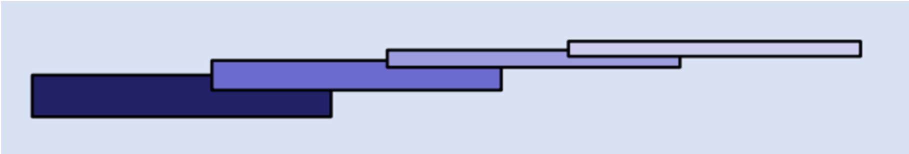

Figure 7. Double-depth telescopic fork

- Triple depth (four movable elements concerning the fixed body):
  They have four movable elements concerning the fixed body. These forks perform a bilateral movement called "in triple depth"; they can move the loads stored in the shelving on three lines. However, these forks are often used as double depths in cases where a reduced length of the fixed body is required, or when the load to be handled is particularly heavy.

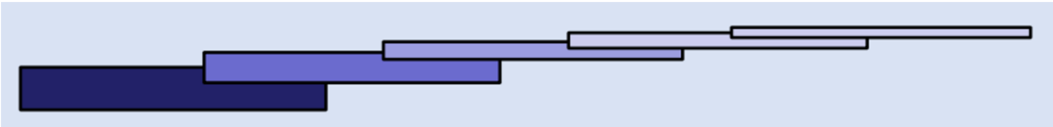

Figure 8. Triple depth telescopic fork

The motion is transmitted by the gear motor to the first mobile element; the second extension will move at twice the speed of the first thanks to a series of gears, chains, or belts linked to the fixed body. In the case of telescopic forks in double (or triple) depth, the motion is returned to the third (or fourth) extension. To obtain the relative sliding between the sliding elements, wheels are used while the lateral guide is obtained thanks to polytene or bronze skids.

4.3. Problem statement and methodology definition

The research has the ambition to make improvements within the assembly line of the telescopic forks, produced by Eurofork. The increase in production volumes has in fact brought out the need to create a more organized and smooth flow. Furthermore, through the improvements, the goal is to increase the well-being of the operator and consequently reduce the risks related to safety.

As already mentioned, the ideal means to achieve this goal was identified in the Lean production methodology, which was applied following the steps proposed by the Lean Six sigma.

The research can be divided into four macro areas:

1. Define
2. Measure
3. Analyze
4. Improve

4.3.1. Define

The first phase consisted in the study and definition of the context to be analyzed. It is in fact essential to understand in detail the process and methodologies rooted in the culture of the company analyzed, to then be able to propose changes. A flow chart that describes the flow of information and material within the production of a telescopic fork was made. This first part aimed to describe the process in its entirety, and then go into detail through the composition of the AS-IS value stream mapping. The latter had a dual function: on the one hand the description of the analyzed production flow and on the other hand an initial analysis of potential critical points and non-value-added activities.

4.3.2. Measure

The research then has been concentrated on the collection of a set of data, essential for the next part of the analysis. The team has taken measurements directly on the assembly line, leading to the creation of two different datasets: timing of single-depth forks and timing of double-deep forks.

Once the datasets have been created, they were analyzed, searching for possible outliers and highlighted the most critical activities. This phase was of great importance because it allowed to move from a qualitative to a quantitative analysis, and therefore to add numerical evidence to the observations previously made.

4.3.3. Analyze

This phase represents the heart of the application of Lean manufacturing. In fact, all the Lean principles previously illustrated were applied, in order to bring out all the issues and the consequent possible improvements. After the analysis of the AS-IS context, a TO-BE scenario, which would improve the critical points, has been proposed.

4.3.4. Improve

In the end, after the theoretical description, the Lean principles were concretely applied in the production line, to observe how the line reacted to the change. The first step was the 5S application, followed by a real application of the results in the production of a double depth telescopic fork

5. Telescopic fork process

5.1. Description of the material and information flow

To understand, analyze and propose improvement solutions for the production line of telescopic forks, the flow of material and information of this product has been studied and described, starting from the management of the order up to the shipment of the finished product.

The process starts in the commercial area, where a first contact takes place between Eurofork and the potential customer. If this turns out to be positive, the potential order is managed by the pre-sales area, which takes care of the basic design of the project. The process then continues in the design area with the detailed design of the product, which is followed by an order receipt signal from the purchasing department. At this point, the order is opened, and the production warehouse takes charge of it.

Regarding the specific order, it is then established whether it is a C / L (Work Account) or an F / P (Full Supply). If it is a C / L, the raw material, previously purchased by Eurofork, is sent to the supplier so that it can be processed. If, on the other hand, we are talking about F / P, the order is fully managed by the supplier, who will ship the already processed piece. In both cases, the components are then sent to paint externally and are then ready to be assembled.
All the components purchased directly from the sales office (i.e. screws, washers, nuts, ...) are managed in the warehouse and not on order like the rest of the components.
These pieces are periodically ordered and loaded into the vertical warehouse, to then be picked up for the preparation of the specific order.
Once the material for the order is ready and a pre-assembly of the main components has been made, the transfer to the production warehouse takes place.

Inside the production warehouse, component preparation and pre-assembly operations are carried out in line, in support of the actual assembly. However, the assembly line of the telescopic forks will be described in detail in the following paragraphs. Once the product is complete, testing and then finishing takes place. If critical issues are found during the testing operation, Eurofork works backward to understand the origin of the problem. If the problem persists, it is also possible to modify the initial project, thus having to interface with the customer again.
Finally, after testing and finishing, the finished telescopic fork is transferred back to the production warehouse, where it is packaged and shipped to the customer.

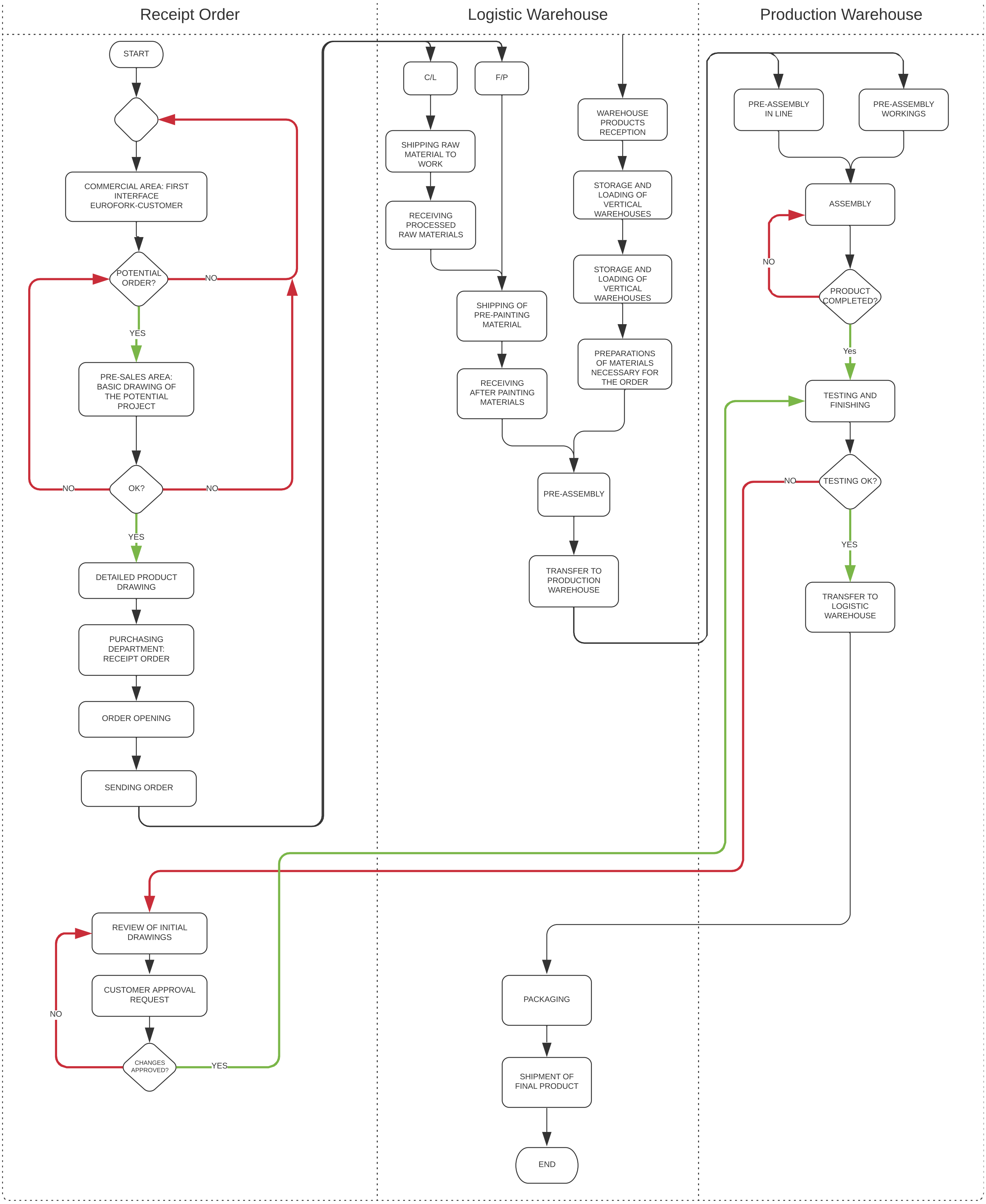

Figure 9. Eurofork telescopic fork flowchart

5.2. *Value Stream Mapping AS-IS*

VSM is one of the most important and powerful Lean tools for an organization to implement and improve on its lean journey. The car manufacturer Toyota co. Japan was the first company to use VSM techniques in its lean concept implementation. It is a graphical tool that is created using a predefined set of standardized icons that helps the organization to see and understand the flow of material and information as the product goes along different stages. After drawing the value stream, it helps the organization to differentiate value-adding activities from non-value-adding activities from the current condition and identify kaizen opportunities.

For all these reasons, a VSM implementation of the production line of Eurofork is carried out.

As seen before, the supplier and the customer interact mainly with the logistic warehouse, which oversees receiving materials from the supplier, shipping to the production warehouse what is required for each order with a forklift, receiving from the production warehouse the finished product, and lastly shipping it to the customer. Regarding the Eurofork supply chain, all the orders are managed following a fully-pull approach. For that reason, there is no information in VSM about forecasting time in referment of orders to suppliers; following the receipt of an order, the pieces are sorted from the various suppliers.

The production warehouse represents the beating heart of the assembly of telescopic forks, a flagship product for Eurofork. However, the information summarized in this paragraph represents an estimate and a generalization of the process due on the one hand to the lack of a sufficiently accurate and detailed database and on the other hand to jobs managed to order with peculiar differences between them.

The process analyzed below refers to a single-depth telescopic fork and all the values are referring to a couple of telescopic forks.

Firstly, the various components (fixed body, upper slide, and lower slide) are moved and positioned inline in the predetermined positions. The fixed body's handling requires a longer timeframe than that of the slide members due to the greater weight and volume. These operations are not characterized by a great variability between order and order. Moreover, there is a setup time due to the trolley preparation; indeed, each telescopic fork assembled by Eurofork is fully customized and so it is characterized by different lengths and weights.

Once placed in line, the components are cleaned and prepared for assembly. Even in this case, the timing is standard and there are no significant variations between the different orders. There are no buffers after the cleaning operation because, at this point, the actual assembly immediately begins. As far as slides are concerned, this operation does not require specific know-how and therefore can be carried out by almost all operators. For that reason, after the slides assembly, they have located buffers. These operations are standardized and quicker than the fixed body assembly and often lots of assembled slides wait for the next operations.
Since it contains more numerous and varied components, the fixed body generally requires a much longer time frame than the slide pieces.
Once the assembly is complete, the latter are coupled, and then perform the final coupling between the sliding assembly and the fixed body. These operations are the most complex and require greater know-how and experience. Furthermore, the sequence of operations within this phase is not always standard, and therefore it must be considered a medium variability. It is possible to notice a considerable variation in the timing between order and order.

Finally, the fully assembled telescopic fork is transferred to the finishing station. It represents the last step before the testing, and it is not subject to significant variations in timing. However, the duration of this task is not negligible.

At the end, the finished telescopic fork is transferred to the testing station. This phase requires relatively long times, also due to the station's set-up time. As said before, the differences between the orders force the company to adapt the testing station to each telescopic fork's dimension and specifications.
Moreover, being the longest operation, the testing area requires a quite large buffer.
The variability is to be considered high since, together with the possible problems encountered during testing, the phase can last more or less.

Once the piece has been tested, the process ends with the packaging phase, which takes little time.

In the VSM, through the *Kaizen lightning bursts,* wastes and opportunities for improvement are highlighted. Firstly, observing the process, it happens an over-production of slides, that do not bring any added value. On the other hand, the testing represents the most complex operation, particularly because of the high setup time. These are the main opportunities for improvement.

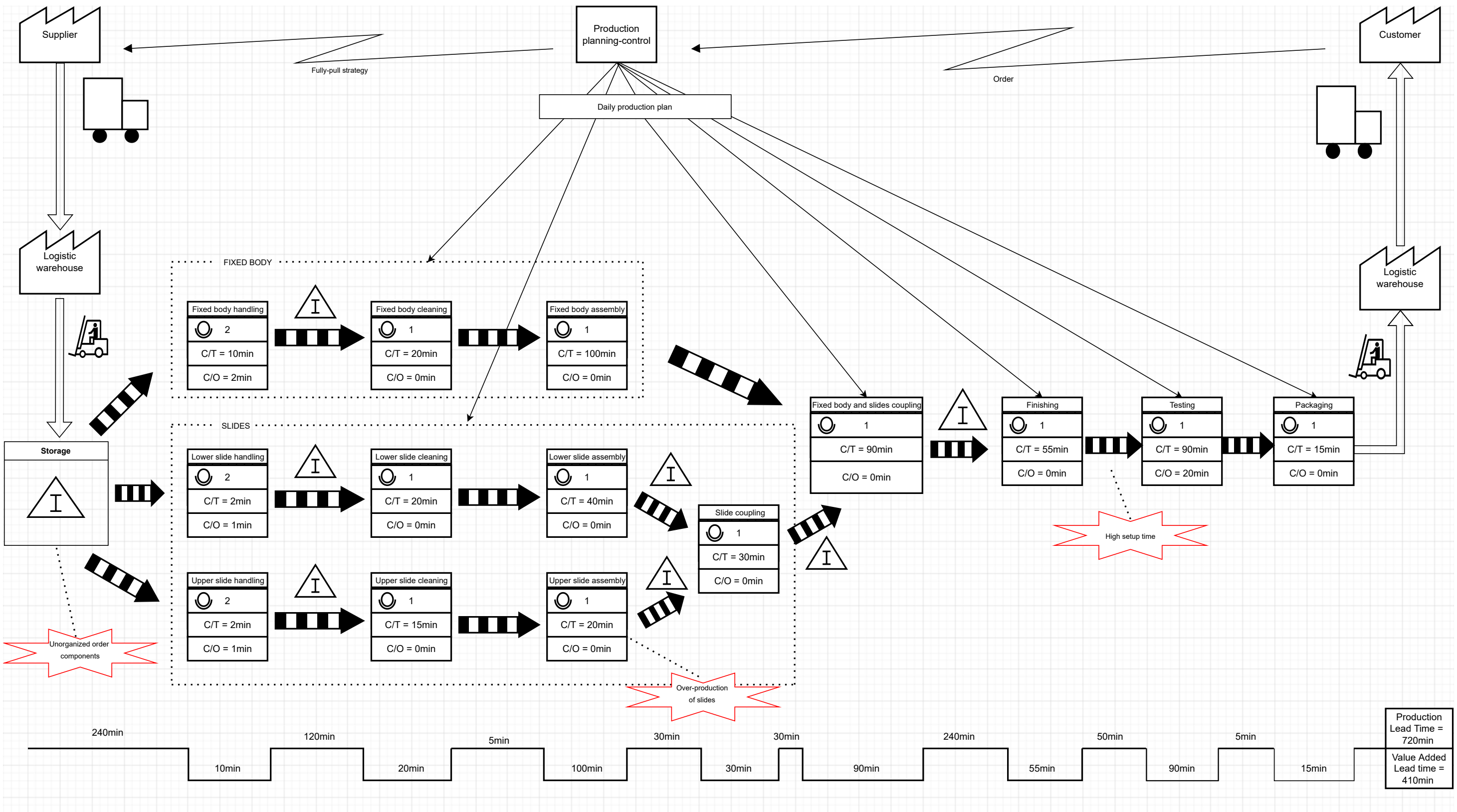

Figure 10. AS-IS VSM of SD telescopic fork

Taking into consideration a double depth telescopic fork, the VSM does not change radically. The most substantial differences are found in the presence of the intermediate slide, which requires its handling, cleaning, and assembly, and in the need for a double coupling. Finally, being more articulated forks, the testing phase lasts on average much longer.

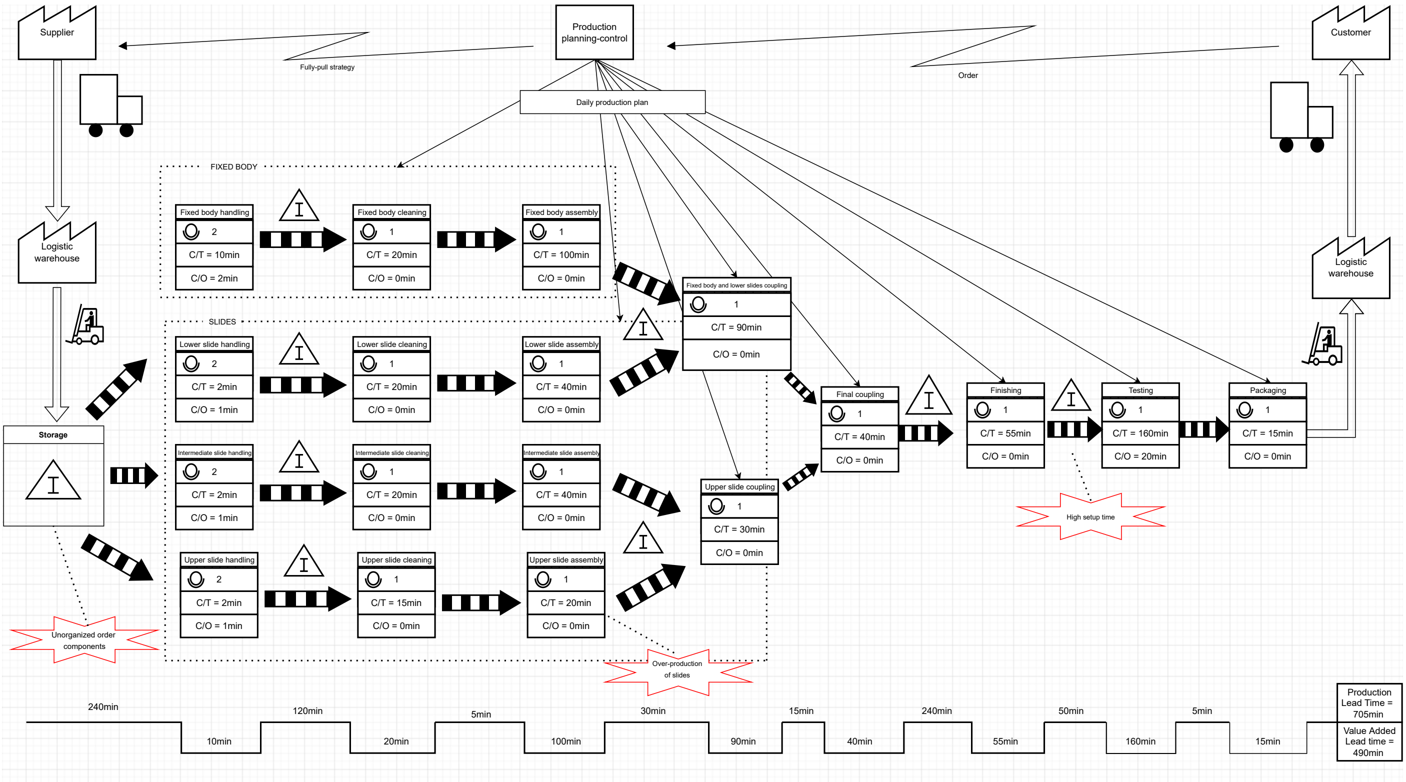

Figure 11. AS-IS VSM of DD telescopic fork

6. Data collection

After having described and defined the flow of information and processes of the telescopic forks, the analysis moved towards the creation and identification of a data set to objectively describe the AS-IS situation. Data is a key ingredient in any type of analysis and helps distinguish what you think is happening from what is happening. Furthermore, the measurement of the performance of the AS-IS process allows to establish a basic level of performance and to evaluate the impact of the changes implemented on the process itself.

Due to the difficulties in continuously measuring process performance, the analysis was carried out through the identification of a statistical sample, to allow, with limited margins of errors, the generalization of the results to the entire population.

This approach is often chosen by companies for reasons:

1. Reduction of sampling costs
2. Reduction of sampling times and/or efforts
3. Presence of destructive evidence

The sampling of the units to be analyzed was carried out in two different steps. On the one hand the data provided directly by the operators, and on the other hand according to a manual measurement on the assembly line of each work phase. The desirable output of the analysis was to understand the duration of each phase for each type of telescopic fork.
In particular, the data were segmented into two different groups, representing the single-depth and double-depth forks, respectively.

The definitive dataset includes the measurement of the process duration of thirty different single dept telescopic forks and thirty double depth ones. All the values are referring to a couple of forks. As it can be seen, there is a great difference between the SD telescopic fork and the DD one. The presence of an additional slide entails extra work phases.

MEASUREMENT	FIXED BODY			LOWER SLIDE			UPPER SLIDE			SLIDE COUPLING	FIXED BODY AND SLIDE COUPLING	FINISHES	TESTING	PACKAGING	TOTAL
	HANDLING	CLEANING	ASSEMBLY	HANDLING	CLEANING	ASSEMBLY	HANDLING	CLEANING	ASSEMBLY						
1	2,03	21,38	90,02	1,99	20,04	43,74	1,97	14,10	21,80	26,57	85,17	55,19	33,90	14,44	**432,34**
2	2,00	20,00	67,21	2,03	19,09	34,62	2,08	15,50	19,20	32,36	92,61	59,49	98,70	15,38	**480,27**
3	2,02	20,50	88,99	2,02	19,71	39,21	1,94	16,40	20,10	33,66	110,00	44,76	71,64	13,99	**484,94**
4	1,98	21,27	97,31	2,01	22,44	40,26	1,99	15,00	20,90	28,88	84,41	61,34	97,22	16,42	**511,43**
5	2,03	22,33	132,62	2,01	20,46	41,72	2,00	14,80	19,50	29,06	90,57	55,08	100,80	15,49	**548,47**
6	2,05	21,10	78,68	1,96	18,87	34,87	1,94	15,50	16,60	21,08	104,60	48,85	133,00	14,69	**513,79**
7	1,97	19,25	113,10	1,99	19,04	41,08	2,01	16,40	19,20	32,34	85,19	59,62	91,33	14,73	**517,25**
8	2,03	19,56	92,38	2,04	20,85	35,61	2,04	15,50	21,00	26,72	110,40	54,42	100,90	15,23	**518,68**
9	2,04	18,42	75,54	2,02	19,68	42,50	1,99	14,50	16,20	30,83	62,98	52,74	58,02	15,99	**413,45**
10	1,94	19,20	102,69	2,01	19,79	45,77	1,96	14,20	19,00	27,50	104,50	53,32	111,00	14,73	**537,61**
11	2,03	20,58	112,06	1,97	19,04	37,88	2,04	14,80	20,10	33,24	47,36	53,72	100,60	14,23	**479,65**
12	2,02	18,63	105,21	1,93	20,10	36,19	1,97	14,20	18,60	29,06	69,70	43,53	59,33	15,57	**436,04**
13	1,93	19,43	91,47	2,01	19,56	35,14	1,96	15,60	21,90	29,83	103,20	52,38	92,36	15,69	**502,46**
14	2,03	18,97	153,89	2,04	19,50	43,92	1,97	14,80	18,70	34,64	72,35	64,92	47,19	13,81	**508,73**
15	1,97	19,80	102,84	1,94	20,07	47,92	2,00	13,90	21,60	36,40	111,90	56,04	103,50	14,28	**554,16**
16	1,98	19,69	86,67	1,96	19,11	41,32	2,00	15,00	24,90	20,20	102,10	62,05	108,20	15,71	**520,89**
17	2,04	20,34	96,67	1,94	20,78	39,87	1,95	14,40	18,30	37,46	86,25	50,44	76,31	14,35	**481,10**
18	1,99	20,30	122,32	2,04	19,27	41,46	2,08	15,60	18,80	32,58	112,90	60,56	66,26	14,09	**530,25**
19	1,98	19,75	100,26	2,06	20,16	33,85	2,01	14,90	22,00	26,14	75,75	55,80	116,80	15,38	**506,84**
20	1,91	19,28	90,06	1,93	22,35	42,97	2,01	13,90	20,70	31,36	87,61	55,64	132,30	15,70	**537,72**
21	2,05	21,47	85,31	2,04	20,76	38,40	2,04	12,90	21,40	42,70	109,50	52,19	85,51	13,52	**509,79**
22	1,97	19,28	112,51	2,02	20,00	40,91	2,09	15,70	20,60	32,07	87,89	50,29	124,50	15,63	**545,46**
23	2,07	20,69	112,13	2,02	18,11	36,15	1,98	13,60	19,40	26,27	111,70	53,44	100,80	15,06	**533,42**
24	2,01	20,35	64,33	1,99	20,47	39,94	2,04	14,70	19,80	43,52	65,43	55,60	112,20	14,30	**476,68**
25	2,00	20,27	91,08	1,95	20,26	42,51	2,05	14,30	19,60	32,58	82,10	42,79	68,55	15,63	**455,67**
26	2,00	17,22	95,64	1,98	19,53	47,38	2,05	14,00	17,90	30,37	93,39	51,16	114,30	14,40	**521,32**
27	2,08	20,00	101,91	1,99	21,44	35,67	2,08	14,80	18,40	29,76	89,92	55,42	99,03	15,33	**507,83**
28	2,00	18,83	93,82	2,01	20,74	32,88	1,95	13,40	19,30	33,52	61,15	49,41	73,75	14,81	**437,57**
29	2,02	19,33	95,14	1,99	20,22	37,54	1,94	15,30	19,00	32,64	86,38	46,05	94,50	14,21	**486,26**
30	2,00	21,90	159,87	1,99	20,45	37,87	1,93	15,40	22,00	24,02	131,20	51,37	84,10	15,35	**589,45**

Figure 12.SD telescopic fork dataset

MEASUREMENT	FIXED BODY			LOWER SLIDE			UPPER SLIDE			INTERMEDIATE SLIDE		
	HANDLING	CLEANING	ASSEMBLY	HANDLING	CLEANING	ASSEMBLY	HANDLING	CLEANING	ASSEMBLY	HANDLING	CLEANING	ASSEMBLY
1	2,03	21,38	90,02	1,99	20,04	43,74	1,97	14,1	21,8	1,95	19,31	46,36
2	2,00	20,00	67,21	2,03	19,09	34,62	2,08	15,50	19,20	1,94	19,61	39,46
3	2,02	20,50	88,99	2,02	19,71	39,21	1,94	16,40	20,10	1,95	19,77	36,80
4	1,98	21,27	97,31	2,01	22,44	40,26	1,99	15,00	20,90	2,01	18,40	40,32
5	2,03	22,33	132,62	2,01	20,46	41,72	2,00	14,80	19,50	2,00	19,39	40,90
6	2,05	21,10	78,68	1,96	18,87	34,87	1,94	15,50	16,60	2,02	19,14	44,85
7	1,97	19,25	113,10	1,99	19,04	41,08	2,01	16,40	19,20	2,00	20,26	43,00
8	2,03	19,56	92,38	2,04	20,85	35,61	2,04	15,50	21,00	1,98	19,93	40,85
9	2,04	18,42	75,54	2,02	19,68	42,50	1,99	14,50	16,20	2,08	20,06	42,68
10	1,94	19,20	102,69	2,01	19,79	45,77	1,96	14,20	19,00	2,02	20,84	33,50
11	2,03	20,58	112,06	1,97	19,04	37,88	2,04	14,80	20,10	1,97	18,29	46,53
12	2,02	18,63	105,21	1,93	20,10	36,19	1,97	14,20	18,60	2,03	18,68	43,84
13	1,93	19,43	91,47	2,01	19,56	35,14	1,96	15,60	21,90	1,97	20,17	39,04
14	2,03	18,97	153,89	2,04	19,50	43,92	1,97	14,80	18,70	2,06	20,97	38,13
15	1,97	19,80	102,84	1,94	20,07	47,92	2,00	13,90	21,60	1,95	22,24	35,56
16	1,98	19,69	86,67	1,96	19,11	41,32	2,00	15,00	24,90	2,06	21,63	38,20
17	2,04	20,34	96,67	1,94	20,78	39,87	1,95	14,40	18,30	1,99	20,54	42,88
18	1,99	20,30	122,32	2,04	19,27	41,46	2,08	15,60	18,80	1,96	20,08	42,27
19	1,98	19,75	100,26	2,06	20,16	33,85	2,01	14,90	22,00	1,99	20,04	48,98
20	1,91	19,28	90,06	1,93	22,35	42,97	2,01	13,90	20,70	1,97	20,54	34,41
21	2,05	21,47	85,31	2,04	20,76	38,40	2,04	12,90	21,40	1,96	21,70	50,21
22	1,97	19,28	112,51	2,02	20,00	40,91	2,09	15,70	20,60	2,02	19,10	34,87
23	2,07	20,69	112,13	2,02	18,11	36,15	1,98	13,60	19,40	1,96	18,09	40,92
24	2,01	20,35	64,33	1,99	20,47	39,94	2,04	14,70	19,80	1,91	20,91	35,95
25	2,00	20,27	91,08	1,95	20,26	42,51	2,05	14,30	19,60	1,98	20,91	39,06
26	2,00	17,22	95,64	1,98	19,53	47,38	2,05	14,00	17,90	1,93	19,67	25,33
27	2,08	20,00	101,91	1,99	21,44	35,67	2,08	14,80	18,40	2,01	20,05	29,18
28	2,00	18,83	93,82	2,01	20,74	32,88	1,95	13,40	19,30	1,94	20,40	35,00
29	2,02	19,33	95,14	1,99	20,22	37,54	1,94	15,30	19,00	1,95	21,36	45,60
30	2,00	21,90	159,87	1,99	20,45	37,87	1,93	15,40	22,00	1,98	20,59	42,53

Figure 13. DD telescopic fork dataset (1)

MEASUREMENT	UPPER SLIDE COUPLING	FIXED BODY AND LOWER SLIDE COUPLING	FINAL COUPLING	FINISHES	TESTING	PACKAGING	TOTAL
1	22,63	120,4	38,04	55,19	143,4	14,44	**678,79**
2	27,66	90,59	44,76	59,49	115,00	15,38	**595,62**
3	26,98	115,00	43,63	44,76	180,50	13,99	**694,27**
4	23,58	96,01	30,68	61,34	151,30	16,42	**663,22**
5	38,94	87,02	31,92	55,08	129,20	15,49	**677,41**
6	30,75	104,40	32,25	48,85	97,70	14,69	**586,22**
7	28,36	108,40	48,56	59,62	190,10	14,73	**749,07**
8	35,17	58,39	32,45	54,42	194,20	15,23	**663,63**
9	26,70	59,53	36,60	52,74	150,10	15,99	**599,37**
10	28,85	72,29	44,92	53,32	132,60	14,73	**629,63**
11	27,19	77,69	40,36	53,72	216,90	14,23	**727,38**
12	25,83	88,90	59,71	43,53	103,50	15,57	**620,44**
13	34,50	106,40	39,04	52,38	128,40	15,69	**646,59**
14	28,97	83,76	48,86	64,92	75,06	13,81	**652,36**
15	34,37	120,70	47,00	56,04	175,70	14,28	**739,88**
16	27,11	78,87	34,09	62,05	200,00	15,71	**692,35**
17	32,26	76,20	40,45	50,44	155,30	14,35	**650,70**
18	31,44	99,72	42,81	60,56	255,60	14,09	**812,39**
19	38,44	81,45	39,18	55,80	155,10	15,38	**673,33**
20	30,14	87,97	24,59	55,64	205,10	15,70	**691,17**
21	26,24	110,10	37,98	52,19	62,26	13,52	**582,53**
22	28,76	89,37	43,27	50,29	247,90	15,63	**766,29**
23	30,36	63,08	38,99	53,44	225,40	15,06	**713,45**
24	28,71	103,20	46,26	55,60	103,50	14,30	**595,97**
25	36,42	78,07	34,47	42,79	158,86	15,63	**642,21**
26	27,62	85,40	39,31	51,16	141,40	14,40	**623,92**
27	30,81	96,45	52,76	55,42	221,60	15,33	**741,98**
28	28,89	89,65	21,29	49,41	158,00	14,81	**624,32**
29	28,07	87,91	40,18	46,05	199,00	14,21	**696,81**
30	32,38	85,03	45,51	51,37	164,60	15,35	**742,75**

Figure 14. DD telescopic fork dataset (2)

6.1. Box Plot analysis

The data collected have been analyzed through Box Plot graphical representation.

Box Plot is a graphical representation that allows to quickly determine the variability of a distribution. It is built through the identification of statistical indicators such as:

- Position indicators (first quartile, median and third quartile)
- Dispersion indicators (interquartile difference, range)

For the research, this representation has been crucial to easily identify the most variable work phases.

First, the dataset regarding the SD forks has been considered.

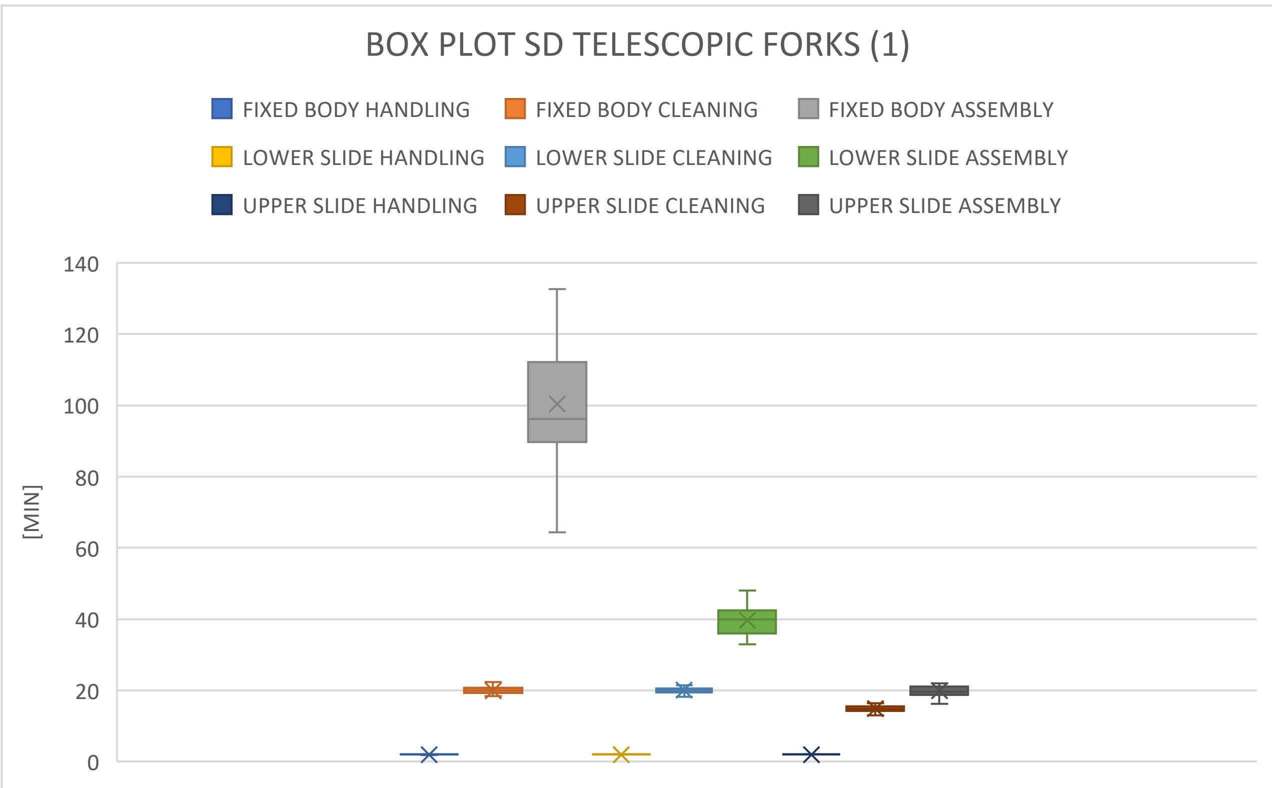

Figure 15. Box Plot SD Telescopic Forks (1)

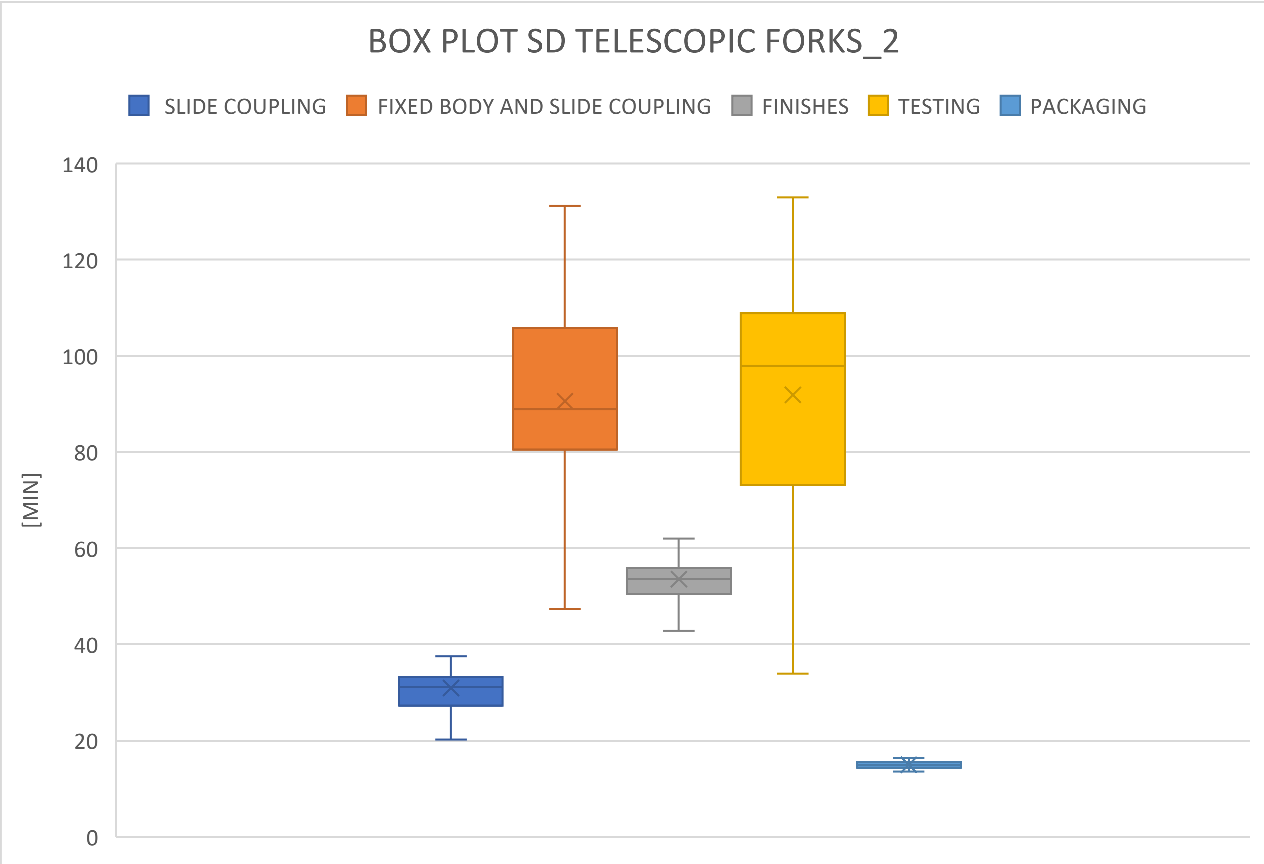

Figure 16. Box Plot SD Telescopic Forks (2)

The graphs clearly show how the most variable tasks are the fixed body assembly, the fixed body and slide coupling, and the testing. These results do not appear surprising as these operations are those with the highest level of complexity, as also highlighted previously in the description of the VSM. Furthermore, it is important to remember that the product offered by Eurofork is totally customized, and therefore it is normal there are variations in the timing, as the products are all different. Regarding the assembly of the slides instead, the variability is limited because in these components the number of pieces to be assembled is low.
Evenly, all the cleaning and handling operations, being largely standardized, do not present a great variability. In the end, the finished operation shows how the size of the variability is not always linked with the duration of the task. The finishes usually take a relatively long time, but the operations to be done are often similar, bringing down the variability.

Despite the presence of additional tasks, the situation appears to be very similar if DD telescopic forks have been considered. However, it's significant to notice how the testing of the DD fork lasts almost double the one of the SD forks.

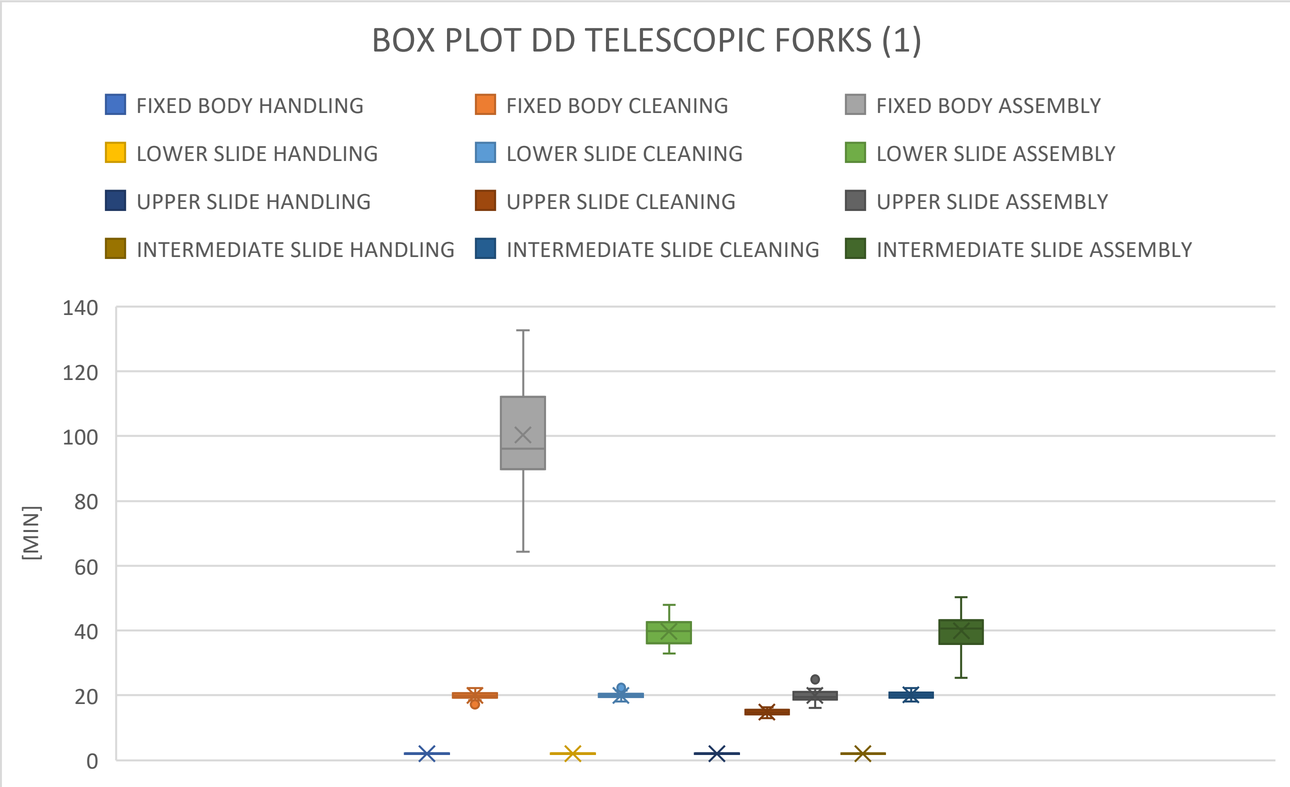

Figure 17. Box Plot DD Telescopic Forks (1)

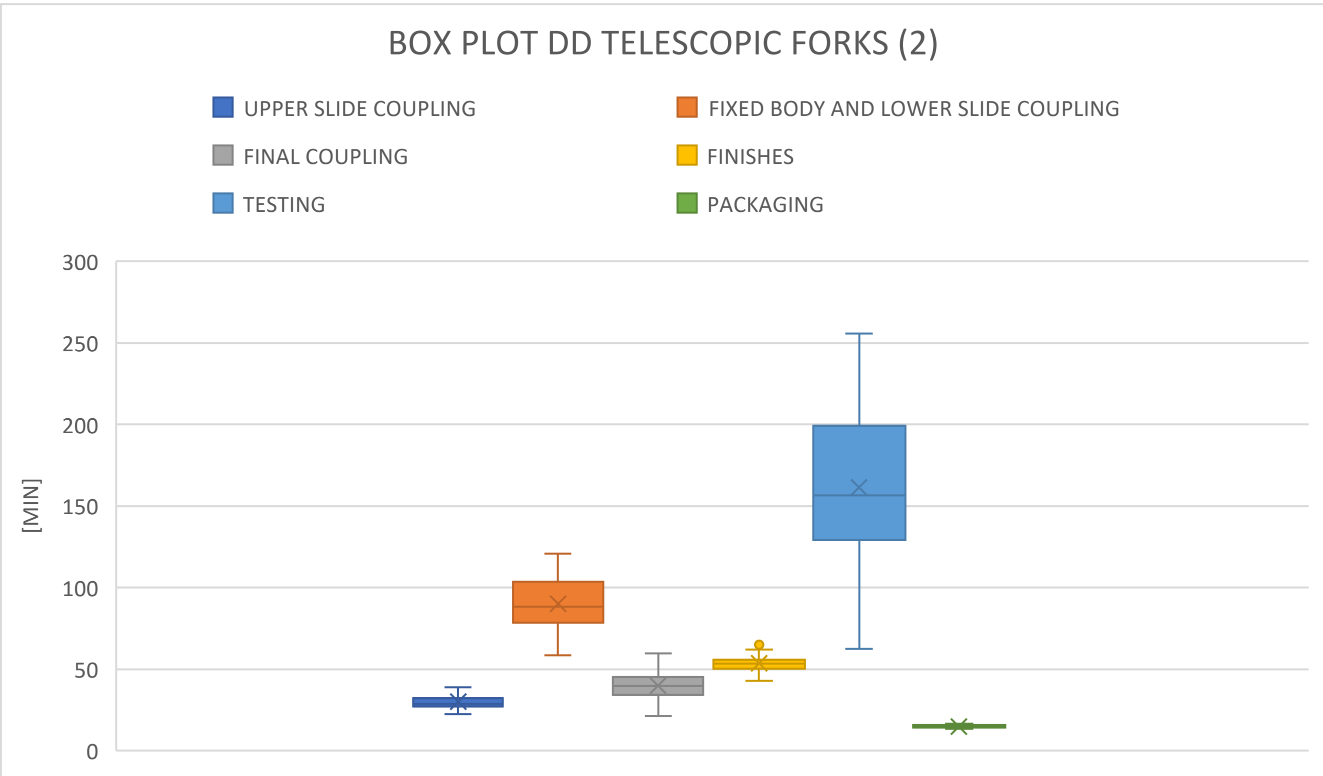

Figure 18. Box Plot DD Telescopic Forks (2)

6.2. *Critical task analysis*

The analysis of the box plot has highlighted which, according to the data, are the most critical tasks within the process. However, the results do not differ much from the qualitative analysis carried out earlier in the research.

The assembly of the fixed body contains criticalities since it is a phrase that requires a lot of differential activities and the use of a lot of various equipment and pieces. Problems in the layout and arrangement of resources may therefore have influenced to this extent. In addition, customization often affects fixed bodies in a more relevant way, such as the position of the motors or the gear system.

The coupling of the fixed body with extensions is likewise a task that depends very much on the dimensions of the various components and the handling system used.

Finally, the test is characterized by a considerable setup time, due to the preparation of the test bench concerning the dimensions of the fork. Furthermore, the testing is a phase in which you look for any problems, and therefore the timing depends very much on the issues found and, on the time, needed to solve them, which is not predictable.

6.3. *Outliers' identification*

The dataset, after the first analysis, has been studied searching for possible outliers. Those are unusually large or small observations compared to the others. They may therefore not belong to the distribution describing the remaining points. The approach followed in this research is:

1. Calculation of the upper and lower limit of the distribution, thanks to the "Quartile Method":

$$Upper\ limit\ = Q_3 + 1{,}5 * (Q_3 - Q_1)$$

$$Lower\ limit\ = Q_3 - 1{,}5 * (Q_3 - Q_1)$$

2. Identification of the outliers from a graphical representation
3. Verify the reason for their presence
4. Intervene or remove the data.

For simplicity, it is shown only the outliers' identification process of the critical tasks previously analyzed, from the set of data of DD telescopic forks.

6.3.1. Fixed body assembly

MIN [min]	Q1 [min]	MED [min]	Q3 [min]	MAX [min]
64,33	90,03	96,16	110,35	159,87

Table 1. Fixed Body assembly statistic value

1.

$$Upper\ limit\ = Q_3 + 1{,}5 * (Q_3 - Q_1) = 140{,}82$$

$$Lower\ limit\ = Q_3 - 1{,}5 * (Q_3 - Q_1) = 79{,}87$$

2.

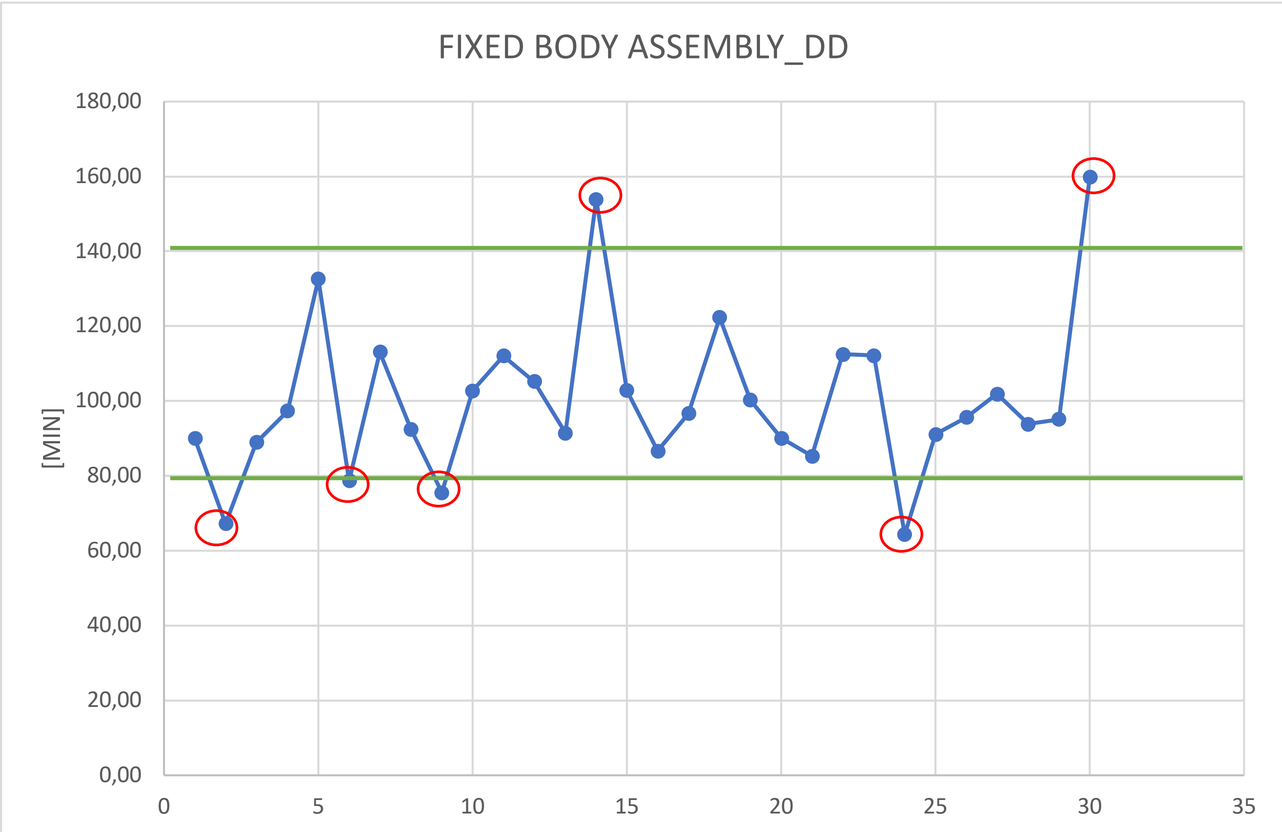

Figure 19. Fixed Body Assembly outliers' identification

After having checked the dataset, it has been emerged how some measures, in particular the ones that start in one day and continue the day after, are not so precise. For that reason, the data that represent the outlier has been removed from the dataset.

6.3.2. Fixed body and lower slide coupling

MIN	Q1	MED	Q3	MAX
58,39	79,52	88,44	102,33	120,70

Table 2. Fixed Body and lower slide coupling statistic value

1.

$$Upper\ limit\ = Q_3 + 1{,}5 * (Q_3 - Q_1) = 136{,}55$$

$$Lower\ limit\ = Q_3 - 1{,}5 * (Q_3 - Q_1) = 68{,}11$$

2.

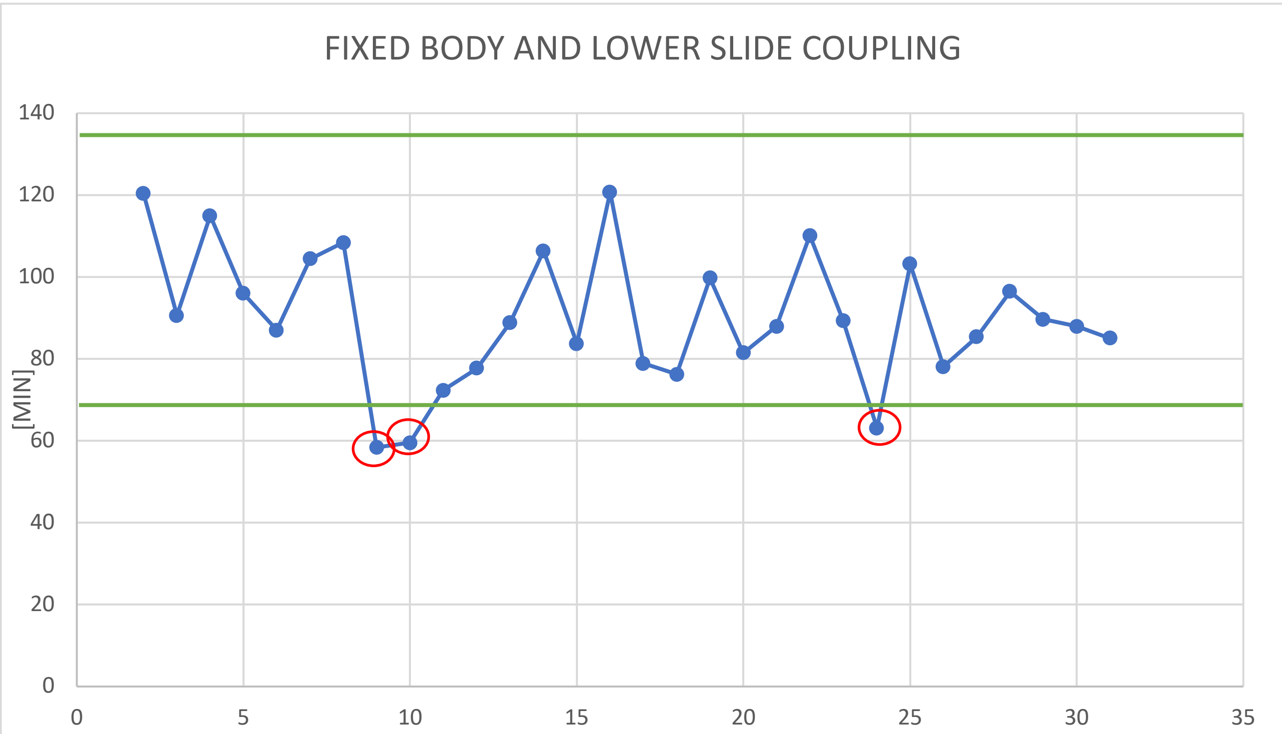

Figure 20. Fixed Body and lower slide coupling outliers' identification

For the same reason explained above, also the outliers found in this task have been removed from the dataset.

6.3.3. Testing

MIN	Q1	MED	Q3	MAX
62,26	130,05	156,65	197,80	255,60

Table 3. Testing statistic value

1.

$$Upper\ limit\ = Q_3 + 1{,}5 * (Q_3 - Q_1) = 299{,}43$$

$$Lower\ limit\ = Q_3 - 1{,}5 * (Q_3 - Q_1) = 96{,}18$$

2.

Figure 21. Testing outliers' identification

As said before, the testing operation strictly depends on typologies of telescopic fork. In fact, after having checked the nature of the outliers, it emerged that there were no measurement errors, but they were only testing of a special fork of very small dimensions. So that, these measurements have not been removed from the dataset.

7. LEAN principles: AS-IS situation

This phase of the research, after having defined the process and having measured its performance, wants to identify the root causes of the problem, and quantify, even if at times approximately, the influence on the behavior of the telescopic fork assembly line.

7.1. Identification of waste

The production line of telescopic forks was taken into consideration to identify the sources of waste and classify them following the Lean principles.

- Overproduction: As highlighted within the VSM, there is a phenomenon of excessive production in the assembly and coupling phases of the slides. Since these operations are simple and standardized, they are carried out quickly and consecutively, without however bringing a benefit to the total production time. These processes are not critical within the total cycle and therefore an excessive number of components is generated compared to the demand of the line.

- Waiting: Closely linked to the previous point, there are often already assembled slides that await the assembly of the fixed body in the production line. This phenomenon is also partially found at the bottom of the line before testing. The setup time and the length of the latter often generate waits.

- Transportation and excess motion: One of the primary problems of the telescopic fork line is undoubtedly the lack of a linear flow. For this reason, there are often very long movements and transports that generate a considerable waste of time, as well as a danger given the considerable weight of some components transported.

7.2. Spaghetti chart

The following graph concretely highlights the problems and waste mentioned above. The surveys refer to a single operator for one hour of activity.

Primarily, it is clear how the components are positioned in a disordered and disproportionate way. The overproduction of slides compared to fixed bodies is clear. This phenomenon, in addition to generating many components waiting, reduces the space for the incoming slides. In fact, there are several unprocessed slides, upper and lower, at the end of the line, contrary to what is the real flow of operations.

Secondly, the movements of the operator highlight two problems. Firstly, it can be seen how the operator must even leave the line to look for parts and components for the order being assembled; these movements represent a considerable waste of time if considered for an entire working day. On the other hand, due to the lack of organization of the line, the operator is forced to travel a long way to pick up the coupled slides and take them to the station of the fixed body, also having to pass through other operators at work carrying a considerable weight. This step, in addition to being a waste of time, also represents a significant risk for the operator's safety.

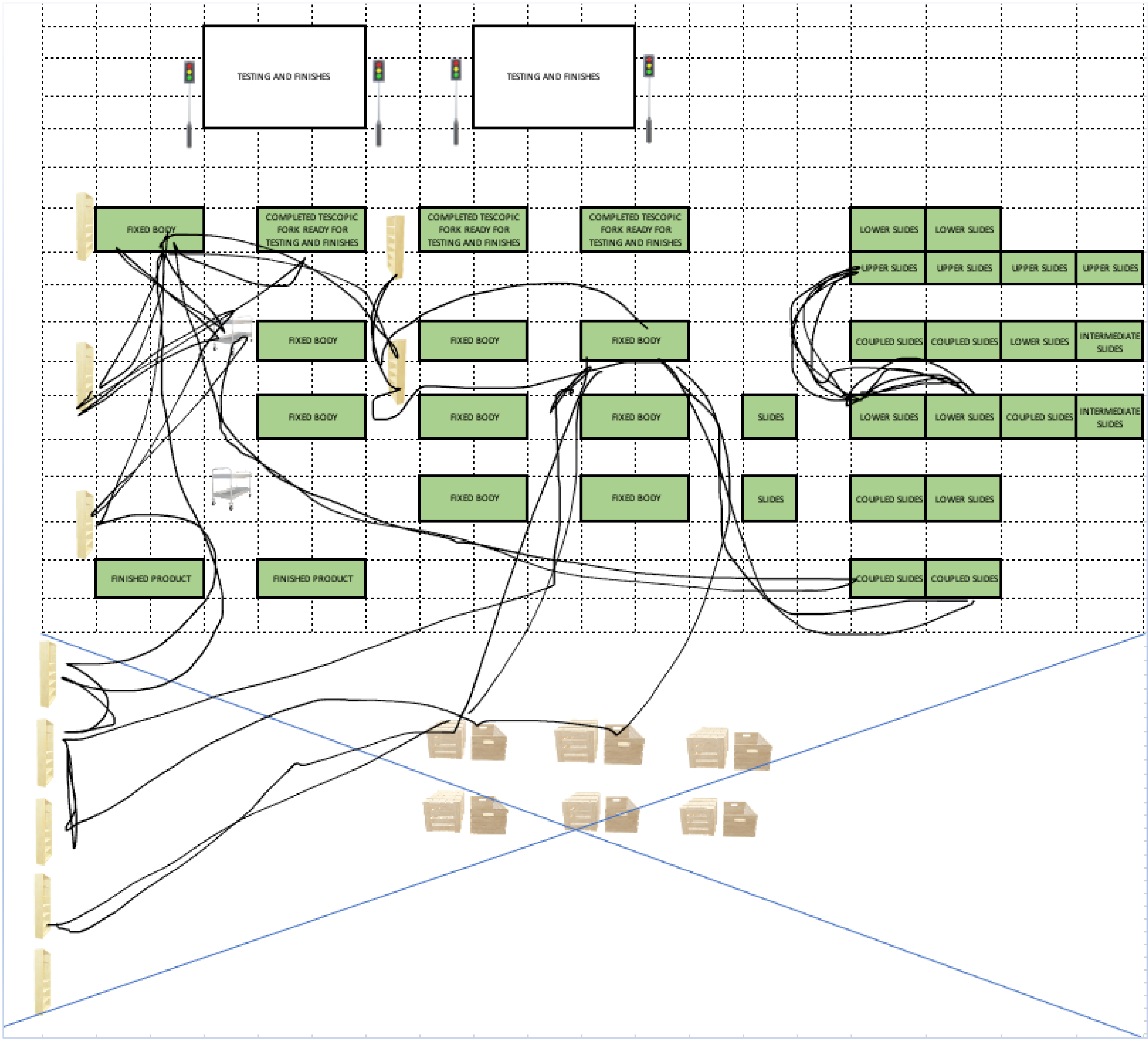

Figure 22. Spaghetti Chart

7.3. *Cause and effect relationship*

The cause-effect diagram is a graphical representation of all possible causes, related to a particular effect. It represents in an orderly and complete way all the possible causes that could allow a certain problem.

Developed in Japan by Kaoru Ishikawa in 1943, cause and effect diagrams are among the most used tools for solving business problems. It is also called Ishikawa Diagram or Fishbone Diagram due to the particular configuration it assumes when the graphical compilation is completed. The problem whose solution is to be studied is arranged at the end of a line, at the sides of which are grafted other lines that represent the main branches, or the primary causes of the problem; on these are grafted in turn the secondary causes and so on.

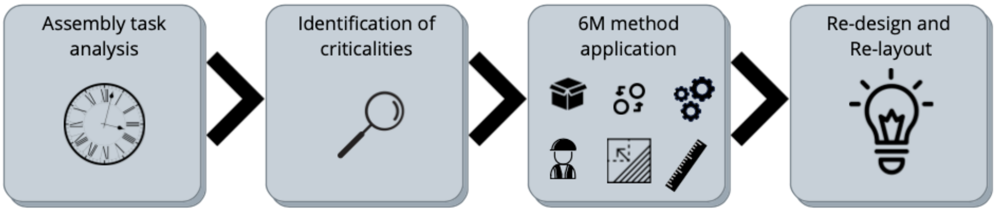

Figure 23. Cause-effect approach

The proposed 6M approach is based on observing and analyzing each task of an existing manual assembly line. The five 6M considered within the approach are:

- *Materials* – Assembly issues related to the product and components design.
- *Methods* – Assembly issues related to the assembly procedure.
- *Machines* – Assembly issues related to the machines and workstation layout
- *Man* – Assembly issues related to the workers.
- *Measurements* – Assembly issues related to the measurement process.
- *Mother Nature/Environment* – Assembly issues related to the environment

The analysis was applied to the company's reality, trying to identify the root causes of the problem of lack of order and waste of time within the production line of telescopic forks.

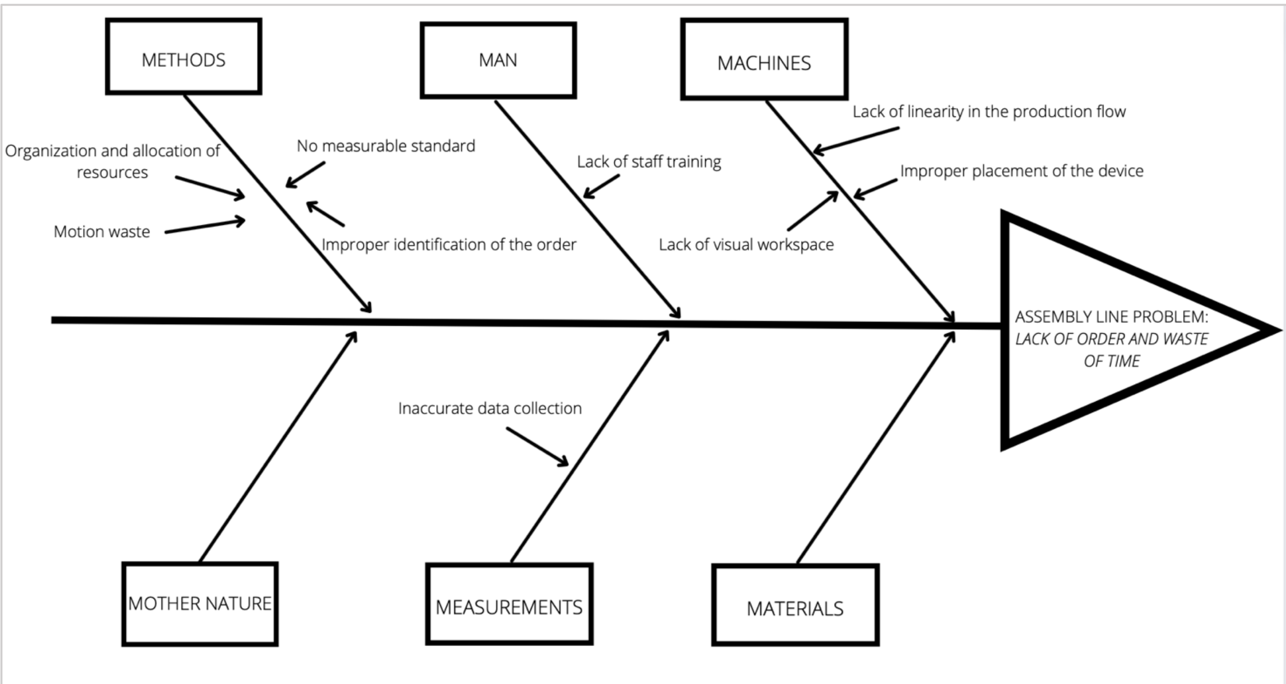

Figure 24. 6M analysis

The most significant issues were identified about the methods. In fact, through observation and the consequent brainstorming with the production team, problems emerged in the identification and organization of the material of each order. This consequently generates, as shown previously in the spaghetti chart, excessive movement by the operator in search of the materials and tools. Regarding the machines, a lack of linearity in the production flow has been seen, which can sometimes generate a lack of space and view of the workplace. Finally, the measurements and data regarding fork production do not have a high level of accuracy.

7.4. Five Whys

Cause that contributes the problem in the telescopic fork assembly process		
Primary cause	Secondary cause	Detailed information
1. METHODS	1.1 Organization and allocation of resources 1.2 Motion waste 1.3 No measurable standard 1.4 Improper identification of the order	1.1.1 Resources are not properly assigned about the task complexity 1.1.2 Resources are not organized concerning the length of each task, too many resources are assigned to relatively quick tasks 1.2.1 Distance between concurrent activity is too far apart 1.2.2 Components and pieces required for a specific order are in a different part of the warehouse, causing useless flows 1.4.1 Orders are not identified in a standardized and efficient way 1.4.2 Some components identified through a piece of paper that can be easily detached and lost
2. MAN	2.1. Lack of staff training	2.1.1 Staff are not homogeneously prepared; only a few can perform all the tasks
3. MACHINE	3.1 Improper placement of the device 3.2 Lack of visual workspace 3.3 Lack of linearity in the production flow	3.1.1 Some devices that generate potentially dangerous processes are placed in the center of the line 3.2.1 The stations of different tasks are located too near one each other, bringing difficulty to staff movements 3.3.1 The workstations are not located following the flow of materials and working tasks
4. MEASUREMENT	4.1 Inaccurate data collection	4.1.1 Inefficiency in measuring and collecting data that could be useful to monitor the process

Table 4. Five Whys

8. LEAN principles: TO-BE situation

After taking into consideration the AS-IS situation, the research moved to the next step: the definition of the potential TO-BE context, which has the ambition to limit and where possible eliminate the restrictions and issues that emerged during the analysis.

8.1. Value Stream Mapping TO-BE

The TO-BE value stream mapping has presented without the *Kaizen lightning bursts* shown during the AS-IS analysis. Firstly, the problem of the order components disorganization is considered. The organization of the order material has been revolutionized, allowing the operator to save time and physical and mental strength. The material now arrives from the logistics warehouse differently, with the components divided by type and work phase. This will allow the assembly phase of the fixed body, which has been identified as a critical phase, to last significantly less, given the high number of components required for it and therefore the consequent search for them by the operators.

Secondly, the overproduction of slides has been solved through a re-organization of production warehouse. The components have been organized trying to follow the physical flow, removing all the operations useless at this specific time.

At the end, the high set-up time of the testing has been slightly lowered, through the creation of a basic dimension classification of the telescopic forks and the organizations of the two lines consequently.

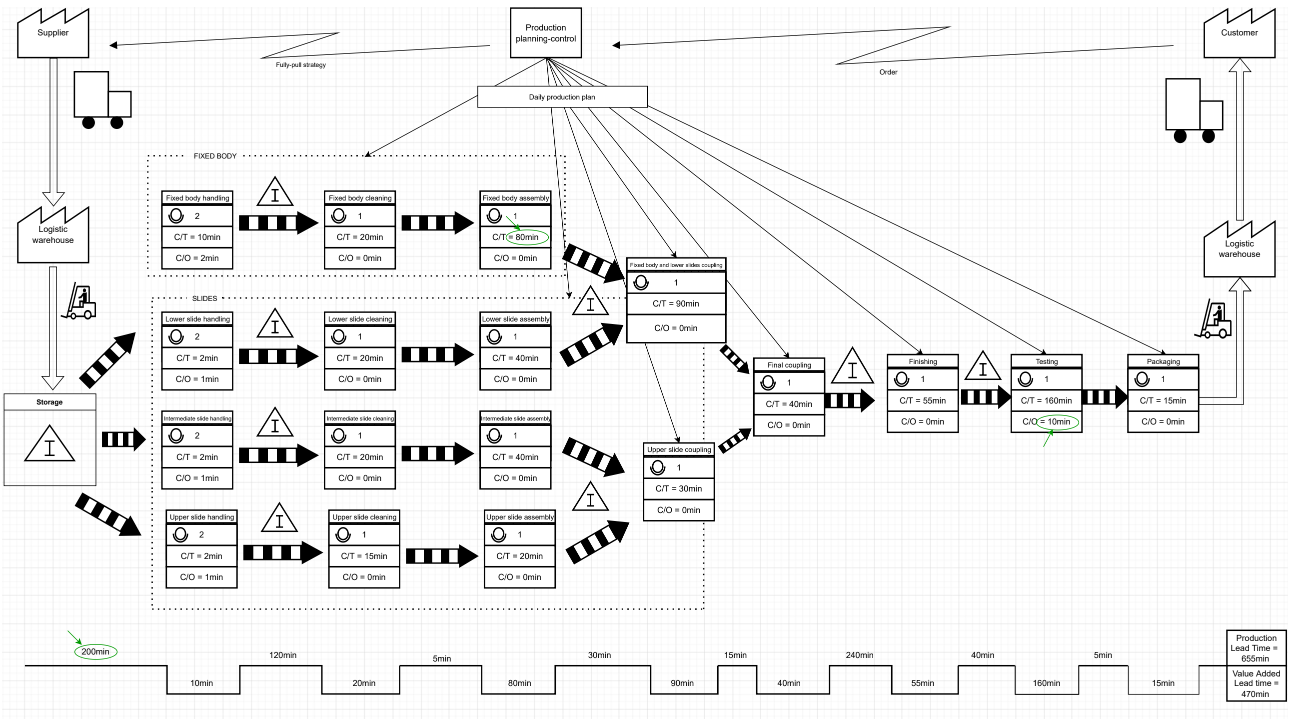

Figure 25. TO-BE VSM of DD telescopic fork

8.2. Five Whys: Guidelines for improvement

The analysis of the Five Whys made it possible to understand in depth what are the primary causes of the problems highlighted during the research. The practical phase instead consists in the creation of guidelines for the implementation of a TO-BE context, obviously starting from the problems to be solved.

The table 5 shows the improvement solutions identified during the analysis.

Primary cause	*Detailed information*	*Guidelines for improvement*
1. METHODS	1.1.1 Resources are not properly assigned about the task complexity 1.1.2 Resources are not organized concerning the length of each task, too many resources are assigned to relatively quick tasks 1.2.1 Distance between concurrent activity is too far apart 1.2.2 Components and pieces required for a specific order are in a different part of the warehouse, causing useless flows 1.4.1 Orders are not identified in a standardized and efficient way 1.4.2 Some components identified through a piece of paper that can be easily detached and lost	The issues highlighted in this section are largely due to the lack of an orderly and linear flow. Through the appropriate organization of the different workstations, the resources would consequently be used homogeneously. Furthermore, the material needed for each work phase would be organized by phase and placed directly in line, eliminating unnecessary movement and waste of time. Finally, orders could be identified through a unique coding, making the tracking of each component simpler and more standardized.
2. MAN	2.1.1 Staff are not homogeneously prepared; only a few can perform all the tasks	By organizing specific training courses and demonstrations directly on the assembly line, less experienced operators would quickly close the initial technical knowledge gap.

3. MACHINE	3.1.1 Some devices that generate potentially dangerous processes are placed in the center of the line 3.2.1 The stations of different tasks are located too near one each other, bringing difficulty to staff movements 3.3.1 The workstations are not located following the flow of materials and working tasks	As previously anticipated, the positioning of the workstations according to the workflow and materials would also allow operators to work in a more comfortable and larger space, also reducing the risk of collisions or damage to the machined parts.
4. MEASUREMENT	4.1.1 Inefficiency in measuring and collecting data that could be useful to monitor the process	The process monitoring and control system could be implemented through more accurate measurement and computerized data storage

Table 5. Five Whys: Guidelines for improvement

9. Application of 5S

Figure 26. 5S methodology

The 5S method adopted by Lean Production consists in the identification of a systematic and repeatable procedure for the management of the order and cleaning of the workstations (*Gemba*) and which aims to improve operational performance and standardize the optimization achieved. The expression 5S method originates from the initials of the five Japanese words (obviously in their westernized pronunciation) which summarize the five passages of the methodology.

- SEIRI-Sort, classify equipment / tools present in a workstation by eliminating what is not necessary.

- SEITON-Set in order, arrange and organize what you need in the right place.

- SEISO-Shine, clean the workplace clean and in the previously established state of order.

- SEIKETSU-Standardize, create the standardized principles to keep the area in order by repeating the previous three steps and make these principles visible and applicable for all.

- SHITSUKE-Sustain, making the standard of the 5S method a habit and part of the daily work adequate the adequate discipline and rigor for the continuation.

This methodology has been applied in the telescopic fork assembly line, to create and then maintain standard, cleaning, and order.

Firstly, the Kanban shelving positioned in the line has been analyzed, trying to solve the transportation and excess motion waste. In fact, due to disorganized shelving, the operators are unable to find what they are looking for in a reasonable time.
As the 5S methodology suggests, the material on the shelving has been classified regarding its use in the assembly line. Whatever it has been found something not directly useful in the assembly operations, this has been taken away. After having done the SEIRI passage, the focus shifted to sorting out what was left reasonably. The operation made it necessary to use small boxes, to divide the pieces by type, so that the operator could find what was necessary quicker.
To conclude, the equipment has been identified with different colors, so that after the usage the operators could easily restore the initial order, putting together the tools of the same color.

The figures 27 and 28 show how the equipment have been organized in a different and more efficient way. Firstly, the materials have been divided by type and then each box has been marked with a unique code. These actions have allowed the operators to save time and power through a significant decrease of a non-value-added operations, as the research of proper equipment.

Figure 27. Application of 5S (1)

Figure 28. Application of 5S (2)

The figure 29 offers a focus on the organization of the screws. These small components are fundamental during an assembly operation and a proper organization and identification are of primary importance. In addition, these boxes enable to quickly notice when a piece is about to end and immediately refill the line.

Figure 29. Application of 5S (3)

Considering instead the figure 30, it is possible to highlights the importance of a clean and organized work surface. Into an assembly line, the operator often needs to check the drawings with the project details, to avoid any type of issue. For that reason, a free support surface is of great importance. Moreover, if a drawing has been leaning above pieces required for the order, hiding them, the searching time will dramatically increase, without considering the risk of dropping them.

However, it must be emphasized that the free work plan can only be maintained if the operators follow precise rules. In fact, the application of the 5S has represented only the beginning of a standardization process that must be sustained over time.

At the end, the figure 31 shows the color division of the equipment. This permits to the operators on the one hand to properly tidy up and on the other hand to find quickly what they need.

Figure 30. Application of 5S (4)

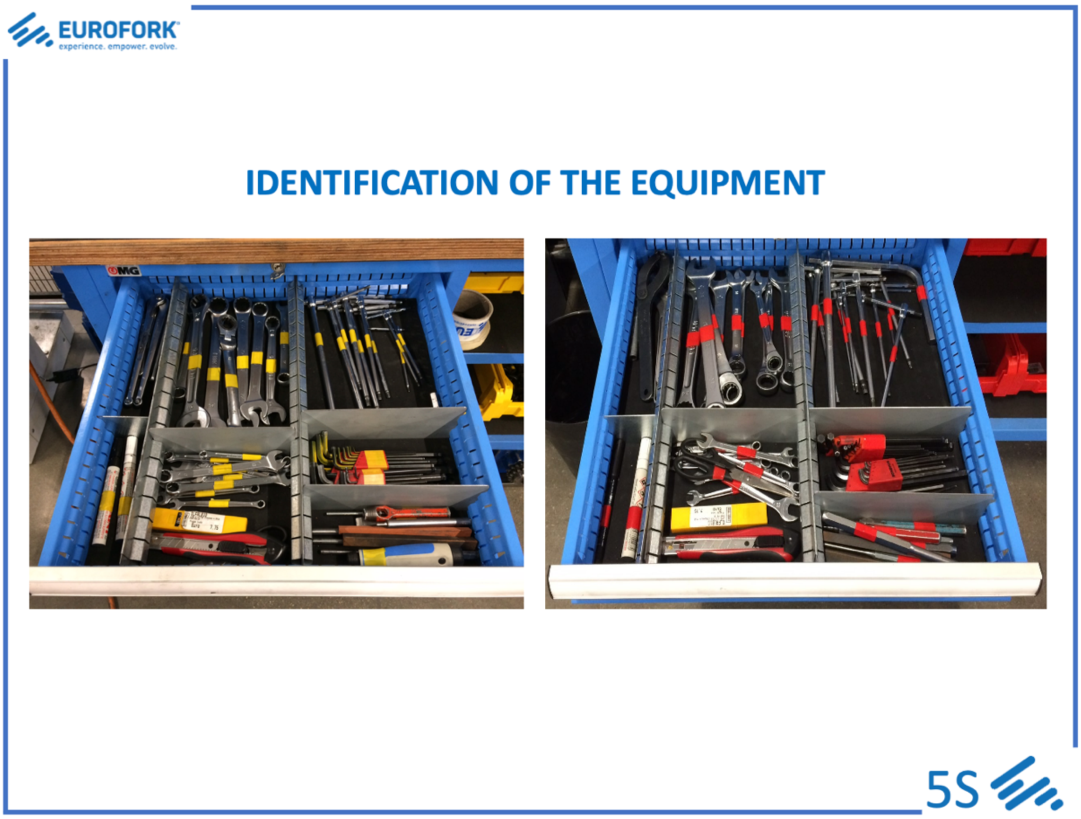

Figure 31. Application of 5S (5)

10. Real application of LEAN principles

10.1. Introduction

Following the description and analysis of the assembly line of telescopic forks, the research has continued with the definition of a TO-BE context, in which the principles of Lean production are applied and sustained over time.
To verify the truthfulness and validity of the assumptions made up to this point, the team planned and implemented a simulation. It is extremely fundamental to translate theory into practice and to understand which proposals and ideas are sustainable and applicable overtime and which ones are not.

The simulation has consisted of the management of the production of a couple of double-depth telescopic forks, from the arrival inside the material production plant to the packaging of the finished product. The job in question was carried out following the indications that emerged from the previously illustrated theory analysis.

The operations that have been carried out by the team are:

1. Preparation of the platform with the order material
2. Organization of the line by creating a flow
3. Monitoring and measurement of the process
4. Analysis of the result

10.2. Material preparation

The first phase of the simulation has been the preparation of the material necessary for the order under consideration. As identified during the analysis, one of the main problems has been the lack of order and organization of the material that generally has been generated:

1. Excessive movements by operators to search for material
2. Waste of time in research
3. Risk of confusion between the various orders

To overcome this problem, the team decided to organize the material according to two criteria: on the one hand the work phase and on the other the need to have the material insight.
In fact, in the current state, the production warehouse has always received the platform with the material still packed and piled up, greatly complicating the work of the operators, often loading them with extra tasks, such as unpacking and dividing the components.

As can be seen in the image below, the platform is usually received with a few visible components and often with overlapping boxes, without any division regarding the different work phases. This methodology is one of the main problems studied in the analysis of the five whys.

Figure 32. AS-IS material preparation

From this setting, the team has begun to make changes, starting from an initial unpacking of the components, up to a division by work phases. It was decided in the first instance to divide the material concerning the component to be assembled (fixed body, upper slide, lower slide, and intermediate slide). Subsequently, a specific platform was created with the material intended for pre-assembly in line, to speed up the division of the operators.

Figures 33,34,35 and 36 illustrate the platforms organized as explained above. A first view allows to notice the great difference from the current organization, as the components are grouped according to a very precise logic. This logistics warehouse job is of great help to assembly line operators, drastically reducing their movements and downtime. Furthermore, thanks to a more specific division of the material and the use of small boxes, operators can bring what they deem necessary directly to the work point, without having to move excessively inside the warehouse.

Figure 33. TO-BE material preparation (1)

Figure 34. TO-BE material preparation (2)

Figure 36. TO-BE material preparation (4)

Figure 35. TO-BE material preparation (3)

As can be seen, the substantial difference is the possibility of having all the components in view, without the need to waste time unpacking or searching for a single piece. Furthermore, thanks to this organization of the material, it is possible to place each box directly in line, near the workstation for which it was created.

To conclude, the gear group to be pre-assembled can now be moved before the rest of the material, if the pre-assembly operations must be performed in advance.

10.3. Workstations arrangement

The second phase of the simulation has dealt with the organization and arrangement of the workstations within the production plant, regarding the assembly of the fork under consideration.

In fact, through the analysis of the AS-IS situation, various problems had emerged, deriving directly from the erroneous arrangement of the workstations. For this reason, a flow that allowed operators not to make excessive movements or long movements of materials was created.

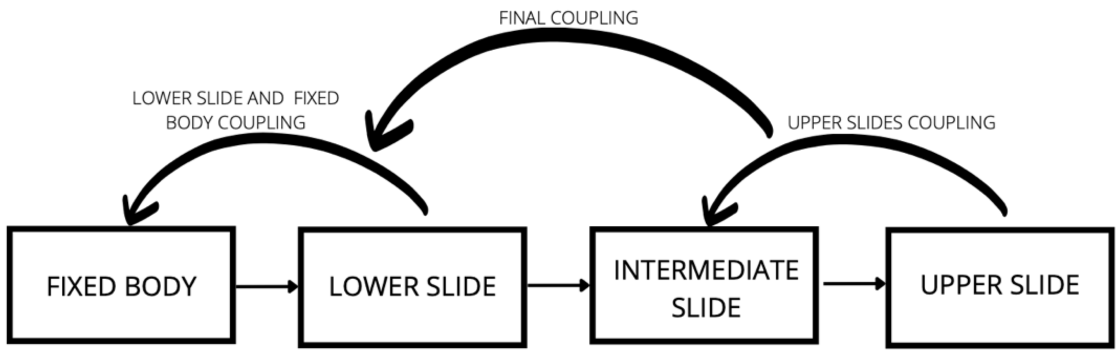

Figure 37. TO-BE Layout of workstations

As it can be seen from the simple layout shown above, four different workstations have been identified: fixed body, lower slide, intermediate slide, and upper slide. Inside each station, all the necessary work (cleaning and assembly) was carried out, after the initial handling within it. This arrangement has the main advantage of allowing an agile coupling, as shown in the figure. In fact, all the components carry out a negligible way, and at the same time the operator is not inclined to make long journeys.

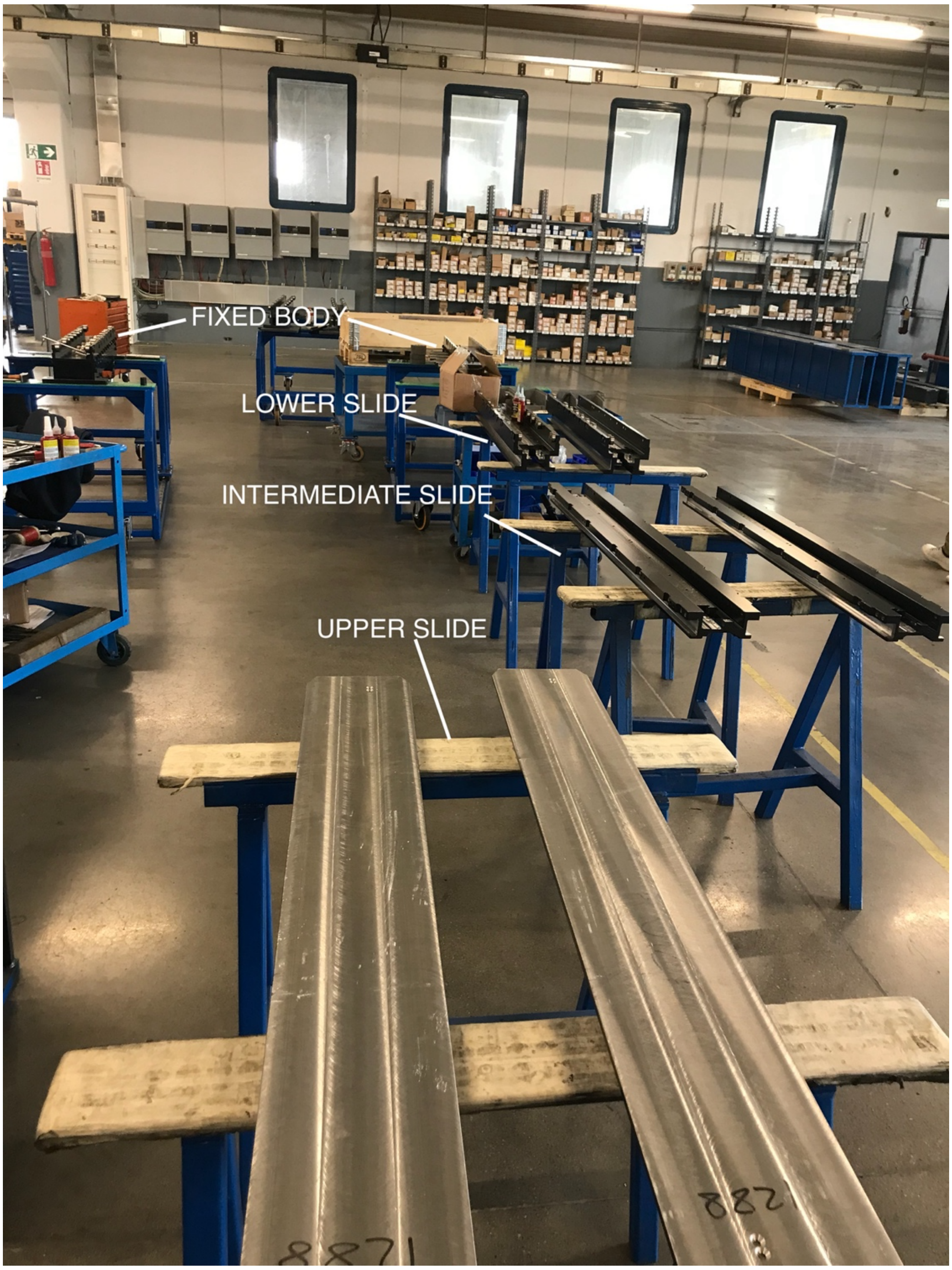

Figure 38. Plant workstations arrangement

10.4. Process monitoring

The team followed step by step, through constant monitoring, each phase of the process, paying attention to all aspects considered critical during the analysis of the assembly line.

The analysis and monitoring were carried out by following on the one hand the measurement of the processing times and on the other hand by observing the flow of materials and the movement of operators.

The table indicates the times for each work phase, with reference to the double depth fork taken into consideration for the simulation.

Work phase		Processing Time [min per couple]
Fixed Body	Handling	10
	Cleaning	14
	Assembling	90
Lowe slide	Handling	2
	Cleaning	13
	Assembling	25
Intermediate slide	Handling	2
	Cleaning	15
	Assembling	21
Upper slide	Handling	2
	Cleaning	10
	Assembling	10
Fixed body and lower slide coupling		123
Upper slides coupling		10
Final coupling		97
Finishes		49
Testing		134
Packaging		12

Table 6. Simulation Processing Time

10.5. Results

The study and monitoring of the real case made it possible to concretely confirm what was said within the research, thanks to the identification of significant performance improvements, both in relation to timing and sources of waste.

10.5.1. Source of Waste

The layout and organization proposed, concerning the waste identified previously, seems to have brought significant improvements.
In particular:

- Overproduction: the arrangement of the material on the line "forces" the operators to follow the desired flow, without devoting themselves to different orders at the same time, thus avoiding the generation of excessive production about the request from the downstream station.

- Waiting: in the same way, by reducing excessive production, the waiting time of the components within the line will consequently be reduced.

- Transportation and excess motion: the operator, thanks to the organization of the material for the order and the arrangement of the flow in line, has significantly reduced unnecessary movements and material transportation. Having the components necessary for assembly divided by phase and in view, journeys for the search for material have decreased. In addition, the proposed layout has eliminated the transport of material for coupling, given the proximity of the different components to be coupled.

10.5.2. Processing Time analysis

In parallel with the qualitative analysis of the process, a quantitative analysis has been implemented, considering the production times collected in the monitoring phase. The times obtained on the sidelines of the simulation have been compared with the data dataset of the AS-IS situation.

The results obtained have shown interesting indications and various food for thought. The graphs below show the timing differences for each work phase.

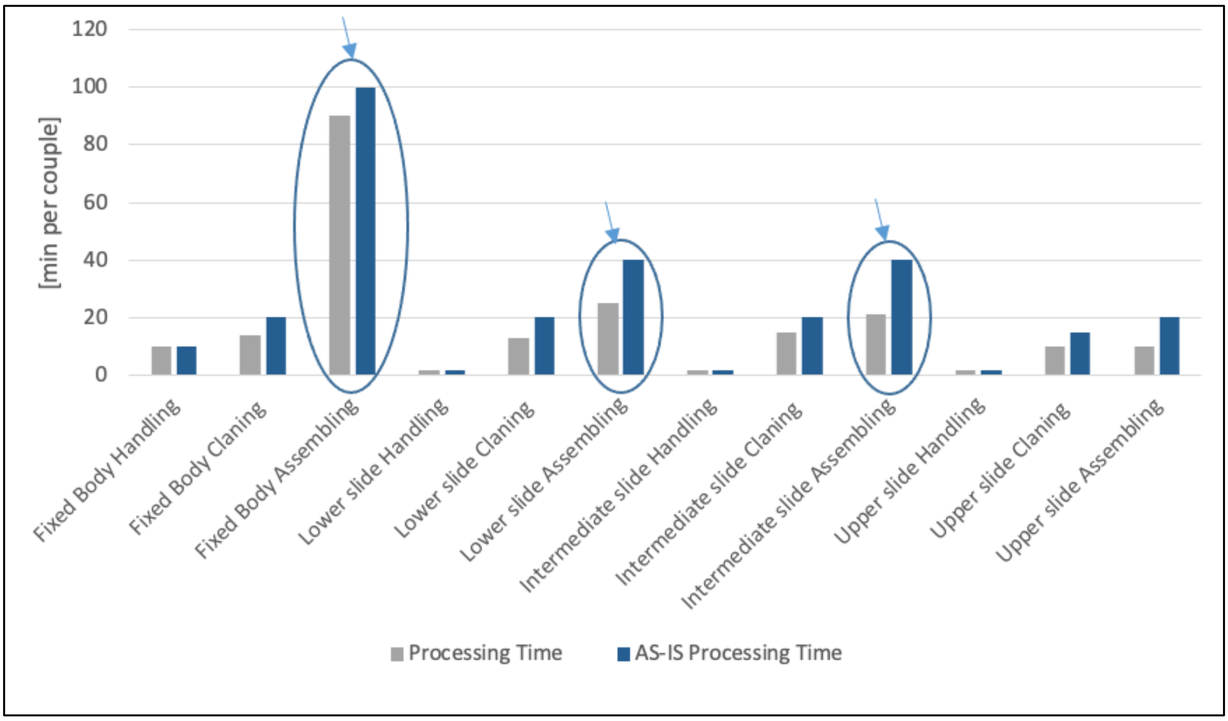

Figure 39. Processing Time Comparison (1)

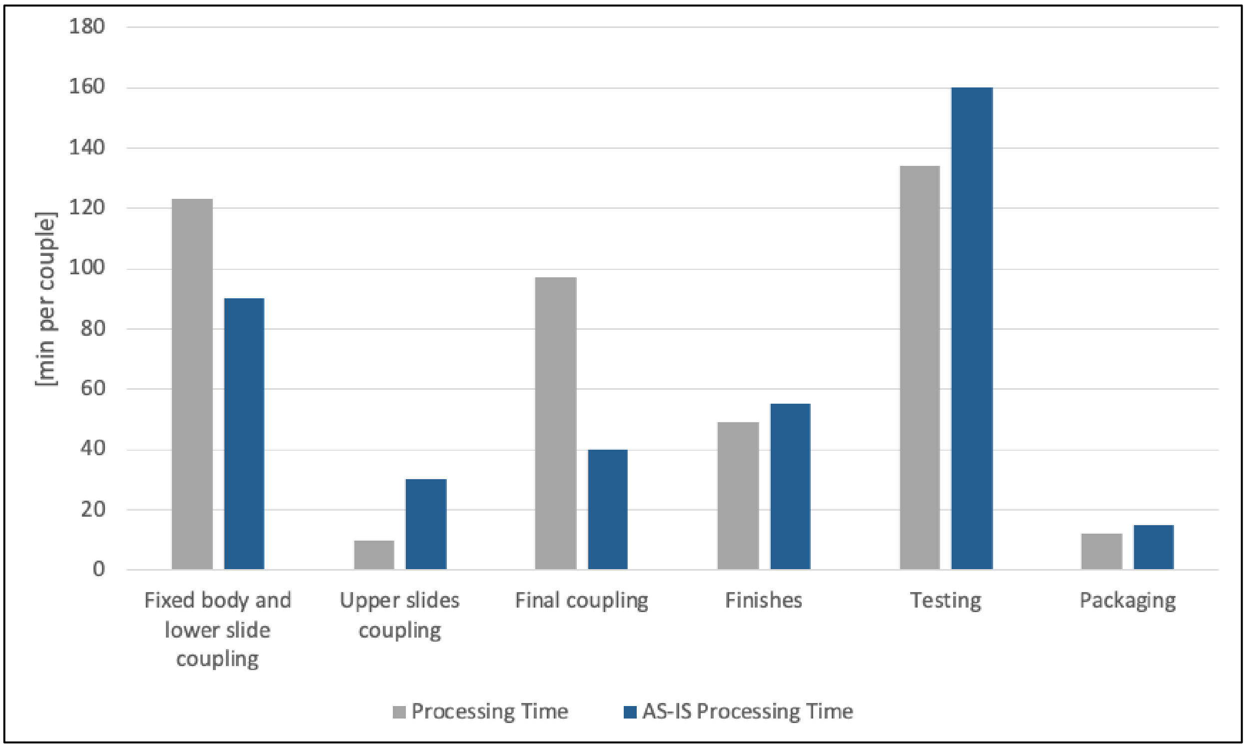

Figure 40. Processing Time Comparison (2)

Starting from a general look, the working time of the fork analyzed in the simulation has turned out to be 639 minutes, while the data set indicates 681 minutes as the average working time for a double-depth telescopic fork. This data, although not very descriptive, has been shown a reduction in the total working time of 7%.

Going specifically, it can be easily seen how the assembly operations of all the components have shorter processing times than the average ones present in the dataset.

Assembly operations	Processing Time	AS-IS Processing Time	%
Fixed Body	90	100	-11%
Lower slide	25	40	-60%
Intermediate slide	21	40	-90%
Upper slide	10	20	-100%

Table 7. Assembly Processing Time

The percentage reductions have been very significant and not random. In fact, these phases require the material for assembly and therefore depend a lot on its organization. It is therefore not surprising a reduction of this magnitude, considering the meticulous work done in the preparation of the material, greatly reducing the search times and unnecessary movements.

The situation has been however very different in the assembly phases. As can be seen from the second graph, the times measured during the simulation have been largely greater than the average of the dataset. This result has also been not surprising, and it has been depended in particular on two aspects.
First, most of the structural differences between the various orders emerge in these work phases.
For example, the fork analyzed within the simulation is called variant, which means it has two different engines; this fact obviously has caused longer times in coupling.
On the other hand, even in the dataset, the coupling phase between the fixed body and the lower extension was characterized by a particularly high standard deviation.

11. Takeaways

The research, after following the Lean production methodology step by step and identifying the issues and possible solutions, ended with a proposal for a future layout and organization. The work carried out has in fact made it possible to understand which solutions could be sustainable over time, both from an organizational and economic point of view. It is obviously essential to be able to find the right balance between available resources, corporate work culture and possible improvements that can be implemented.
Often, in fact, theory and practice do not run totally together, and the greatest difficulties arise when a novelty must be sustained over time; It is very different to implement an improvement in a single job than to change the habits and way of working of a work team.

11.1. Organization of the materials

The organization of the material necessary for each order has represented one of the critical points within the research. Through the real application of Lean principles, a division of the platforms was tested in relation to the work phases, as well as for each group of components. This setting has brought significant benefits to the production process and because of this it will be implemented on an ongoing basis by the work team.

The platforms will then be prepared with the components in view, and through a first division by work phase. Only experimentation and continuous monitoring of performance will allow to determine the optimal solution.

11.2. Layout

Considering all the aspects taking in consideration within the research, a layout, that would marry the business needs, was identified.

The first point taken into consideration was the need to create a layout that followed the production flow, so that excessive movements were minimized. For this, as seen in Figure 41, two different lines have been created, one for the double-depth forks and one for the single-depth ones. This provision has the ambition to also make improvements in reference to the set-up time of the testing station. In fact, a large part of this time is caused by the different dimensions of the forks and the consequent need to set the work surface. By working with two lines dedicated to each macro-category of forks, this non-value-added timing could improve.

The stations were created in relation to the different work phases, in particular following the assembly operations of the various macro-components (fixed body and respective slides). This choice was dictated by the need to have the pieces in sequence to facilitate coupling.

The proposed layout is nothing more than a summary of everything that emerged within the research, in an attempt to minimize waste and identified critical issues thanks to the application of the Lean methodology.

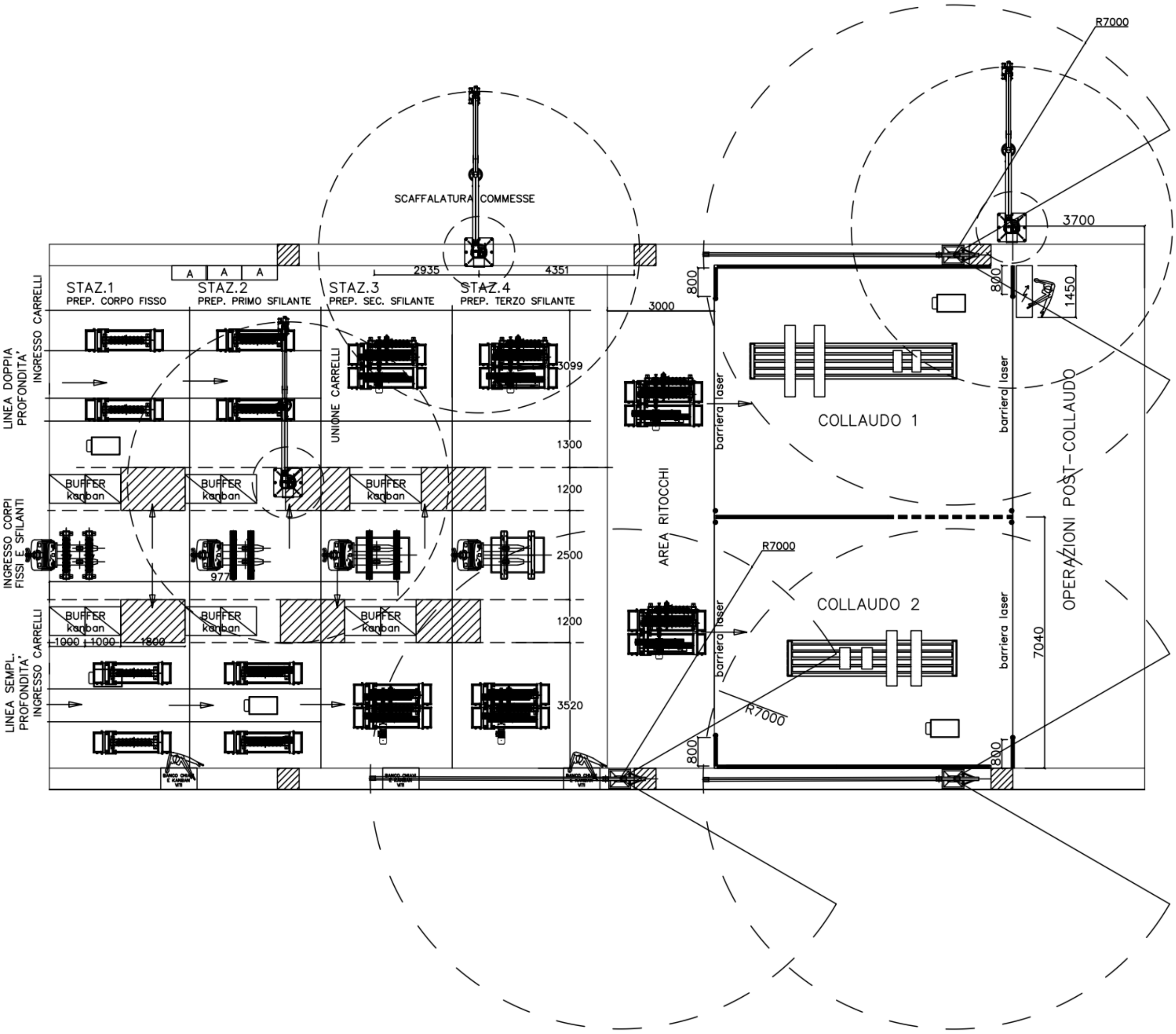

Figure 41. Proposed layout

12. Conclusion

Improving the efficiency of the manufacturing plant is a common problem for each industry and has increased attention as a result of the need to improve productivity. The Lean manufacturing methodology gives the company worldwide a set of tools to identify problems and propose solutions. Due to the increasing competition among the markets and the speed in finding innovative solutions, almost all companies are forced to look inward. Indeed, one of the ways to gain a competitive advantage is to apply a resource-based approach, so the way to use and improve resources becomes difficult to emulate. The lean manufacturing process was used in this work to address an inefficient production.

Despite the fact the Lean approach provides sequential phases for developing, it is often a slow and time-consuming approach, particularly in context in which that methodology has not been already applied. This paper's case study of the telescopic fork's assembly line took five months to define and illustrate the current situation and suggest possible improvements.

This study attempts to demonstrate the implementation of the principles of the Lean Manufacturing through the application of its main tools. The redesigned line successfully improved the facility's overall productivity. The results show that significant benefits, both in time and operators' welfare, has gotten. The suggest re-layout also stresses improved practices that increase safety in the plant.

In conclusion, the actual application of the principles suggests a significant reduction in time for the most critical assembly activities.

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