UNIVERSITA' DEGLI STUDI DI PADOVA
DIPARTIMENTO DI SCIENZE ECONOMICHE E AZIENDALI
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CORSO DI LAUREA MAGISTRALE IN BUSINESS ADMINISTRATION
LM-77 Classe delle lauree magistrali in Scienze economico-aziendali

Tesi di laurea

SMED implementation in a manufacturing firm: the case of miniGears SpA

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ANNO ACCADEMICO 2018 - 2019

A mio padre,
che avrebbe voluto più di ogni altra cosa
vedermi raggiungere questo traguardo...

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Introduction

Lean production was pioneered by Toyota after World War II. At the end of the forties, it was a small Japanese automobile company, whose machinery was obsolete and its market shares derisory. For this reason, the Taylorist-Fordist production model could not be applied. Taiichi Ōno, at the time was an engineer who specialized in mechanics. Later he became an Executive Board member who, decided to adopt a new road, directed at increasing the flexibility of the machinery to produce smaller batches in short periods. With this strategy the company would have been able to respond immediately to market changes and consequently the production would have been adjusted continuously according to market demand. The eastern model of Toyota was based, not so much on the introduction of new technologies in the productive system, but on an internal reorganization of the plant with the creation of robust processes that gave high importance to human contribution in terms of intelligence and responsibility.

At the base of this model, later called *lean philosophy* by two American theorists, there are two key concepts: combating waste and creating value to customers. *Monozukuri* and *Hitozukuri* are two fundamental principles aimed to guarantee the highest value to the customer. The first principle, Monozukuri, means "making of things" and aims to always trying to improve quality and reduce costs through continuous improvement (kaizen).

The second one, Hitozukuri, means "making people" and regards the passion and art of developing people through an educational process, with an emphasis on lifelong learning. It is about developing a person's skills in their area of expertise, as well as their ability to work beyond functional boundaries.

Lean production arrived in Europe in the 1990s with the publication of the book *The Machine That Changed the World* (Womack, Jones, 1990). Authors tried to understand why Toyota was so far ahead of Western automakers. For years there have been discussions about the strengths of Toyota, but in the end, it became more dynamic and efficient than Western companies. This was not only due to cultural diversity, but above all, thanks to a persisting fight against waste.

Developed between 1948 and 1975, the Toyota Production System (TPS) consists of the idea of "doing more with less" by using the (few) resources available with the aim of drastically increasing the productivity of the factory. Waste had to be fought -*muda* in Japanese- because it does not create any value for the customer.

Lean is not just a production system, but a way of thinking. The main principles are value, value stream (mapping), flow, "pulled" production and perfection (or in other words continuous improvement, a concept explained with kaizen) (Womack, Jones, 1997). If these principles are clearly understood and linked, it will be easier to maintain a smooth path to the consumer.
When lean thinking arrived in Italy, it concerned traditional factory environments and internal logistics (lean production), motivating them to evolve to the so-called lean supply chain. It was conceived as a simple industrial technique to be applied to production plants to be more efficient, reduce waste and to increase market supply in a shorter time-frame. Today lean culture has become widespread, yet very few companies have brought the lean principles off the factory walls to apply them to offices and other business processes (Cappellozza, Bruni, Panizzolo, 2009).

This work can be divided into two main parts. The first two chapters give a theoretical background of what the lean philosophy is and how it has been developed. These chapters also define what its main principles, techniques and tools are. In particular the second chapter explains the *Single Minute Exchange Die* methodology, which is the core argument of this work.
The other half of the thesis covers chapter three and on. In these chapters, a personal experimentation was completed during a six-month internship with Considi Srl which is located in Grisignano di Zocco (VI). This location is specialized in management systems consulting and focuses mainly on the application of lean philosophy in the industrial field. In collaboration with this sector, I worked on the German group hGears project. Here I focused on one of its production sites, Minigears SpA which is located in Padova.
hGears Group is one of the world's leading manufacturers of precision components and gear kits for power transmissions and complex systems. With more than 1000 employees and offices in Germany, Italy and China; hGears works constantly with its customers to develop and design technological solutions in the automotive, e-bike, power tools and gardening sectors.
The objective of the project is to improve a changeover of a hobbing machine and see how this impacts the OEE and some KPIs. Moreover, it is important to translate a simple time value into the economic benefits that could be achieved by reducing changeover time.

Chapter 1 – Lean Thinking

What is lean philosophy?

The focus of lean thinking is to achieve a flow of materials, information or customers that delivers exactly what customers want (perfect quality), in exact quantities (neither too much not too little), exactly when needed (not too early nor to late), exactly when required in the right location and at the lowest possible cost (Slack, Chambers, Johnston, 2016).

Manufacturing techniques have evolved over time from artisanal production during the nineteenth century, to mass production during the twentieth century, to the present tendency of mass customization characterized by high variability and small quantity per product. In parallel, the production system itself has evolved from “batch & queue” to “single piece” transfer-line manufacturing, to full automated manufacturing cells, complemented with lean manufacturing techniques following the TPS (Rüttimann & Stöckli, 2016).

Lean management has its roots in Toyota after World War II. Toyota faced a great challenge: to reach the productivity of the three big American automakers (Ford, QM, Chrysler) in a few years, or alternatively to die. The Toyota Production System was born from these premises and immediately it was characterized as a management system that involved the whole company. It regards not only producing what is needed when needed, but also producing what the market requires. However, TPS does not stop at the logistical and market aspects but covers the various management areas of the company. From an organizational point of view, inter-functional conflicts must be overcome, privileging the logic of processes (Furlan, et al., 2018). Autonomation is implemented only if it is supportive to people and only if it is accompanied by efficient processes. The corporate culture revolves around the pivots of continuous improvement and respect for people. Through Kaizen the potential of people is developed both individually and in groups.

Description	USA	TOYOTA
Productivity (hours/vehicle)	31	16
Defects per 100 cars	130	45
Space for assembling	0.75	0.45
Inventories of parts	2 weeks	2 hours
Average hours for design (millions)	3.1	1.7
Average time for development	60.4	46.2
Supplier contribution to design and development	14%	51%
Number of suppliers per factory	509	170
Proposition of components from one source	69.30%	12.10%

Table 1 - Productivity gap between USA and Japan at the beginning of the 80s (source: Womack, Jones, Roos, 1990)

Finally, visual tools and a management control that provides simple and timely information must be used.

For decades the mass production system dominated the world. The entire Fordist regime and its associated mass production system functioned remarkably well. With the ending of the long post-war boom in the late 1960s and early 1970s, however, the system entered into an extended period of crisis, which, even now, has not fully run its course. Competition from Japan and the newly industrializing countries became ever more intense and dealt a serious blow to mass production sectors in core regions throughout North America and western Europe (Scott, 1988). By the early 1970s, mass production slowly began to decline due to the increasing speed of change in the business environment which required flexible firms; customers' desires which became more individual and the global competition which required companies to be simultaneously efficient, flexible within processes, innovative in product and process, high quality manufacturers.

Lean doesn't require to plan ahead. The idea is that companies decide what to produce on the basis of the actual and real demand. A company which applies a perfect lean system buys only when and what is needed, produces only what is "pulled" by the demand and delivers only when the customer is waiting for the product. This is also called "just in time", a concept introduced first by Toyota. The Toyota Production System (TPS), originally called "just-in-time production", is "a framework for conserving resources by eliminating waste. People who participate in the system learn to identify expenditures of material, effort and time that do not generate value for customers and to eliminate them"[1].

Going into detail, it is a system which provides the best quality, lowest cost and shortest lead time through the elimination of waste (Marchwinski, Shook, 2003). It is comprised of two pillars: just-in-time and Jidoka. This will be further covered in the latter part of this thesis.

Types of muda

The core idea of lean management is to maximize customer value while minimizing waste. More simply, lean means creating more value for customers with fewer resources or in other words producing more with less. Waste is an important word for lean management. In Japanese

[1] Toyota Motor Corporation (1998). *The Toyota Production System – Leaner manufacturing for a greener planet*. TMC, Public Affairs Division, Tokyo.

it is called *muda* and defines everything that the customer is not willing to pay for. By eliminating it, the customer value increases.

As so often in lean philosophy, Japanese terms are used to describe core ideas and waste elimination is certainly a core idea. The terms *muda*, *mura* and *mudi* are Japanese words conveying three causes of waste that should be reduced or eliminated (Slack, Chambers, Johnston, 2016):

- *Muda* – means activities in a process that are wasteful because they do not add any value to the operation or the customer. The main causes are likely to be poorly communicated objectives or the inefficient use of resources;
- *Mura* – means lack of consistency that results in a periodic overloading of staff or equipment. If activities are not properly documented so that different people at different time performs a task differently, then the result may be different;
- *Muri* – means absurd or unreasonable. It is based on the idea that unnecessary or unreasonable requirements put on a process will result in poor outcomes. Waste can be caused by failing to carry out basic operations planning tasks such as prioritizing activities (sequencing), understanding the necessary time (scheduling) and resources (loading) to perform activities.

Figure 1 - Three types of MUs (source: www.company.com)

Toyota has identified seven types of waste, which can be found in many different types of operations – both service and production – and which form the core of lean philosophy[2]:

● **Over-production**. Producing more than what is immediately needed by the next process in the operation. It is highly costly to a manufacturing plant because it prohibits the smooth flow of materials and degrades quality and productivity. The solution is to schedule and produce only what can be immediately sold/shipped and improve machine changeover/set-up capability.

● **Waiting time**. Equipment efficiency and labour efficiency are two popular measures which are used to measure equipment and labour waiting time, respectively. Typically, more than 99%

[2] https://www.emsstrategies.com/dm090203article2.html, https://www.aretena.it/post/i-5-principi-del-lean-thinking

of a product's life in traditional batch-and-queue manufacture will be spent waiting to be processed. While waiting, the firm is burning its intelligence and the operators' one who are not working. A solution invented by Toyota is the *jidoka*. It means equipping each machine with a system and training each worker to be able to stop the production process at the first sign of some anomalous condition. If a defect or malfunction is discovered, the machinery must stop automatically and the individual operators must immediately correct the problem, interrupting the production flow. This way of doing allows us to " build-in quality" at every stage of our process, separating men and machines to get more efficient work from both. Much of a product's lead time is tied up in waiting for the next operation; this is usually because material flow is poor, production runs are too long, and distances between work centres are too great. Linking processes together so that one feeds directly into the next can dramatically reduce waiting. A famous Toyota proverb says ""*Stop production so that production never stops*".

● **Transportation**. Moving items around the operation, together with the double and triple handling of WIP, does not add value. Transportation can be difficult to reduce due to the perceived costs of moving equipment and processes closer together. Furthermore, it is often hard to determine which processes should be next to each other. Mapping product flows can make this easier to visualize. Transportation is important also in the external value chain, that's why local suppliers are considered lean.

● **Over-processing**. The process itself may be a source of waste. Some operations may exist only because of poor component design or poor maintenance and so could be eliminated. It regards in other words, doing something that does not add any value to the costumer. For example, at the airport passports are checked 4/5 times because each actor at each stage has a different aim (airport security, customs, airline security etc.) and there is not communication between them.

● **Inventory**. All inventory should become a target for elimination. Having excess inventory means that the company is very slow, and TT is long too. Inventory faces quality issues since when there are many items on stock, it is quite difficult to manage all the defective products as it is hard to identify them and resolve in order to improve operating performance. Excess inventory increases lead times, consumes productive floor space, delays the identification of problems, and inhibits communication. A solution proposed by Toyota is *Jidoka* again since the machine is able to stop in case of quality problems and does not allow the process to continue.

● **Motion**. An operator may look busy but sometimes no value is being added by the work. This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. These are also health and safety issues, which in today's litigious society are becoming more of a problem for organizations. Jobs with excessive motion should be analysed and redesigned for plant personnel. Simplification of work is a rich source of reduction in the waste of motion.

● **Defects**. Quality waste is often very significant in operations. Total costs of quality are much greater than has traditionally been considered and it is therefore more important to attack the causes of such costs. Associated costs include quarantining inventory, re-inspecting, rescheduling, and capacity loss. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Through employee involvement and Continuous Process Improvement (CPI), there is a huge opportunity to reduce defects at many facilities.

The five principles of lean management

Womack and Jones (1996) in their book *"Lean Thinking"*, declined 5 guiding principles that delineate the Toyota management system, the TPS (Toyota Production system): value, mapping value, flow, pull and perfection.

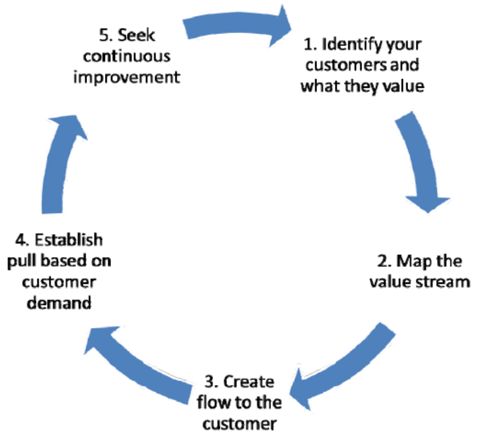

Figure 2 - Five principles of lean thinking

The application of the five principles in the company causes a great change both on the "physical plan" and on the organizational level (reduction of hierarchical levels, process orientation, cross-functional teams, empowerment, delegation and development of skills at operational levels, streamlining of functions, etc..); all this therefore entails a radical change of mentality on the part of all the personnel and a real "cultural revolution". It is a courageous choice, made by a strong, dynamic, innovative and modern direction.

1. Define value

Define value means standing from the customer viewpoint and understand how “products” and “processes” can satisfy customer’s needs.

Only a small part of the actions and total time spent to produce or provide a service adds real value to the end customer. It is therefore essential to clearly define the value of a specific product or service from the customer's perspective, so that it is possible to proceed with the removal of all the non-value activities or *muda*, step by step.

The value, as explained before, can only be defined from the point of view of the final customer. Therefore, it is important to understand what the customer is willing to pay and clarify the real customer’s needs to provide a specific product (good/service) able to satisfy the customer's requests. Giving something that he/she does not perceive as "value" is like not giving him/her something needed.

Sometimes companies find it difficult to define exactly the value creation, since it may occur through different endeavours who define it differently according to their needs (Womack, Jones, 2011). Think about an airport and how many times a passport is checked or how many times the boarding pass has to be shown. In this specific case, the problem is not the involvement of more than one company, but the fact that every single step provides a partial service, without looking at the product/service as a whole from the customer perspective. Since all the steps are unnecessary and do not create value for the customer, one should ask oneself whether it is possible for a single person to carry out the passport control only once, thus saving time and resources (Womack, Jones, 2011).

KPIs can be used in order to measure the value provided to customers; in particular there are 3 main areas to measure the performance of operations:

- **Quality**: of products and services provided to customers (KPI: % of first-time-through)
- **Time**: the amount of time that customers wait to obtain the product/service they asked for (KPI: order-to-delivery)
- **Cost**: cost of production which has a direct reflection on the charged price (KPI: total cost/units)

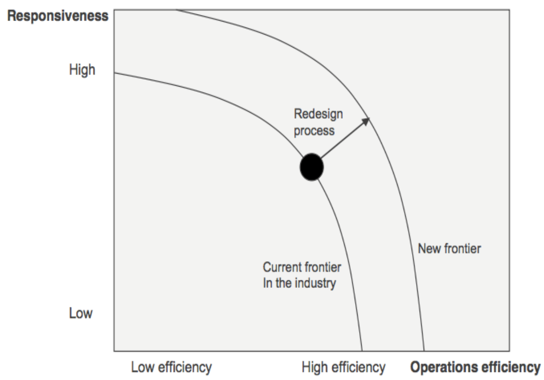

Figure 3 - Efficient frontier (source: www.cxpert.com.au)

Normally these 3 elements are in trade off since if quality is pursued, it is necessary to spend more; if the company wants to be very fast, the cost will increase etc. With the lean philosophy there is no such trade-off: the idea behind is to achieve high quality, low cost and short time **simultaneously** to increase customer value.

Said in other words, when a company is below the efficient frontier and for instance aims to reach high quality, it can reduce the costs performance by hiring new people, by investing in new machineries or by better training the staff (all this kind of operations will increase costs). The idea of lean is that no company will never be on the efficient frontier, but always below it for two reasons:

- it will always be possible to increase the performance of costs and increase quality simultaneously;

- there will be always wastes that distance the company form the efficient frontier.

2. Mapping value

There is one question that all firms approaching a change to lean should ask themselves: which activities carried out by the company and its resources are "important" and which are not? Answering this question means having in mind the principle number two.

All the activities that create value perceived by the customer are important, while all others must be viewed with suspicion. In Japanese philosophy, activities that do not generate value are considered "wasteful" and must be fought. All activities can be divided into three categories (Hines, Rich, 1997):

- Value activities (VA): generate a value perceived and recognized by the customer (activities for which the customer is ready to pay) such as casting, manufacturing, printing, assembly. They must be improved.
- Non-value activities (MUDA): waste that can be eliminated immediately such as moving, controlling, transporting, storing, etc.. They must be removed.
- Non-value but necessary activities (NVA-N): although not generating value, they are currently necessary for the company. They are activities that do not give added value, but that in certain circumstances must be carried out. Some are: product development, order management and production systems. They must be minimized.

Identify value consists in mapping the tasks required to bring a specific product through two critical processes:

- ❖ Information process: from order-taking through detailed scheduling to delivery
- ❖ Production process: physical transformation from raw-materials to finished products in the hands of the customer.

Mapping the processing is also important because lean firms are usually organized in "**value stream**". It regards all the actions (both value-added and non-value added) currently required to make a product through the main flows: (1) the production flow from raw material into the arms and (2) the design flow from concept to launch (Rother, Shook, 2003). Taking a value stream perspective means working on the big picture, not just individual processes, and improving the whole, not just optimizing the parts. Ideally there should be one value stream for each product.

3. Flow

Lean thinking reverses the traditional way of producing through "batches", "functions" and "offices". In fact, the tasks can always be performed more effectively if the product is worked continuously from the raw material to the finished product.

The continuous flow in production is reached through radical interventions, which allow to transform the manufacturing from a batch and queue system, to a continuous flow. Waiting time, large production batches, stocks, interruptions due to lack of information and inefficiency of suppliers, set-ups, are all enemies of the flow. The concept of flow impose that a stage cannot produce another piece if the next one is still busy, but production is allowed only if the second stage has moved its piece on.

The flow consists of a sequence of equal “homework” periods called Takt Periods, each terminating in an Integrative Event. The Takt Periods are of equal and short durations whose role is to provide a constant, common, and frequent rhythm to the entire team. Within each Period, work is executed by any suitable architecture of concurrent and synchronized teams, part-time employees who are dynamically allocated from their functional departments, and individuals, all assigned as needed to assure the timely completion of the work within the given Period (Oppenheim, 2004).

“Make one, move one” is a principle that overcomes the concept of batch. Batches are calculated in order to reduce holding costs, ordering costs and set-up costs. The economic batch quantity (EBQ) depends on these values. With lean this concept is overcome in favour to produce one piece at a time where set-up costs can always be reduced as well as the items in one batch. Optimal result is a factory that starts with a long production line that never stops and always flows. Of course, it is not always possible to produce a perfect flow. When there are differences in the speed of production through each stage, it is very difficult to create a flow. In particular, this happens when the production is partially automated so that there are big differences between machines and operators’ speed.

4. Pull logic

Value activities, although they must run without interruption, must be "pulled" by customers, otherwise there is the risk of raising a cost without generating value, falling back into *muda*. Waste generated by producing valuable goods before the customer asks for them or in greater quantities than requested, have to be eliminated.

It is necessary to implement a **pull system**, pulled by the customer intended as both the external one and the internal customer (downstream). No activity must be undertaken without a specific request from the client. Kanban and supermarket are the most used tools for the implementation of the pull system. Pull differs from the traditional push logic, according to which it is the firm that "pushes" the product towards the market.

PUSH LOGIC	PULL LOGIC
Each stage is not connected with downstream and upstream stage	Each stage produces only if an information from downstream stage/customer triggers the production
Each stage receives its work orders from the MRP calculations	No MRP
Production schedule is based on forecasts	Based on real and actual demand

Table 2 - Push logic vs. Pull logic

5. Perfection

One of the foundations of lean thinking is the awareness that there is no end to the process of reducing costs, space, waste. The steps of a lean path are a circle: when an improvement phase is concluded, one must return to the first step of the path in order to obtain a process even closer to the customer's needs, identifying an additional value to be maximized (fig. 1.7). The image that is often used to describe a lean change path is a straight line "uphill", as opposed to the classic step-by-step improvements, typical of traditional change projects. In the ambit of lean processes, there is the "virtuous circle" PDCA:

- Plan – define an objective to make an improvement plan;
- Do – analyse the current situation and find solutions;
- Check – check the results and decide recovery actions;
- Action – activate the plan and prepare the next steps.

In a lean company, the tension to change never stops and this explains the fundamental essential importance of people involvement who day after day have to become makers of improvement. In this sense, the fifth principle must be a spur for the incessant application of lean principles and must always be a new starting point. Once finished, the process restart to bring out new waste and eliminate it.

Value Stream Mapping in-depth analysis

Value stream mapping (VSM) can be considered as a pencil and paper tool that helps to see and understand the information and material flows as a product makes its way through the value stream. It is one of the easiest and at the same time efficient way to see value and trace waste (Rother, Shook, 2003).

VSM is an essential tool for several reasons:

- It helps to visualize besides the single-process level, the flow too;

- It helps to see the sources of waste in the value stream;
- It forms the basis of an implementation plan becoming the blueprint for the process;
- It shows the linkage between the information flow and the material flow. No other tool does this;
- It is a qualitative tool which describes in detail how the facility should operate in order to create flow.

Better said, VSM is one of the main tools that can be used to map the flow of value, thus making it possible to identify value-based and non-value activities for the customer. Thanks to the VSM it is therefore possible to pursue the second principle that characterizes Lean Thinking. Lean companies are usually organized in value streams, operations containing all the main business functions. Ideally one value stream should encompass one product.

VSM can be executed at different levels of the company depending on the type of information to be obtained. It is possible to map:

- a single process within a single department;
- the entire flow inside the production plant, i.e. an overall process from the raw materials entering to the exit of the finished products (it is the most frequent mapping);
- the entire supply chain, starting from the second or first level suppliers to first or second level customers.

Clearly each level provides different information and, consequently, the mapping choice must be based on own objectives.

As can be seen in the figure, there are four main steps to follow in order to perform VSM:

1. select a family of products to be analysed;
2. draw the map of the current state;
3. draw the map of the future state;
4. define objectives and an improvement plan to be implemented.

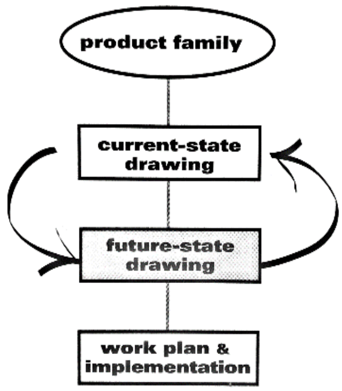

Figure 4 - Initial VSM steps (source: Rother, Shook, 2003)

Step 1: Identify a product family

The first step requires to identify a group of products that pass through a similar processing step and over common equipment in the downstream process (Rother, Shook, 2003).

To make the selection of the product family the following tools can be used:

- *Product-Quantity Analysis-PO Analysis*[3]: Pareto's analysis identifies codes with the largest production volumes and VSM is concentrated on them;
- *Product-Routing Analysis-PR Analysis*[4]*:* If the product mix is complicated, a matrix can be created with assembly steps and equipment on the vertical axis and products on the horizontal axis.

The objective is to group together as many products as possible in homogeneous families characterized by the same process, thus being able to concentrate the mapping only on this common process.

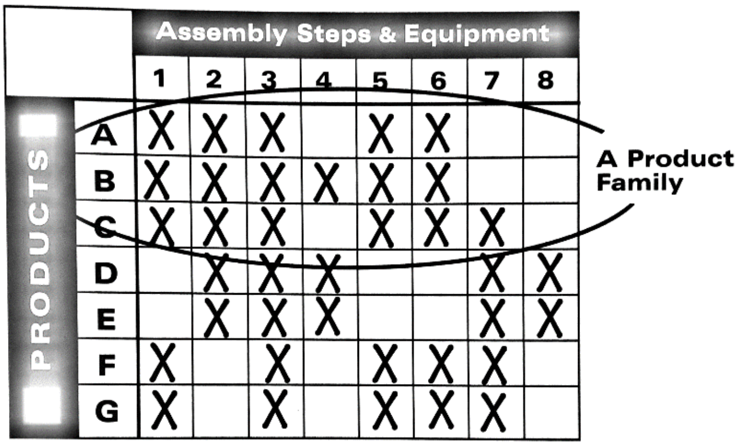

Figure 5 - Matrix products/processes (source: Rother, Shook, 2003)

Step 2: Current state drawing (AS IS)

This stage regards drawing the basic production process. To indicate a process, it is usually used a process box considered as an area where material is always flowing. The process box stops wherever processes are disconnected and the material flow interrupts. Since drawing one box for every process would make the mapping process bumbling and unwieldy, there are some tricks that can be used. In case of an assembly process with many connected workstations and with some WIP inventory between them, that process would be drawn as one process box.

[3] Panizzolo R., 2016, *course of "Gestione snella dei processi"*, University of Padua

[4] Rother, M., & Shook, J., 2003 "*Learning to see: value stream mapping to add value and eliminate muda*", Lean Enterprise Institute

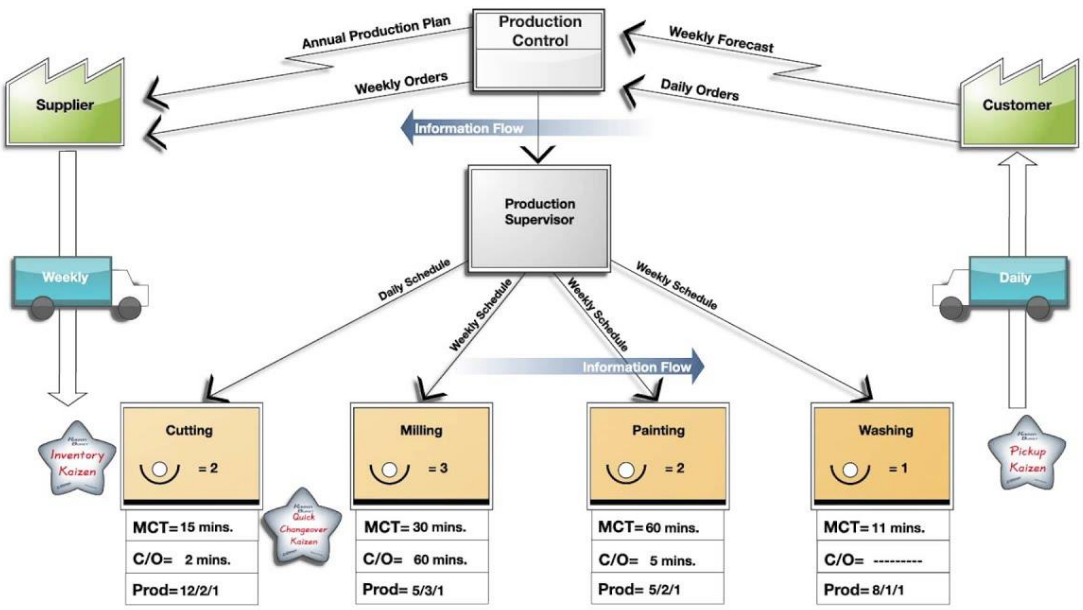

Figure 6 - Example of value stream mapping (source: www.youtube.com "VSM: Explanation of Value Stream Mapping Icons and Language")

Instead, in case one assembly process is disconnected from the next assembly process downstream, with stagnating and accumulating inventory, then two process boxes can be used.

Step 3: Define the future state (TO BE)

Once all the necessary information is obtained to understand the AS IS situation and the relative critical points, it is fundamental to define the future state (TO BE) that one company wants to achieve.

The aim is to prepare various drafts about future proposals by taking into consideration both the flow and pull logic. It is necessary to build a chain of production characterized by continuous flow (*make one, move one* logic) where every individual process works only in case of a signal from the downstream customer. In other words, all operations are activated only when there is a demand asking for their products/services that could come from the external customer and directly from the next stage.

One important question to be asked is: what's the takt time for the chosen product family?

The word "Takt" is a German word meaning *beat*. Takt-time is the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate) (Frandson et al. 2013).

It represents the pace at which customers ask for a product. Its calculation starts with the available working time for one shift minus any non-working time. The customer demand per shift is divided into the available working time. Lean companies' aim is to have a cycle time (production speed) as close as possible to takt time. A significant gap between takt time and cycle time

(CT > TT) indicates the existence of production problems that cause unplanned downtime. Even the opposite situation is serious: if a plant is faster than demand it produces inventory which is *muda*.

Step 4: Achieving the Future - State

The plan for achieving the future-state value stream can be a compact document that includes the following items:

1) future-state map

2) any detailed process-level maps or layout that are necessary

3) a yearly value-stream plan

The first question that usually arise in planning implementation is "in what order should we implement? A starting point could be to look for loops (Rother, Shook, 2003):

- Where the process is well-understood by people;
- Where the likelihood of success is high (to build momentum)
- Where it is possible to predict big bang for the buck (this sometimes leads to areas that have major problems to be solved, which can lead to conflicts with the previous criteria)

The Toyota Production System House

The Toyota Production System model was developed by the Toyota Motor Corporation for its production plant, but the principles and activities it encompasses can be applied to nearly any industry.

When discussing the TPS and its many features, it can be helpful to think about the system like a house. The "house" of the Toyota Production system is built upon a strong and stable foundation, has two main pillars, with the overarching goal of TPS on the roof.

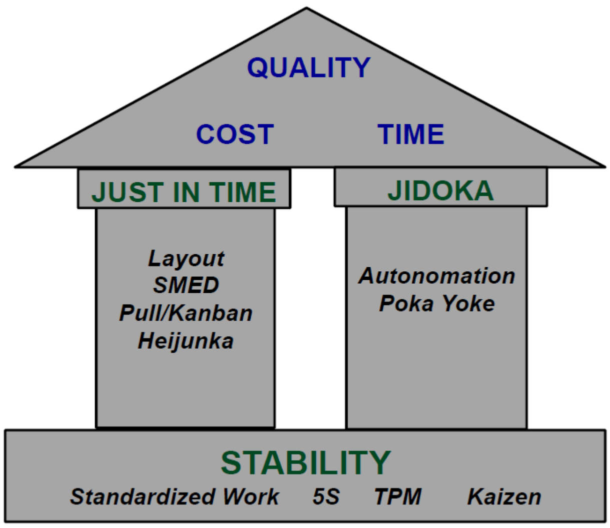

Figure 7 - Toyota Production System house (source: Furlan, 2019 Advanced Operations Management course, University of Padua)

The Roof

The easiest way to understand the concept of the Toyota Production System is to start with the roof of the TPS-House. It represents the goals of the system which are: increasing quality, reducing costs and shortening time. The former directly refers to the reduction of defective products as well as their rework. All repairs, any garbage, reproduction and inspection are all activities which do not add any value to the final product. Thus, all these activities are a waste of motion, time and energy (Liker, 2014). Hence, the total avoidance of waste can shorten the throughput times and thus improve the process quality.

By reducing the costs, the profitability and competitiveness of any organization can be increased. Therefore, only the right quantity can be produced while the workers have to be implemented effectively or sometimes even have to be released (Li, 2012; Ohno, 2013).

The First Pillar: Just in Time

The first main pillar is the idea of just-in-time manufacturing. This emphasizes three main practices: continuous flow, takt time, and a pull system. The idea of JIT manufacturing is to implement a production method that emphasizes the minimization of waste and workers being able to operate efficiently. Instead of producing items as you have the materials, certain steps of the production phase shouldn't start until an order triggers it.

In conventional planning, demand and production quantities and timing are often different, resulting in idle inventory and "lumpy" demand. JIT means getting the right quantity of goods at the right place at the right time while keeping inventory at minimum, established levels[5].

JIT brings many benefits to the organization adopting it:

- Improved overall productivity and elimination of waste
- Reduces inventories to a minimum and it allows saving direct inventory carrying costs
- Cost-effective production using a minimum amount of facilities, equipment, materials and human resources
- Reduced delivery lead time
- Exposes problems and bottlenecks caused by variability
- JIT is accomplished through the application of elements that require total employee involvement and teamwork

[5] Furlan A. 2019, course of "*Advanced Operation Management*", University of Padua

Layout

Conventional functional layouts create pipeline inventory, delays, movement costs and other forms of waste. In the JIT approach: operations should be arranged to achieve a logical flow (e.g. cell, line); equipment should be close together to reduce cost of movement; use of "U" shaped to increase visibility and teamwork.

Moreover, even the size of the machines has an impact on the layout and its productivity. Generally, the conventional Western approach is to purchase large machines to get 'economies of scale'.

The problem is that they have often long, complex set-ups, and make big batches, quickly creating 'waste'.

A solution could be buying small machines for several reasons:

• Using many small machines allows simultaneous processing
• Flexible scheduling options
• Ease to move in the plant
• Quick set-up
• Easier planned maintenance (more robust)

SMED

The *Single Minute Exchange Die Method* (SMED) belongs to those methods which concretize lean philosophy by eliminating waste throughout the entire process. The primary aim is to keep downtimes minimized as long as possible.

The SMED method proposes the reduction and simplification of the activities for the change of equipment and for all the adjustments that precede the production (set-ups).

The logic behind it makes it possible to overcome two concepts on which set-up activities were based in the past (Cappellozza, Bruni, Panizzolo, 2009):

1. Performing set-ups on production efficiently and effectively requires technicians with high skills and abilities and years of experience and training;
2. Producing in large batches alleviate the negative effect of set-ups and counteracts the related costs.

The starting point is the subdivision of the entire set-up time (or production change time) into two distinct entities:

- ➢ The internal set-up time
- ➢ The external set-up time

The set-up time is defined as "*the time interval that elapses between the end of the production of the last piece (product, sub-set, component ...) compliant without defects, of the previous batch, and the beginning of the production of the first piece of the next batch*" [6].

An industrial engineer's perspective of SMED, set out by Bille (1989), confirms that moving tasks from internal time to external time can be viewed in industry as the major theme of the SMED methodology: [it] describes how to reduce set-up times from hours to less than 10 minutes by separating inside and outside exchange of dies.

From an academic standpoint, Burcher *et al.* (1996) describe their view of activity that is required to reduce set-up (changeover) time: "Set-up has two elements, internal and external [...] To reduce the effective set-up time you need either to remove the need for the set-up entirely (e.g. by using dedicated machines) or move from internal to external set-up" (McIntosh, Culley, Mileham, Owen, 2000).

Internal activities have to be done when the machine (or the line, or the production process) is stopped, otherwise it would not be possible to complete the set-up. During this time, no value is added to the product.

External activities are done in the interval of time that passes after, during which some activities necessary for the set-up are carried out while the process is continuing (such as bringing or removing materials and products, preparing or putting in place tool...). A part of this time can elapse before the internal set-up activity and another part after. The initial strategy of SMED is to create a clear distinction between the two temporal entities, of internal and external set-up time, and to ensure that all those activities that could be carried out "externally" are removed from the "internal" zone.

The next steps are:

- drastic reduction of internal activities (necessary)
- rationalization and reorganization of all external and internal activities.

These basic techniques of SMED work to gradually reduce set-up times and reach minimum durations.

Pull System

Implementing a pull system works to keep the factory from overproduction. Certain processes and steps in the manufacturing process will only begin when a worker receives a specific signal. By doing so, unnecessary inventory will not be created, and bottlenecks will be reduced.

[6] Source: Considi Srl

Takt time, another strategy used in just-in-time manufacturing, ensures the rate of manufacturing between stations is even. Takt time is useful in giving the pace to the production in order to meet customer demand.

Kanban is one of the operating methods used to enforce the pull logic and control just-in-time processing. The most common form of Kanban is a rectangular piece of paper in a vinyl envelope. The information listed on the paper includes pick up information, transfer information, and production information. It basically tells a worker how many of which parts to pick up or which parts to assemble (Monden, 2011).

All movements in the plant are systematized this way. Overproduction is prevented by Kanban, because it starts in final assembly and works backward to create a "pull" of parts through the process. It controls the flow of goods through the plant, but only works if practiced under strict rules.

FUNCTIONS OF KANBAN	RULES FOR USE
Provides pick-up or transport information	Later process picks up the number of items indicated by the kanban at the earlier process
Provides production information	Earlier process produces items in the quantity and sequence indicated by the kanban
Prevents overproduction and excessive transport	No items are made or transported without a Kanban
Serves as a work order attached to goods	Always attach a kanban to the goods
Identifies the process that produces defective products and stops the production	Defective products are not sent on to the subsequent process. The result is 100% defect-free goods
Reveals existing problems and maintains inventory control	Reducing the number of kanban increases their sensitivity

Table 3 - Kanban (source: Monden, 2011)

Heijunka

Toyota defines heijunka as “distributing the production of different body types evenly over the course of a day, a week and a month in the assembly process. It refers to the effort to match the daily production sequence to the actual mixed-model demand encountered by Toyota’s retail dealers” (Coleman, Vaghefi, 1994). It goes a step beyond the basic idea of mixed-model production to match demand. It also incorporates the concept of levelling, line balancing.

A mix of products created through heijunka logic, is critical to avoid:

– Long lead times

– Increasing inventories

– Greater opportunity to defects

– Excessive idle time and/or overtime

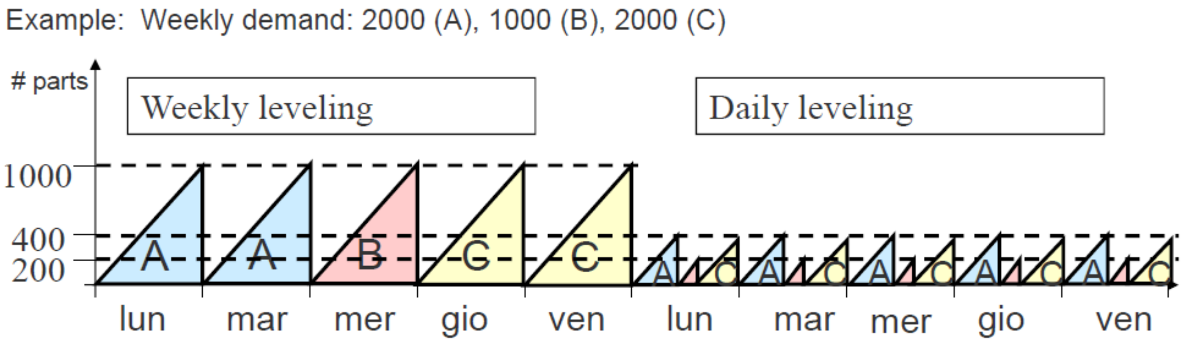

Figure 8 - Heijunka example (source: Furlan, 2019 Advanced Operations Management course, University of Padua)

The Second Pillar: Jidoka

The second pillar of the Toyota Production System contains the concept of autonomation (Jidoka). It provides machines and operators the ability to detect when an abnormal condition has occurred and immediately stop work. It enables operations to build in quality at each process and to separate men and machines for more efficient work (Marchwinski, Shook, 2003).

Autonomation

The autonomation process stops the production when a problem first occurs and seeks to find causes. For this reason, machines belonging to Toyota Production System can be considered intelligent machines (Ohno, 2013). This approach leads to quality improvements by eliminating the root causes of defects. In other words, quality control is done by the workers themselves at each stage and no defective items can pass to the next station. If the line stops, an investigation is done to prevent similar defects in the future.

Moreover, this approach is more cost-effective than quality inspections on a regular basis (Monden, 1993).

However, TPS does not rely only on autonomation to detect defects within the system, but many visual controls are used to monitor the state of the line. The most common visual control systems that can be found in each line are *andon* and call lights.

The former is used to call a supervisor, maintenance worker or general worker who can help the operator to solve the problem. The light usually has different colours which represent a different type of needed assistance. There are usually five colours with the following meaning (Fritze, 2016):

- red – machine trouble
- white – end of a production run; the required quantity has been produced
- green – no work due to shortage of materials

- blue – defective unit
- yellow – set-up required (includes also tool changes, etc.)

The latter is called *andon* and it is the name of an indicator board showing when a worker has stopped the line. Operators have to flick the switch in case of breakdown, delay, defects at a particular station and automatically the line will be stopped.

In such a situation, a red light turns on and the andon board indicates which station has stopped the line. This is a signal for the supervisor to go immediately to the workstation to investigate and take all the necessary actions to solve the problem (Monden, 1993) (Ohno, 2013).

Poka Yoke

The name *poka-yoke*, established in 1963, was translated as "resistance to errors" (avoid “yoker” errors resulting from inattention “poka”).

This method aims to prevent defects and errors originating in the mistake. It helps operators to avoid mistakes in their work caused by choosing the wrong part, leaving out a part, or installing a part backwards (Marchwinski, Shook, 2003).

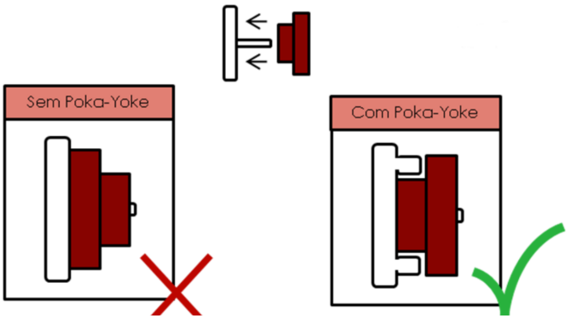

Figure 9 - Poka Yoke example (source: www.leanmanufacturing.it)

Poka Yoke devices are usually quite simple, inexpensive, and either inform the operator that a mistake is about to be made or prevent the mistake altogether.

The philosophy behind it is the respect of human rights and above all human intelligence (Dudek-Burlikowska, Szewieczek, 2009).

At each stage of the product life cycle, in each process and its operations there is a possibility of errors. It is not acceptable to produce even small quantities of defective products: for lean companies, production of 100% non-defective items is not only a challenge but a necessity (Patel, Dale, Shaw, 2001).

A defect can exist in two states: the defect either has already occurred, calling for defect detection, or is about to occur, calling for defect prediction (Lachajczyk, Dudek-Burlikowska, 2006).

Today, with the possibility of using automatic signalling mechanisms, Poka Yoke develops more and more through luminous signals (andon visible management) or sound, or line blocking and through the design of equipment for the cell.

The Foundation

The pillars of the Toyota Production System are built upon a stable foundation of standardized work, 5S, continuous improvement (kaizen), total productive maintenance (TPM). The goal of using the techniques of Toyota and Lean manufacturing, like Kanban, Takt time, and Andon lights, is to create high quality products at the lowest cost to the manufacturer with the shortest lead time. This is possible also thanks to the stability given by the foundation.

Standardized Work

The Standard Work is one of the most powerful tools in Lean Thinking programs. The Standard Work represents the best way to put into practise the continuous improvement (Kaizen). When a better way is identified to carry out the operations, a new standard is defined. The improvement of the standard is a never-ending process. The Standardized Work is based on three elements:

- the takt time, or the frequency at which a company must produce to follow the market requests;
- the precise sequence of operations to be followed by the operators;
- the stocks of materials, including the parts in process required - to keep the process active without problems.

The standardized work allows: to guarantee the repeatability of the performances; prevent problems; work without "surprises"; work safely and ergonomically; train operators; stimulate continuous improvement; get excellent results.

The formula for setting standards combines technical and process standards (Bianchi F., Bianchi M., 2012). To be effective in achieving the lowest cost, the highest quality level and the shortest delivery time for each product, it is necessary to incorporate both types of standard, as shown in the figure.

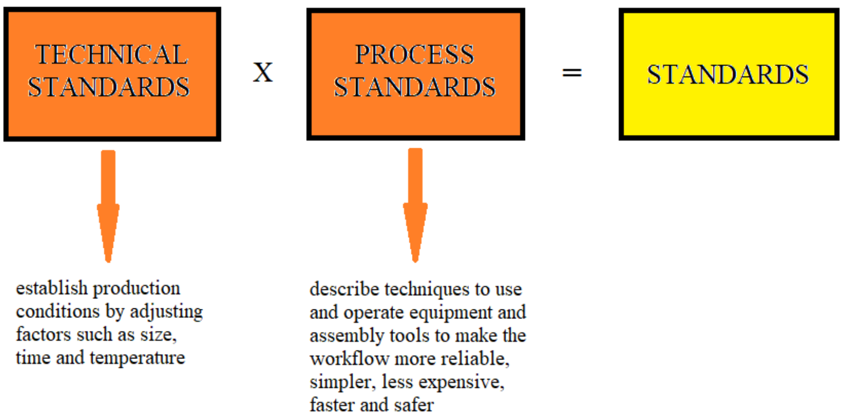

Figure 10 - Formula to determine standards (source: Bianchi F., Bianchi M., 2012)

5S

5S is a system for organizing spaces so that work can be performed efficiently, effectively, and safely. This system focuses on putting everything where it belongs and keeping the workplace clean, which makes it easier for people to do their jobs without wasting time or risking injury. Wastes are difficult to be seen when the workplace is in dis-array. That's why cleaning and organizing the workplace helps the team to uncover wastes.

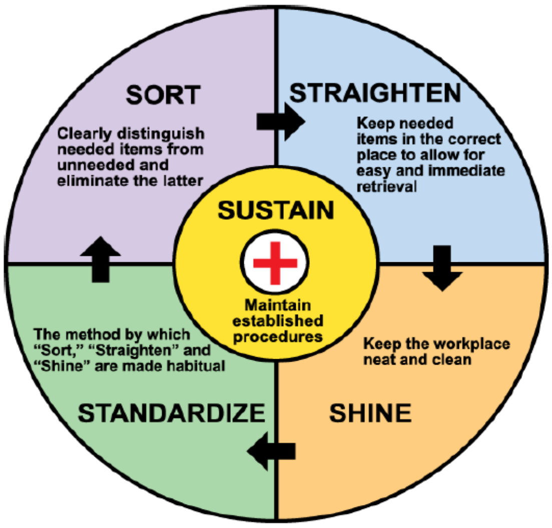

Figure 11- The 5S (source: Furlan, 2019 Advanced Operations Management course, University of Padua)

5S methodology must not be a one-shot action, as a Westernized company would normally do, but must trigger and maintain a process of continuous improvement in the day-to-day operations of the organization (Cappellozza, Bruni, Panizzolo, 2009). The 5S are:

1. **Sort** (*Seiri*)

   Seiri in Japanese means separating, selecting, classifying, eliminating, organizing. It is based on the separation of all the useful materials, tools, equipment that are present in an area/workstation, from the superfluous, bulky and useless objects. These latter ones must be disposed of, thus recovering areas and space in the workstations and at the same time simplifying routine operations, by reducing the number of objects needed.

   After having elaborated the "Map of working sites" with the subdivision of the different areas, it is advisable to take a series of photographs of each work area, to document how it appears before starting the project and compare them later with the ones after project. The work with the first S begins by freeing up the area from all the things that have stratified over time and that prevent or hinder what is really needed to work. Some criteria are followed to perform the first S:

   > The instruments and materials not used for at least one year are to be eliminated;

   > The tools and materials used once/twice in the last six months must be placed in a transitory area, to verify in the end how to get them back into the first or subsequent classes;

   > The tools and materials used at least once a month must be placed in a secluded but visible position;

> The tools and materials used at least once a week are located in a central area and visible to the operator;

> The instruments and materials daily used must be located in an ergonomic position, visible and close to the operator's workstation.

A practice normally used to select a given object is to label and highlight unnecessary materials and tools in the area subject to analyse with red cards. At this point, the objects thus highlighted must be moved to a temporary area, to then decide what to do with choosing from the various possible options: eliminate, dispose of, transfer to thirds or move to other uses.

2. **Straighten** (*Seiton*)

The second "S" refers to put in order, to arrange, to rearrange things in such a way that they can be easily reached whenever they are needed.

In this second phase, instruments and materials reclassified as useful will be relocated near the area (of analysis) or the work station that uses them in a rational and ergonomic way, with the aim of reducing time. Each object will be located more or less close to the work area depending also on the frequency of use (the more the frequency rises, the closer it approaches). The tools normally used for the systematization and sorting of materials can be:

> Physical structures for the storage and planting of different types of materials and tools;

> Physical highlighting with defined and different colours of areas, routes and corridors, specialized and reclassified by process/product;

> Billboards and other systems with easy and immediate indications.

3. **Shine** (*Seiso*)

Seiso means cleaning in a systematic way and has the objective of cleaning according to two points of view (general and dedicated):

- Clean the overall work environment;
- Clean up tools, machines and work equipment in a specific and dedicated way.

This phase can be supported very well through an audit plan on the execution and the thoroughness of the cleaning itself. In order not to face the same problems after a short time and repeat again the 5S procedure, it is convenient from this stage to analyse the primary causes. Human resources have to work on the root causes, they have to be sensitized and apply a rational and controllable working method.

4. **Standardize** (*Seiketsu*)

   Seiketsu is the fourth S of the methodological application and aims to standardize all the activities taken under examination, with the explicit aim of not finding the company after a few months in the same starting conditions. The means of standardization can be the procedures, the work instructions, the technical specifications, the audit lists, etc. In this stage, 'who does what', the objectives to be achieved and how these ones are monitored, must be defined. It is evident that in this phase the way through which information is transmitted, updated and perceived becomes increasingly important, because it is also in this phase that corporate behaviour is influenced and evenly directed.

5. **Sustain** (*Shitsuke*)

   The fifth S -from Japanese: discipline, training, support- represents the effort and attention that the company management must devote to pursuing the goal of keeping alive the new vision developed through the 5S methodology, i.e. a new perception of one's workplace and a consideration of work as a continuous process of improvement. The management must guarantee continuous adequate training and identification of the roles and responsibilities in equally explicit and transparent matters, a check on the results and on the goals achieved. In other words, it regards developing a commitment and a strong discipline in order to keep standards.

Over time, the 5S methodology leads to many benefits, including:

- Reduced costs
- Higher quality
- Increased productivity
- Greater employee satisfaction
- Safer work environment

TPM

Total productive maintenance (TPM) regards daily routines of maintenance (cleaning, inspection, oiling and re-tightening) to prevent failures and to prolong the life cycle of equipment (preventive maintenance).

It includes optimizing the effectiveness of manufacturing equipment and tooling carried out by all employees through small group activities (autonomous maintenance).

Maintenance personnel's role involves:

- ✓ training operators in relevant maintenance skills
- ✓ long-term planned maintenance
- ✓ condition monitoring

- ✓ designing or specifying equipment that doesn't break down and easy to maintain (maintenance prevention)

In addition, TPM implementation in an organization can also lead to realization of intangible benefits in the form of improved image of the organization, leading to the possibility of increased orders. After introduction of autonomous maintenance activity, operators take care of machines by themselves without being ordered to (Ahuja, Khamba, 2008). With the achievement of zero breakdowns, zero accidents and zero defects, operators get new confidence in their own abilities and the organizations also realize the importance of employee contributions towards the realization of manufacturing performance (Dossenbach, 2006).

Kaizen

Kaizen is a Japanese management strategy that means "change for the better" or "slow and continuous improvement", based on the belief that all aspects of life can be constantly improved. It derives from the Japanese words "*kai*" which means "continuous" or "change" and "*zen*" which means "improvement", "better".

For translation, it is a process aimed to generate continuous improvement concerning both products and internal processes (development, production, distribution, sales etc..).

This Japanese method encourages small improvements to be made on a day-to-day basis in a continuous manner. It is based on the principle that energy comes from below, that's why the results in a company are not achieved by management, but by the direct work of workers.

The most important aspect of Kaizen is precisely the process of continuous improvement that is at the base. It is a soft and gradual method which is opposed to the Western habits of eliminating everything that does not seem to work well to do it again.

Kaizen is the word that was originally used to describe the key element of the Toyota Production System with the meaning of 'doing things the way they should be done'. It means creating an atmosphere of continuous improvement by changing one's point of view and way of thinking to do something better than what is already being done. In practical use, Kaizen describes an environment in which the company and the individuals proactively commit to improving processes.

Improvements are usually not accompanied by the use of sophisticated or expensive techniques or the use of particular materials. Instead of investing money in the purchase of new machinery or equipment, in fact, Kaizen leads the organization to pay more attention to important details that are often overlooked. Managers, therefore, are encouraged to improve the efficiency of existing infrastructures rather than invest in new resources.

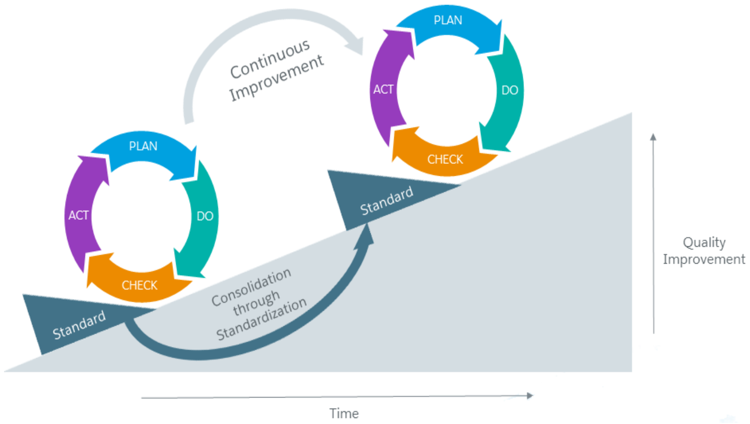

Figure 12 - The process of continuous improvement (source: https://commons.wikimedia.org)

The fundamental idea behind Kaizen is closely related to the Deming cycle (or PDCA cycle) where:

- a person has an idea to improve something (**Plan**)
- tests and simulations are performed to verify the validity of the idea (**Do**)
- the results achieved are evaluated to determine if the idea has achieved the objective that was set (**Check**)
- if so, the standard procedures are changed, adopting the new method (**Act**)

The Kaizen involves every collaborator, from the management to the workers. Managers must strive, first of all, to help employees by providing suggestions for improving the work of the individual and the company in general, no matter how much they are centred. This way of doing will help people to be more critical and push them to better examine the way they do things.

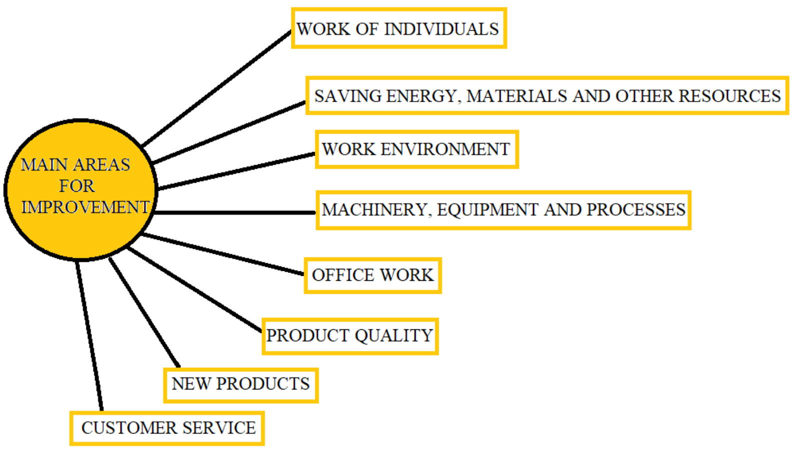

Figure 13 - Main areas of continuous improvement (source: www.qualitiamo.com)

Kaizen goals include:

- creating quality in each step of the process;

- standardization of operations in accordance with the involved employees and their tasks;

- achieving a conscious and responsible avoidance of waste of resources (e.g. time, materials, etc..).

There are two different types of Kaizen which need daily activity, as shown in the table (Liker, Convis, 2012).

MAINTENANCE KAIZEN	IMPROVEMENT KAIZEN
It deals with unpredictable events like mistakes, breakdowns, changes or variations that can occur every day to meet the expected standard. The goal is to bring the system back to the standard. It is an urgent and immediate approach in which the work group is expected to select the right measurements to make sure this event will never occur in the future.	It is usually simply called Kaizen and it represents the real goal of the TPS. It does not only aim to maintain the standards, but it rather tries to improve the standards and bring them to the next level. It does not matter of how many improvements were already done because every process contains waste, and this leads to the opportunity of continuous improvement.

Table 4 - Types of kaizen (source: Liker, Convis, 2012)

The foundations represent the basis for daily success by creating smooth and standardized processes which help to eliminate internal and external variations.

Additionally, the pillars of the TPS make breakdowns, delays and defects more visible by reducing the inventory and lead times as well as the opportunity of stopping the whole process. That means, this concept makes it possible to identify and eliminate problems within the system and to implement process improvement solutions (Fritze, 2016).

Importance of People

Yoshihito Wakamatsu was one of the major specialists of the Toyota system, who worked for years alongside Taiichi Ono, sharing his experiences and internalizing his teachings.

In one of his studies (Wakamatsu, 2013), he affirmed that *Monozukuri* is *Hitozukuri*, i.e. the ability to successful production is linked to the ability to train people. It follows that everything that normally represents the factory is supported and developed by the people who work in the company. If companies decide to apply *Hitozukuri*, it will be necessary to put people in the best conditions to do it, which means pushing them to observe, experiment, question themselves and to continuously develop their skills.

What Taiichi Ono stressed everyday was the awareness that human beings are extraordinary beings. One of his constant thoughts was to put man at the centre and reflect on how his ingenuity could be expressed. The fundamental element of the TPS lies precisely in ‘enhancing people’. One aspect to be pointed out is the respect of people and their ability to think.

Kaizen is the main element of *Hitozukuri*. Children learn by discovering new concepts and new words. Teenagers learn through the discovery of facts and procedures. However, adults already know most of these things and are full of their personal experience. For adults, learning is essentially problem solving-based: by solving specific problems, adults compare what they know from experience (what they "remember") with what they experience at that moment (their "actual experience") and this comparison leads to new discoveries, new ideas and new memories; in other words, new learning.

Toyota's theory on the development of people at work is based on:

1. **Knowing the job**: understand the contents of the work, the theoretical basis of each concrete step and the problems that can occur in different contexts;
2. **Motivation**: be confident of own success and willing to face a challenge;
3. **Space to think**: face a concrete challenge with enough time to think and try things until finding a new and better method;
4. **See progress of oneself:** in terms of the ability to do work in more difficult conditions, in terms of working better with others, to see one's initiatives accepted by one's peers and in terms of assuming more or different responsibilities.

It is a problem when people are not aligned with the organization: they can be lost and unmotivated because they do not know the direction of the company (the True North), because they do not recognize themselves in the role they hold or because they cannot work in groups. Lean principles of value flow for the customer, reduction of waste in the *Gemba* and involvement of people are what unite the various solutions as a whole provide the ingredients for a sustainable lean transformation over time (Furlan, 2018).

Chapter 2 – SMED

This work will go to analyse in practice what SMED is and how it is applied in concrete in a organizational environment. That's why before explaining my experience with miniGears SpA it may be necessary to stress the story of SMED and its application over the years.

Introduction

The scenario in which companies operate today is characterized by a widening of the markets which, in addition to expanding the number of possible customers and the typology of their needs, it also increases the number of competitors. Italian companies have focused on increasing the variety of products to maintain their competitiveness and increase sales. This trend is a generally shared opinion which will continue and might be accentuated in the coming years. The production systems *in series* designed to produce large batches of identical products, placed in the warehouse and subsequently sent to the customers when ordered, are no longer able to guarantee the profitability of the company. Storing large quantities of materials, in addition to committing money, lay the groundwork for future losses (obsolescence and subsequent scrapping of products, components and materials).

Large batch production produces an excess of stocks. Excess stock is a particularly negative waste because it hides other problems. When there is a high stockpile, people are not motivated to make improvements. Furthermore, the existence of stocks at any stage of the process causes further losses such as transport, storage, damage and delay in deliveries.

Producing in small lots, on the other hand, makes it possible to reduce stocks of materials and semi-finished products, reduce waiting times for reintegrating a stock and reduce waste. To produce cheaply in small batches, a company must learn to reduce the time required for production changes. That is exactly the SMED methodology which is aimed at reducing set-up time.

What is SMED?

The acronym SMED -meaning *Single Minute Exchange of Die*- is a theory and a set of techniques that make it possible to carry out set-up and changeover operations in less than ten minutes namely, in a time shorter than the double digit. The approach was born in the context of production processes based on the use of molds and processing tools. Later its basic principles were successfully extended to all types of processes. It is important to point out that the time interval of the single digit may not be reachable in all types of processes but that in almost all situations the SMED is in any case able to ensure a strong reduction in set-up times. This drastic reduction can bring great advantages both at the company level and operator level.

Nowadays, customers are looking for a growing variety of products in small quantities. They expect high quality levels, low prices and fast shipping; exactly the goals expressed on the TPS house. SMED helps companies to meet the needs of their customers by helping to reduce waste and make even lower production batches profitable. Many companies produce large batches only because the long set-up times would make it uneconomic to make frequent product changes. As explained before, large batch production has several disadvantages (Bianchi M., 2017):

- **Excessive stocks**: keeping in stock products that are not sold is expensive and keeps company resources blocked without adding any value to the products themselves;
- **Delays**: customers must wait for the company to finish producing large batches rather than just waiting for the exact amount requested by them;
- **Quality deficiencies**: keeping products in stock increases the possibility to be damaged and that they must be discarded or reworked before shipment, with an increase in costs for the company.

History

The first example of a SMED application, dates to 1950 and can be considered as the real birth. In Toyo Kogyo's Mazda plant in Hiroshima, S. Shingō was asked to solve a production problem related to a bottleneck near three large presses. The employer was resigned to buy another press, given that, due to growing market demands, it was necessary to increase production. Since the potential of the three presses was not able to guarantee the required production, the only possible solution seemed to be the purchase of a new press. Shigeo Shingō instead asked to analyse in detail the way in which the presses were used. In fact, he believed that the manufacturing defects were linked to the mismanagement of the machines and he also thought that it was useless to buy a new machine when it was possible to guarantee an increase in production by making better use of the existing ones. Although with some difficulties, Shigeo Shingō was satisfied and the establishment remained stationary for a week, giving the opportunity to carry out all the necessary analyses. He discovered that all three machines were used below their production capacity and that it was enough to take some precautions to improve it. The analysis carried out by the Japanese engineer was based on a simple principle: first he identified all the set-up activities; secondly, he made a classification between the operations that had to be carried out with the machine stopped and those that had to be carried out with the machine in motion. Shingo made sure that the activities carried out with the stationary machine were reduced by 50% and thus succeeded in increasing the production capacity without purchasing a new machine.

The second episode that deserves a mention for the development of the SMED technique is dated 1957 and concerned the Mitsubishi plant in Hiroshima. In this circumstance the engineer was asked, to increase the production capacity of a planer utilised to plan ship engine blocks. The problem that was encountered when analysing the operation was the fact that it was very difficult to change the planer's equipment when dealing with large motors. Not being able to

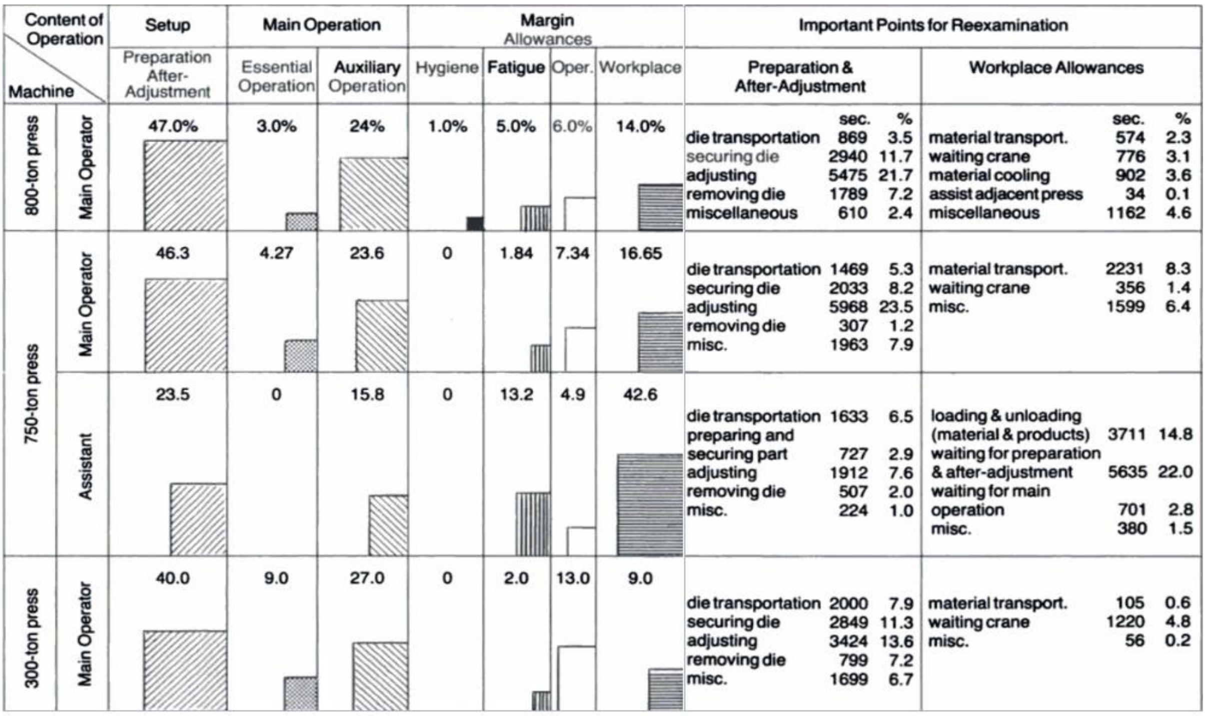

Figure 14 - Production analysis of the three presses located in Mazda plant (source: Shingo, 1985)

carry out a correct set-up, the exploitation of the machine was less than 50% of its potential. The analysis also showed that the greatest part of the set-up time was lost in the ‘centring’ because it was carried out with the machine stopped. The idea advanced by Shingo was to conduct the set-up operations referred to the next engine on a second planer table. By doing so, it was enough to move only the table and not the whole engine. By introducing this novelty in the production process the machine downtime was reduced and a 40% increase in productivity was achieved. The principle that led to the increase in productivity was very simple: even here it was enough to modify the operations carried out with the machine stopped so as to make it an external activity.

The third and last episode, considered a milestone in SMED's history, occurred in 1970 at the main Toyota factory. The goal requested by the management was to halve the set-up time regarding a thousand-ton press that until then had a set-up time of about four hours, equivalent therefore to almost half of a work shift. Japanese executives were aware that the same set-up operations at the Volkswagen factories lasted about half the time. Based on the company's experience it was decided to carry out a rigorous classification of all the operations in internal or external and subsequently it was decided to analyse the actual development of the setting processes in order to perfect them as much as possible. An in-depth analysis of the tooling processes thus allowed a reduction in the set-up time from four hours to two and a half hours, even if the management was still not completely satisfied with the progress achieved (Shingo, 1985).

Reduction of set-up time

Set-up is considered the main 'unproductive' phase of a process because it does not increase any value to the product, it absorbs production capacity of machines, it occupies 'human' capacity in the plant and it constrains the organization of production ('early' batches), interrupting the flow of materials.

In a traditional scenario, set-ups are long and unpredictable, and its activities are not standardized but accepted. Productive system is therefore rigid and poorly reactive to the market.

Through SMED application, there is a need to transform the productive system into a flexible, reactive and predictable one.

In the figure below benefits carried out by SMED are reported. Later, it will be found a distinction between benefits for companies and for operators.

Benefits for companies

SMED changes the idea that set-up must necessarily take a long time. When the set-ups can be done quickly, they can be done as often as necessary. In this way, companies are enabled to produce small batch sizes, achieving significant advantages in terms of:

- ✓ Flexibility: they can meet customer demand changes without having to hold high product stocks (improvement of Customer Service);
- ✓ Delivery speed: small batch production means shorten the crossing times in production and reduce the customer's waiting time;
- ✓ Better quality: less stock means less defective stocked products. SMED reduces defects also by reducing set-up errors and eliminating post-change test times;
- ✓ Increased productivity: faster changes reduce downtime with a consequent increase in productivity.

Benefits for operators

The speeding up of set-ups makes the company more competitive by ensuring the maintenance of workplaces and improves the daily work of operators making production more fluid and productive. Simplified and shorter set-ups mean for an operator:

- ✓ safer changes, with less physical effort and less risk of injury;
- ✓ less materials parked in the working environment, which makes work easier and safer;
- ✓ standardized set-up tools which means less variety of tools to keep under control.

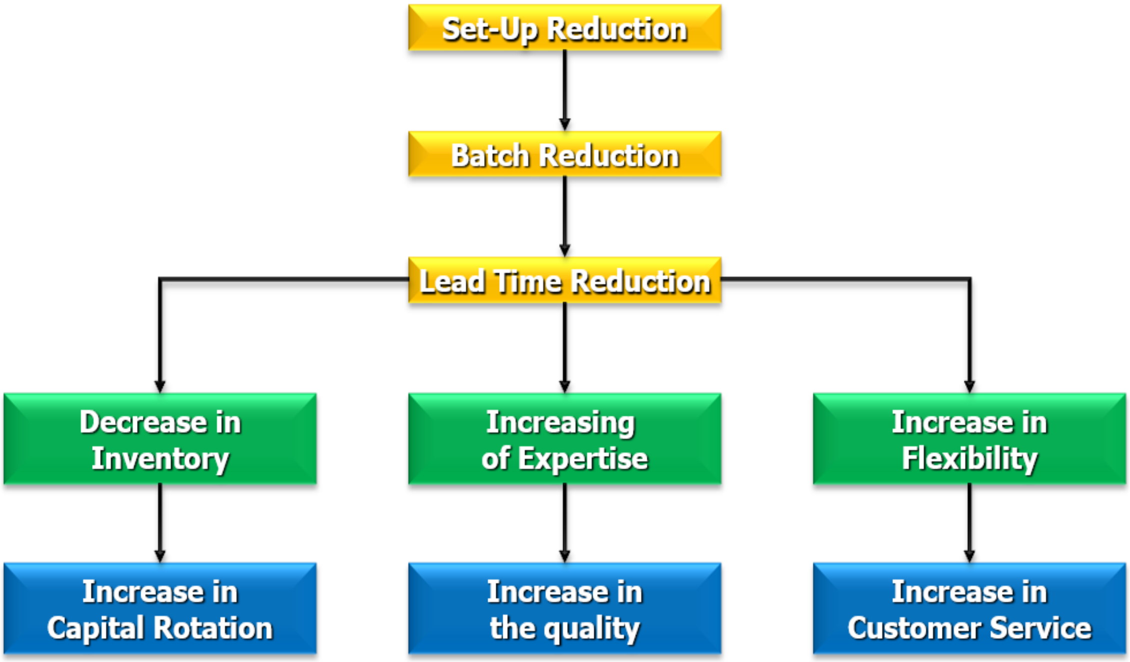

Figure 15 - Benefits of SMED (source: Considi Srl)

The Method

Set-up time is that time between the last good piece of the previous batch and the first good piece of the next production batch (for 'good' piece it is intended an item that meets the characteristics dictated by the customer). It is important to pay attention to this last definition because even if the first item has no defects, but the following ones have, that SMED cannot be

Figure 16 - Set-up time (source: Considi Srl)

said to have been successful. That first item cannot be anymore considered a good item, and so set-up time becomes longer because adjustments have to be done in order to achieve conformity.

SMED method requires to (necessary in order):

- Standardize all the activities (bring under control the procedure);
- Shorten time of doing the activities.

Be standardized means creating a repeatable and dependable process. If the changeover lasts on average five hours, it should be accomplished by both an experienced workman and by a newcomer in always the same amount of time.

SMED applications are widely distributed across industries such as paper products, foods, beverages, personal care items, fiber, rather than assembled products such as refrigerators, cell phones or automobiles (Ulutas, 2011).

Its application aims to optimize machine utilization, enabling small batch sizes, reducing production times, reducing the time that machine does not operate. Moreover, it is addressed to shorten preparation and machine adjustment times and to reduce stocks.

There are two main reasons to be taken into consideration when a company decides to improve a changeover:

1) it has to be representative, that is when the majority of parts of the machine are handled;

2) it has to be done on medium-high frequency.

Set-up procedure comprises a sequence of steps that are illustrated below and in the following paragraphs they will be explained in detail.

The presence of arrows is fundamental because they indicate that SMED process never stops but when it gets to the end, it should start again from Step 1 in order to continuously improve.

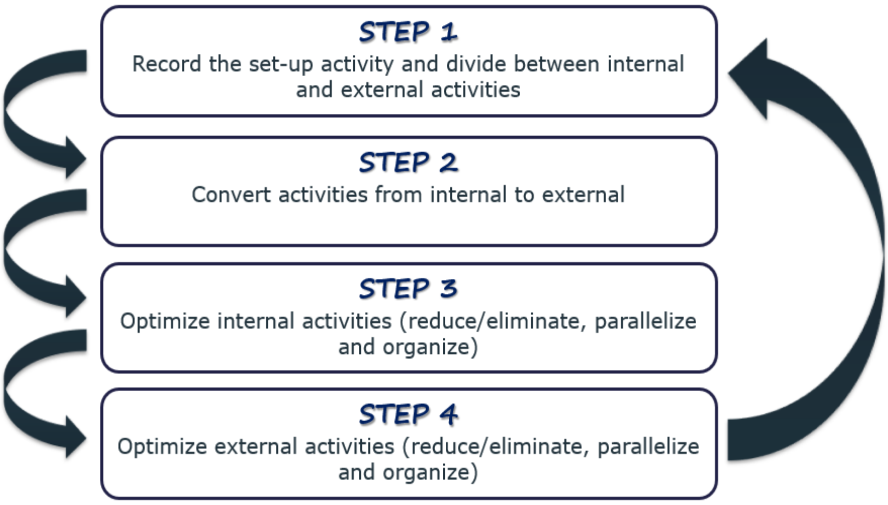

Figure 17 - The four steps of SMED (source: Considi Srl)

First Step: recording set-up and distinguishing between internal and external activities

The set-up analysis consists of two main phases:

- observation and detection of the set-up
- analysis of the set-up in detail

This phase is usually performed by a work group which facilitates the subsequent analysis by recording the changeover with a video camera. The operator(s) who made the change, should also participate in the video analysis. In this way, in fact, they will be able to comment on all the operations they were carrying out and highlight any problems encountered. It is important to study the video in detail, take notes of the time taken and the movements made for each set-up activity.

The most important thing to effectively implement SMED is to distinguish between internal and external set-up times. Very often, there is no clear distinction between internal and external activities. These two groups of activities are mixed together and there are jobs that are done internally even if they could be done externally. There are typical problems that emerge from a careful analysis of the activities: for example, the change of production materials is made while the machine is stopped (in other words internal set-up); the equipment (blades, molds, inserts, etc.) is brought close to the machine in internal time; all the necessary tools are far from the machine to be equipped; it turns out during the set-up that the equipment is broken or not suitable; the equipment is not checked and after the production starts, it is realized that the produced items are not good and must be replaced, with the production of waste (Busatto, Iannella, Tanaka, 2001).

Usually, by converting some internal operations into external (that is, performing while the machine is still running, such as preparation and transport), it is possible to reduce the internal set-up time from 30% to 50%.

Many instruments are used in order to implement this phase:

- The **Set-Up Registration Form** is a data collection document used to record the activities performed during a changeover. It contains at least the following information:
    - ✓ Activity progressive number
    - ✓ Activity description
    - ✓ Activity start time
    - ✓ Duration

✓ Internal/external classification

Data:____________________ Rilevatore:____________________

Macchina:____________________ Pag:__________

Nr.	Inizio attività [mm:ss]	Operazione	Durata [s]	Durata att. Int. [s]	Durata att. Est. [s]	Note / Idee di miglioramento
		TEMPO TOTALE DI QUESTA PAGINA				
		TEMPO TOTALE COMPLESSIVO				

Figure 18 - Paper format of a Set-up Registration Form (source: Considi Srl)

Companies generally make use of a software called '*Timer Pro Professional'*, a video-based measurement solution which helps in doing all these activities in an efficient way (for example it calculates automatically the duration of each activity, it gives a progressive number to each operation etc.);

- The **Spaghetti Chart** is the tool to track all the movements made by the operators assigned to do the set-up and determine the actual distance travelled during the changeover. This tool allows to get numerous suggestions for improvement because it is visual and shows in an evident way the presence of problems.
  It can be used both to understand the relative position of cabinets, tools, equipment, small parts, etc. in relation to the set-up activities and to determine the movements of the personnel involved during the individual set-up activity;

Figure 19 - An example of Spaghetti Chart before and after a SMED implementation (source: Considi Srl)

- The **Set-Up Timeline** is composed by the "before set-up timeline" and the "after set-up timeline". The former is used to graphically highlight all the activities performed during the set-up. The timeline will indicate which are the most extensive activities and aims to reduce those activities with greater influence on the overall time of the intervention

(Pareto Analysis). The latter is completed after the SMED implementation and includes the implementation of the improvements.

From the comparison of the "Before Set-up Timeline" and the "After Set-up Timeline" the improvements made are visually highlighted.

Second Step: converting activities from internal to external

The objective of this phase is to attempt to convert the greatest number of internal operations into external. It certainly represents the most technically difficult and demanding part.

Three practical techniques (Bianchi F., Bianchi M., 2012) help transforming internal set-up activities into external ones. They are:

- early preparation of operating conditions
- standardization of fundamental functions
- use of intermediate systems

Preparation of Operating Conditions

Preparing the operating conditions in advance means providing the necessary materials, tools and conditions before the internal set-up begins. Often it is possible to predispose conditions externally such as the temperature, the pressure or the positioning of the materials, while the machine is still working. An example concerns the supply of cable to heavy coils. To bring new coils to the machine, a forklift is needed but often it is not always available. To avoid delays in restarting the machine it is possible to build a temporary storage equipment that is loaded with a new coil while the machine is still running. Once the end of the reel is reached, the operator only has to push the new one into the right position and continue with the machining. Another example of early preparation consists of pre-heating parts of the machine or of the material to bring them to the temperature required for processing. For this type of activity, some companies exploit the heat generated by other machinery.

Standardization of Fundamental Functions

When the instruments and the machine parts used in a new process are different from those used in the previous one, the operators find themselves forced to carry out a series of procedural adjustments (during the changeover) that take a long time, often with stopped machines.

The implementation of functional standardization is based on two steps:

1. the detailed analysis of each single function used in the set-up process to decide whether and what functions to standardize;

2. control of the functions to understand which of them could be carried out more efficiently by changing the fewest possible parts.

The use of checklists and the definition of standard procedures for the execution of the set-up allows the effective separation of internal and external activities and the maintenance of the ideal situation over time.

Use of Intermediate Systems

In many cases it is possible to use intermediate fixing systems to bring a greater portion of the set-up time from internal to external. Intermediate fixing systems are tables or masks of standard dimensions that can be easily removed and put into the machine while it is still working. While the mold attached to one of the fixing systems is in use inside the machine, it is possible to prepare a new mold on another system. With this technical solution, the operation becomes external.

In Considi Srl, an instrument often proposed during this stage, is the set-up mapping, whose purpose is to provide a visual and detailed description of all events and activities completed during set-up in order to reduce it.

They use three different Post-It®, each of which represents a particular element on the map:

- **Event** (big Post-It®)

  They prepare a Post-It® for each event of the 'set-up registration form' and place it on the Map of the set-up process in chronological order;

- **Activity** (medium Post-It®)

  They insert the Post-It® of the activities performed under each event in the corresponding order;

- **Event duration** (small Post-It®)

  They prepare a Post-It® for the duration of each event and place it on the map of the set-up process.

Figure 20 - Set-Up mapping (source: Considi Srl)

Third Step: optimizing internal activities

Once the conversion has been realized, it is necessary to focus on internal operations to understand if there are abnormal activities to be eliminated/reduced.

In other words, it is fundamental to analyse once again the operations performed with the method promoted in Step 2 and to evaluate if further improvements can be made.

To streamline the internal time, it is necessary to work on movements and specifically they have to be simplified, reduced and eliminated if possible.

This stage is composed by two main sub-steps:

- Parallelization of internal activities

  Often workers in the changeover phase, make numerous trips around the machine which lengthen the overall set-up time. If this was made having two available workers (instead of one) who split activities, it would presumably take half of the time. In most cases, however, there is reluctance to adopt this method as no reserve operators are available (in reality there is empirical evidence that it is more convenient to carry out the set-up with two operators instead of one just because the hourly cost of the operator is much lower than the hourly cost of the machine. Even if the total number of set-up hours does not change, by adding one more operator/station, the productive work time of the machine can extend;

- Reduction of the duration of internal activities belonging to the critical path

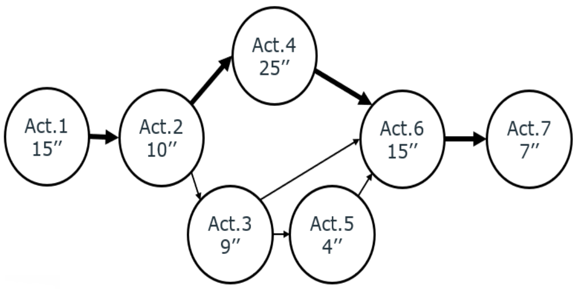

Figure 21 - Example of Critical Path Method (source: Considi Srl)

First, it is necessary to define what critical path is. The *Critical Path Method* (CPM) is a reticular technique of representation of a procedure which highlights the interconnections existing between the various activities. The determination of the duration makes it possible to identify the "critical path", that is the longest path that unites the initial activity to the final one.

To reduce internal set-up time, it will be necessary to reduce/eliminate hand tools, nuts, bolts, hexagonal bolts and replace them with devices that mount/dismount quickly:

  - One-motion fixing system: allows to lock an object with a single action;
  - U-shaped washer method: using a bolt with a diameter smaller than the one belonging to the piece to be clamped, the piece can be extracted very quickly by loosening the nut with only one turn;

- Pear-shaped hole method: once the nut is loosened (with only one turn), the piece can be rotated and detached without the need to completely remove the nut and bolt.

Moreover, within this phase, it is essential to reduce the necessary adjustments during set-ups since experimentally adjustments and tests cover 50% of the overall set-up time. Their elimination therefore allows a considerable increase in performance and a considerable saving of time. The ideal goal of SMED would be to eliminate, and not simply reduce, the need to resort to adjustments (quick changeover for operators). Generally, these adjustments are unavoidable due to dimensioning errors, centring or, in any case, inadequacies in the internal set-up. Therefore, their removal must begin upstream, with a review of the internal set-up process. A crucial point concerns the complete elimination of activities based on the intuition or experience of the operators since they may lack of precision if not following a standardized procedure.

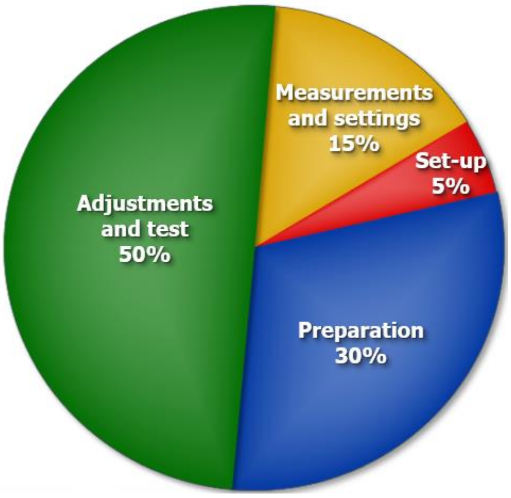

Figure 22 - Composition on average of set-up time (source: Considi Srl)

Fourth Step: optimizing external activities

The basic concept of this last stage is pretty similar to the third one since the activity to be done is the same and what is changing is the subject. Now the aim is to streamline external activities. To reduce external set-up, the same activities explained before can be used. It is always useful to draft the optimal sequence to parallelize external activities and calculate the target downtime in the critical path.

To optimize the external activities, it may be necessary to:

- ✓ prepare check-lists of the equipment and activities to be performed, to support the operator;
- ✓ optimize the layout and organization of the necessary equipment.

SMED as primary source of OEE improvement

OEE (Overall Equipment Effectiveness) is a commonly used indicator for measuring manufacturing productivity. It identifies the percentage of manufacturing time that is truly productive. An OEE score of 100% means that the company is manufacturing only good parts, as fast as possible, with no stop time. In the language of OEE that means 100% **Quality** (only good parts), 100% **Performance** (reaching target speed), and 100% **Availability** (no stop time).

Confusion exists as to whether OEE indeed measures effectiveness or whether it is an efficiency measure. In the literature, effectiveness is defined as a process characteristic that indicates the degree to which the process output conforms to the requirements. Efficiency, on the other hand, is defined as a process characteristic indicating the degree to which the process produces the required output at minimum resource cost (US Department of Energy, 1995).

The three measures captured by the OEE indicates the degree of conformation to output requirements (Muchiri, Pintelon, 2008). Therefore, the OEE index is a measure of effectiveness and not efficiency.

The OEE index is designed to identify losses that reduce the equipment effectiveness. These losses are activities that absorb resources but create no value. The losses that this indicator takes into account are six and explained below (Muchiri, Pintelon, 2008):

1. Downtime losses:
    a. Breakdown losses are categorized as time losses and quantity losses caused by equipment failure or breakdown. For example, a breakdown of palletizing plant motor in a brewery leads to downtime and thus production loss;
    b. Set-up and adjustment losses occur when production is changing over from requirement of one item to another. In a brewery plant, this type of loss is encountered during set-ups between different products, testing during start-ups, and fine tuning of machines and instruments.
2. Speed losses:
    a. Idling and minor stoppage losses occur when production is interrupted by temporary malfunction or when a machine is idling. For example, dirty photocells on palletizing machines cause minor stoppages. Though they are quickly fixed, much capacity is lost due to their frequency;
    b. Reduced speed losses refer to the difference between equipment design speed and actual operating speed. In a palletizing plant, the use of unadopted pallets leads to longer processing times for the same number of bottles leading to speed losses.

3. Quality losses:
    a. Quality defects and rework are losses in quality caused by malfunctioning production equipment. For example, some pallet types get stuck in between palletizer and unpacker and are damage;
    b. Reduced yield during start-up are yield losses that occur from machine start-up to stabilization. For example, in the brewery, poor preparation for morning shift by night shift leads to problems with the filling taps and thus leads to reduced yields.

The six large losses are measured by OEE, which is a function of availability (A), performance (P) and quality rate (Q). Therefore:

$$\text{OEE} = \text{A x P x Q}$$

where:

$$\text{Availability rate (A)} = \frac{Operating\ Time\ (h)}{Loading\ Time\ (h)} \times 100$$

$$\text{Performance rate (P)} = \frac{Net\ Operating\ Time\ (h)}{Operating\ Time\ (h)} \times 100$$

$$\text{Quality rate (Q)} = \frac{Valuable\ Operating\ Time\ (h)}{Net\ Operating\ time\ (h)} \times 100$$

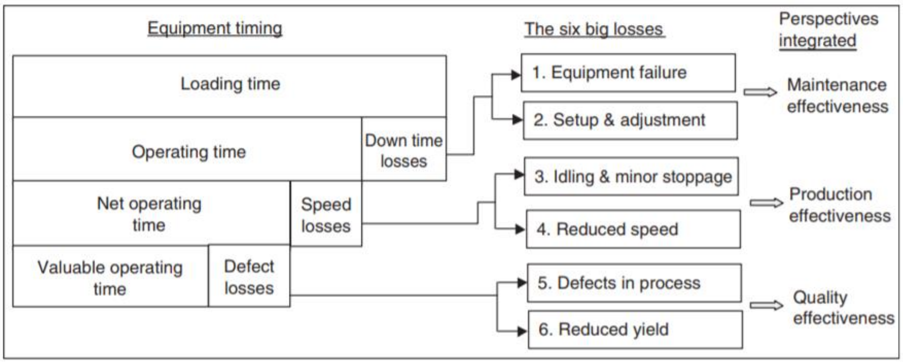

Figure 23 - OEE measurement tool and the perspectives of performance integrated in the tool (source: Muchiri, Pintelon, 2008)

In this work one of the main aim is to measure the percentage increase of the OEE when the SMED method is performed on a machine. There are two ways to economically quantify the increase of OEE by one percentage point[7]:

- **Market response**: if the market is in equilibrium (the productive potential of companies is equal to the absorption capacity of the market itself), 1% more can in total be attributed to an increase in revenues. Therefore, it is necessary to calculate the revenues that have been reached with 1% more of OEE;
- **Capacity response**: in case of a saturated market (it occurs when the productive potential of the companies exceeds the capacity of absorption of the market itself.

[7] Source: Considi Srl

Competition is high and it is not guaranteed that the company will be able to place all its products on the market) it is better to look at internal efficiency. With one percentage point more of OEE, the company is more efficient with equal output as it reaches the same output in less time. Therefore, the costs saved must be calculated.

Batch size

Within the borders of an organization, there are some reasons to avoid inventory that are illustrated in the table below.

COST	SPACE
It ties up working capital and there are high administrative and insurance costs	It occupies physical space
QUALITY	**OPERATIONAL/ ORGANIZATIONAL**
It may deteriorate products overtime and become obsolete or damaged	It may hide problems. For example, inventory conceals defective products when it is huge and bad items could be confused with good ones

Table 5 - Reasons to avoid inventory (source: Furlan, 2019 Advanced Operations Management course, University of Padua)

Storage is defined as any product that a company keeps in stock for future use. According to its nature, different types of stock can be distinguished:

- raw materials;
- semi-finished products;
- in-progress materials;
- finished products.

Alternatively, inventory can be classified by function[8]:

- Cycle stock: buffer stocks to connect the intermittent supply of different goods;
- Safety stock (buffer): to deal with fluctuating and unpredictable demand or supply;
- De-coupling inventory: used to separate two activities within an operation which in general have different speed or capacity;
- Anticipation inventory: safety stock to deal with fluctuating but predictable demand or supply (for example, seasonal demand products required during high demand periods);
- Pipeline stock: products are in transit from allocation and availability, so an inventory is needed from the moment of selling, to the availability to customer.

[8] Furlan, A. (2019). Course's slides of "Advanced Operations Management", University of Padua

As it was explained in the first chapter, inventory represents a complete waste which has a cost and destroys value. The five principles explain how companies could completely abandon the idea of having a warehouse because lean pillars enable companies to not need it anymore. However, it seems that companies prefer to have it as a sort of protection from an uncertain future. Here are just a few reasons why to hold inventory:

- It manages the different realization times of different production phases;
- In distribution it serves to meet fluctuating customer demand;
- It absorbs seasonal fluctuation;
- It can be speculative, in anticipation of a shortage of the product on the market, or of a price increase;
- It protects against unexpected demand peaks.

At this point, an important thing to be decided is the *Economic Batch Quantity* (EBQ). The EBQ is the order size of a production batch that minimizes the total cost. Batch production is a technique which is commonly used today for distributing the total production in a series of small batches rather than mass producing in one go. Sometimes the production of goods in batches are necessary because, for example, certain equipment used in manufacturing (e.g. dyes) may wear out and need replacement (set-up) before the production can run again.

Batch production may be desirable in other cases as well for example in the context of about a year and the objects being produced are perishable. The entire production requirement can’t be manufactured in a week as it might case the goods to expire after some time.

Batch production also reduces the risk of obsolescence as any minor changes required in the specification of goods (e.g. size, colour, etc.) can be made in future batches. This can be done according to the feedback received from customers or retailers instead of producing everything in one go and hoping for the best[9].

Whereas EOQ is suitable for determining the order size when the parts, materials or finished goods are ready to be delivered by external suppliers when the order is placed, EBQ is used to determine the size of a production run (i.e. batch size) when the manufacturing takes place internally and any raw materials or parts required for production are acquired internally.

[9] Source: https://accounting-simplified.com

The EBQ formula is:

$$EBQ = \sqrt[2]{\frac{2 \times D \times Cs}{Ch\,(1 - \frac{demand\ rate}{production\ rate})}}$$

Where:

Cs is the set-up cost of a batch

D is the annual demand

Ch is the annual cost of holding one unit of finished inventory

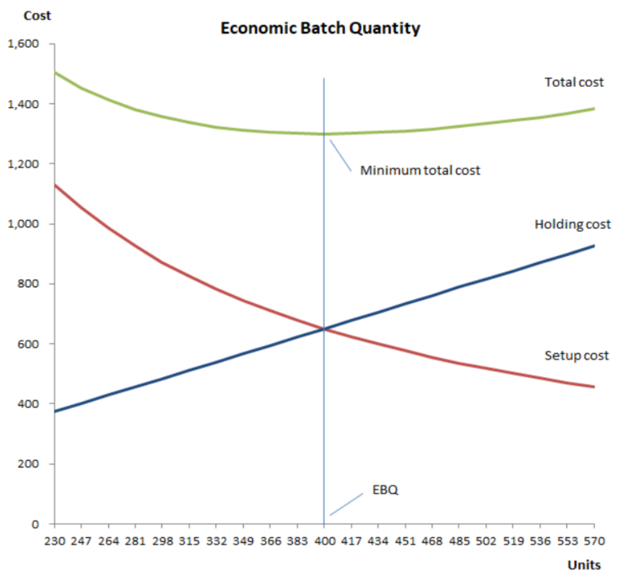

Figure 24 - EBQ (source: www.double-entry-bookkeeping.com)

Looking at the graph, specifically the two cost functions, it is possible to see that the holding cost curve (in blue) is directly proportional to the quantity produced. This means that the greater the batch size, the more the cost of having stock increases. Vice versa the curve of set-up cost (in red) is inversely proportional to Q. This means that the more it is produced in batch, the more the cost of set-up decreases. As the batch size (EBQ) increases, the total set-up cost decreases because the cost is spread over a larger number of units. To calculate the optimal quantity, it is necessary to find the minimum point of the total costs curve, which also corresponds to the intersection of the two cost curves, as indicated on the graph.

As one of the goals of this work is to see the effects of SMED in production, it is now assumed that the implementation of the SMED method, has reduced set-up time and cost by a certain amount. The goal is to extract the effects of the set-up reduction on the optimal batch size. To do that, it is appropriate to report the variation on the same previous graph.

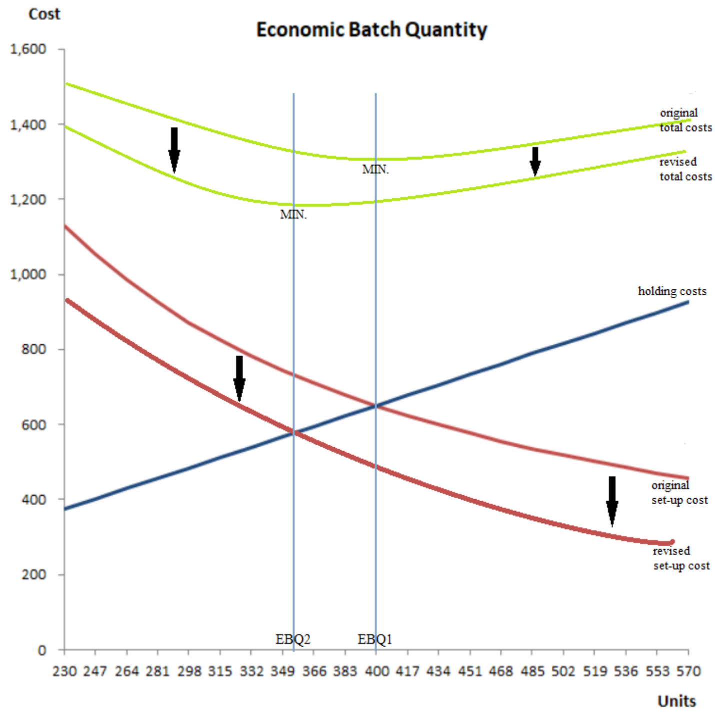

Figure 25 - EBQ variation due to a decrease in set-up cost

As shown on the graph on the left, an implementation of the SMED methodology, aimed at reducing the changeover time, drives the set-up curve down. This leads to a reduction of the batch quantity size (the intersection between the two cost curves) as now performing a changeover is cheaper. Reducing the set-up time in fact, reduces the economic advantage of producing large batches.

Since a reduction on the batch quantity is suggested, the company can allow itself to produce a smaller sum and do rather more changeovers in the same amount of time (*heijunka* concept). The application of SMED, as well as improves the main unproductive phase of a process, works to create a flexible production system which is able to automatically produce a mix of different products and whose work cycle is adaptable and expandable to fluctuations.

To operate the JIT manufacturing system optimally, it is necessary to optimize the activities of both raw materials purchasing and production lot sizing simultaneously, taking all the operating parameters into consideration. A larger manufacturing batch size reduces the set-up cost component to the overall unit product cost. The products produced in one batch (one manufacturing cycle) are delivered to the retailer in *m* small lots at *x* time intervals. So, the inventory forms a saw tooth pattern during the production uptime and a staircase pattern during production downtime in each manufacturing cycle. Likewise, the manufacturer receives *n* small lots of raw material, at regular intervals, during the production uptime of each manufacturing cycle. The raw materials are consumed at a given rate during the production uptime only. It is assumed that the production rate is greater than the demand rate. So, the accumulated inventory during production uptime is used for making delivery during production downtime until the inventory is exhausted. Production is then resumed and the cycle repeated (Khan, Sarker, 2002).

Chapter 3 – The Company

The group

The group hGears was established in 2015 after the acquisition of two production sites: miniGears in Padova, Italy and Herzog in Schramberg, Germany by Finatem.

Born in 2000, Finatem is an independent partner-managed private equity firm based in Frankfurt who invests in majority buy-outs of companies with business activities and/or know-how in German-speaking Europe.

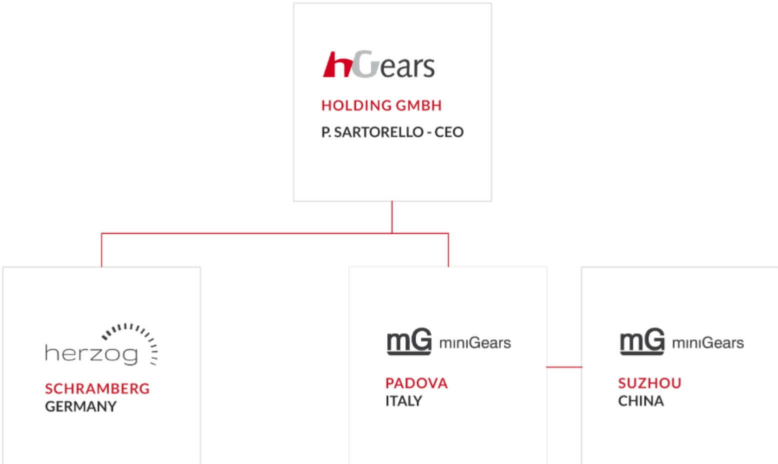

Figure 26 - hGears's group structure (source: https://hgears.com)

Herzog GmbH and miniGears SpA have been joined together in order to create a global leader in the production of gears and components. hGears Holding GmbH manufactures parts such as precision turnings, drive system elements and transmission components as well as complex system solutions on a contract basis for customers in a wide variety of sectors ranging from power tools to cycles. Since its foundation in 1958, Herzog has been one of the leading manufacturers of precision turned parts, gear kits and complex systems solutions. With its working area of 15,400 sqm and 350 employees, Herzog's capabilities range from soft machining, such as multi-spindle turning, in-house heat treatments and hard machining continuing up to the final assembly. It was acquired by the private equity firm in 2011.

Padova's site, miniGears, was established some years later, in 1976. With a headcount of 560 (Padova + Suzhou), it is one of very few companies worldwide to combine traditional Steel Machining with Powder Metal technologies and over

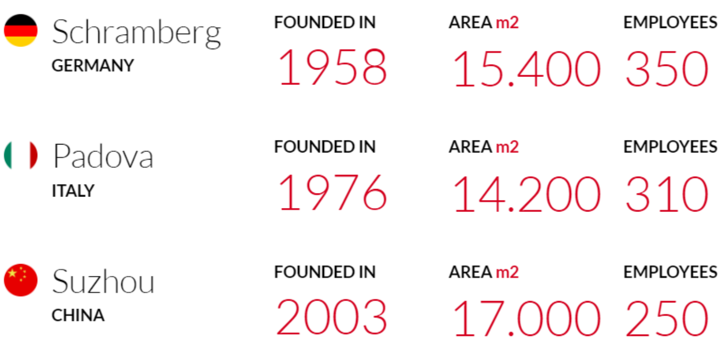

Figure 27 - Three manufacturing sites belong to hGears group (source: https://hgears.com)

the years has achieved a remarkable position in the manufacturing of gears and components. Gear geometry and top-quality powder in regards to the innovation in machining and the constant monitoring of every production stage have always been the drivers of miniGears' performance. In 2003, it decided to open a new plant in Suzhou (China) to respond to the expected market growth in the e-mobility market. In 2014, Padova's plant was acquired by Finatem.
In 2015, the decision to merge was made. The aim was to create a leading European supplier, in the sector of technology for the production of gears and transmission components in small and medium sizes.
The merger was not easy as three countries in two different continents were involved. In addition to the merger, a new brand identity was needed in the worldwide market. As well, they were in need of support to the realignment for the employees located in Italy, Germany and China. Therefore, the transition process needed to be supported with a set of actions and events that involved: employees, clients, prospects, financial institutions, press and suppliers. Through these processes, a new corporation was born, whose primary aim was a rebranding of the group. The first evaluation after the acquisition revealed that market and competitors considered the company to have a unique identity, different from all other global players. The creation of a new identity was focused on enhancing the quality of engineering by combining two basic concepts; the Italian passion and the German precision.

Today the hGears is a world-renowned group that is leveraging on its manufacturing and sales footprint to support customers' challenges on a global level.
The group's turnover in 2018 was 125 million, of which 3% was invested in R&D and 7% was spent in capex investments. The number of employees amounts to about a thousand in the three plants and every year 15,000 hours are spent in training.
hGears' vision comprises of:

- Being one of the top 8 independent companies worldwide in the field of high precision components;
- Partnering with customers on a global level;
- Sustaining profitable growth through superior engineering, quality, customer service and people.

Group's mission instead is characterized by:

- Supporting customers in achieving the highest product performance through best-in-class gearing solutions;
- Combining different technologies to nurture distinctive know how;

- Building competitive advantage through its people.

Core Values

hGears core values guide the company and its employees personally and professionally. In this fast-changing world, core values must be solid. hGears's core values are visible in the practices implemented every day. They are:

- **Customer First**

  The success of its customers determines the success and the stability of the group's future. Customer satisfaction is the precursor of every action;
- **Integrity**

  Actions are transparent, consistent, honest and reliable;
- **Accountability**

  The group is recognized for "we can do" attitude and takes responsibility for results;
- **Innovation**

  It proactively responds to the changing needs of its customers and other stakeholders. Every change represents an opportunity to learn and improve.
- **Team Spirit**

  The success of each of the members depends on the success of the team. It is a fundamental skill to appreciate other individuals' competence while respecting their own cultural identities.

Product Lines

Achieving quality is a cultural mindset to HGears. This is an objective to be pursued from the very first concept of the component in co-engineering with its customers to project management. The same idea applies from the production processes to assembly and functional tests. Reaching the desired quality leads to an increase of value of the work and products.

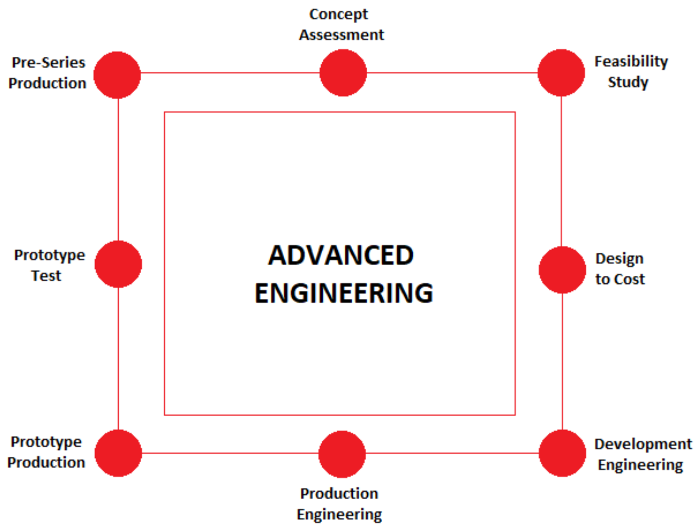

Figure 28 - Product development process (source: https://hgears.com)

R&D teams, in particular, are employed to constantly pursue innovation in materials and production processes. They perform functional tests to evaluate strength and efficiency of sintered as well as machined gears and components. Thanks to the latest technologies, engineers can design new products based on research and tests, meeting the specific requirements of each individual application. Engineering teams work in close connection with customers to develop the right components specifically designed for the required application and to develop the most cost-effective manufacturing solutions. Product development is managed through all its process steps. From concept to design and from manufacturing of prototypes to serial production, hGears's aim is to support its customers in building their success.
Hence the group invests a lot in technology and people's training to provide its customers with high quality products and innovative solutions.

New Mobility

Profound demographic and cultural pressures are dramatically reshaping mobility. The industry supporting human mobility today will undergo a true revolution in the next few years. The current and future requirements of urban mobility results in the need to develop and produce mechanical transmissions and components from a completely new standpoint.
Having excellent quality, being lightweight, and emitting zero noise and vibrations have become absolute prerequisites to serve this industry. There are several factors that make hGears the right partner to play a role in this rapidly growing market. They have consolidated the experience of the production of gears in various fields. This is then combined with the ability to manage the high-quality standards and the typical automotive production volumes. This represents one of the most interesting business opportunities in the coming years.

Power Tools

Power Tools is the original hGears market. Based on a long history of excellence, hGears today enjoys a reputation as a leader in this area, which continues to represent one of the strategic markets for the future. hGears is competent in spiral bevel gears, along with the unique ability to combine the sintering and the steel machining technology within the same applications. This enables hGears' customers to develop best-in-class solutions while at the same time relying on a single partner. The support that hGears offers to its customers starts from the design by calculating and developing either single gears or entire kinematic mechanisms. Choosing the most cost-effective technology for manufacturing and testing prototypes happens before proceeding with mass production.

Automotive

The automotive market requires the highest technical and manufacturing competence applied to top quality products in terms of design and functionality.

Major Italian car brands have chosen hGears to develop high-precision gears and components for a wide range of high-performance and innovative applications. Pressure and fluid control system components, cam phase devices, timing gears and stabilizers control system components represent the main part of hGears portfolio in this segment.

Outdoor Products

The competence of hGears in this market is widely recognized. hGears has achieved worldwide market leadership with the development and supply of complete gearboxes for a variety of outdoor tools. This is the result of the company's distinctive knowledge which integrates the traditional technology of machining with the more innovative technology of sintering in a complete drive unit.

The support that hGears offers to its customers starts from the design by calculating and developing either single gears or entire kinematic mechanisms. The choice of the most cost-effective technology for manufacturing and testing prototypes follow before proceeding with mass production.

Motorbike

hGears tradition and leadership in the motorcycle market is strong and firm. Each machined steel cylindrical gear assembled unit and component is designed and developed by engineers to specifically meet the required performance.

Customers' desires in the motorbike application are:

- More power
- Noise reduction
- Efficiency / Lower consumption
- Longer gear life

Industrial

In addition to having the leading role in traditional markets, like the textile and material handling, hGears has proven to be capable in addressing the distinctive requirements of a variety of industrial applications. This includes: actuating components for HVAC, rolling shutters, swinging doors, hydro-cleaning and medical equipment. hGears can support its customers in many different applications such as providing loose gear or components, as well as complete assembled gear units.

miniGears S.p.A.

Founded in 1976, with a staff of 290 people, miniGears S.p.A. is a leader in the development and production of gears, precision components and transmissions for the automotive sector. The automotive industry requires the most advanced technical skills, applied to high quality products in terms of design and functionality. Thanks to its innovative technologies and efficient systems, miniGears is able to supply excellent products that satisfy the specific requirements of various customers. It is also one of the few companies able to combine the traditional technology of bar or pressed steel processing with that of sintered powders.

Acquisition in China

At the end of the 1990s, miniGears' main customers, from Black & Decker to Bosch, started moving their Italian factories to China. In 1999, Minigears SpA therefore decided to establish a Shanghai trading company, in order to start setting up a stable presence in China and gather information on the local market. In 2001 the company under consideration embarked on the path of purchases' internationalization. This was until in 2004, Minigears Suzhou Co., Ltd. was established (Perrini, Piccinali, 2011). It reached a turnover of over 12 million euros in 2008, resulting from the production and marketing of its products on the spot. If the Italian parent company had not complied with that fundamental step towards China, shares of turnover would have been lost in favour of competitors geographically closer.

After some years, Suzhou realized it was necessary to extend its dimensions to deal with the upcoming market challenges and to become a relevant player in the e-Mobility market. Which is one of the most interesting markets in China in the foreseeable future.

On March 9th 2017, the agreement for the new miniGears Suzhou plant, was finalized. The signing was between Pierluca Sartorello (CEO) and Patrick Heimpold (CFO) of the hGears Group and Zhang Jingen, legal representative of SIP Jinsheng Packaging Co., Ltd.

The new plant is located at 9 Yangpu Road in Suzhou, not far from the previous one. The new location though, has a much wider surface area of 17,000 sqm, as compared to the 12,000 sqm of the previous site.

More space was needed in order to cope with the company's upcoming development plans. In particular, those related to the e-mobility market.

The new plant's chosen location is the result of intense research and it represents the outcome of very precise guidelines. First, it was necessary to retain the competence and expertise of employees and managers, as it developed over 12 years of hGears' presence in China. hGears acknowledges this value and intends to continue investing in its people.

Moreover, a new site became necessary in order to redesign the layout from scratch, under a modern lean manufacturing optic to cope with increasing market challenges. All these elements together, with its unique range of high-precision technologies, place hGears in an ideal position to seize the upcoming e-mobility market opportunities.

For the new site, whose inauguration was held in May 2017, hGears group planned investments in excess of 3 million €.

Financials

Income statements and balance sheets available on Aida dataset correspond to the financial years 2014, 2015, 2016 and 2017. At time of writing, 2018 financial statements are not available yet. From a general analysis, it is possible to infer that 2017 was a financial year less profitable compared to 2016. In specific, a strong growth can be attributed to 2015 and then it has flattened in the following years. In four years revenues grew by 63%, even if the enormous growth can be attributed only to 2015. In the income statement 2017, many values decreased. From 2016 to 2017, EBITDA fell to 15.9%. Although in the other years taken into consideration, the trend has always been growing. The same applies to the net profit of the year (3.330.000 in 2017), where the variation between 2016 and 2017 was negative (-42.2%). However, if net profit of 2017 is compared with the net profit of 2014, growth is strongly positive and corresponds to + 250%.

Net financial position fell in 2017, recording a decrease of -73.8% from 2016.

Furthermore, for all the profitability indicators, the year 2017 was worse than the previous one as the graph below shows. ROE (25.46% in 2016) fell to 15.12%; while ROA remained almost

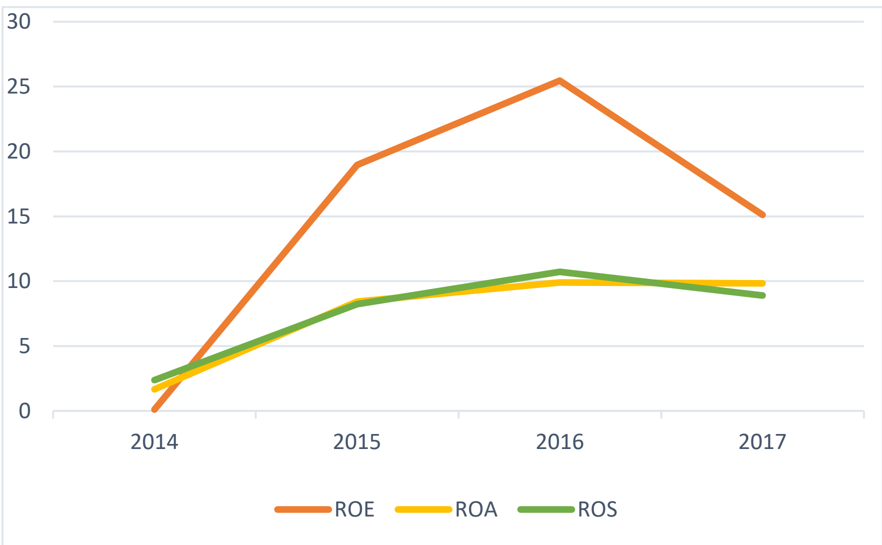

Figure 29 - Performance of main profitability indicators

unchanged (9.82%). Sales profitability (ROS) fell in turn from 10.72% in 2016, to 8.89% in 2017[10].

Year	2014	2015	2016	2017
Revenues	32.056.667	46.471.000	46.492.000	46.474.000
Ebitda	2.738.273	7.214.000	8.698.000	7.315.000
Net Income	13.240	3.207.000	5.764.000	3.330.000
Total Assets	41.322.951	45.224.000	50.484.000	42.154.000
Net Financial Position	-48.410	4.736.000	3.235.000	847.000
Equity	13.509.923	16.923.000	22.640.000	22.031.000
EBITDA/Sales (%)	9,42	15,56	18,65	15,7
ROE (%)	0,1	18,95	25,46	15,12
ROA (%)	1,66	8,42	9,9	9,82
ROS (%)	2,37	8,22	10,72	8,89
Debt/Equity ratio	0,02	0,47	0,15	0,07
Debt/EBITDA ratio	0,11	1,11	0,4	0,2
Employees	138	276	272	263

Table 6 - miniGears' financial data (source: Aida dataset)

Even if miniGears had slowed down in 2017, what emerges is an overall positive growth trend for the company since starting in 2014. Since its acquisition by Finatem in the same year, miniGears became part of a larger project. When the Herzog and Padova plants merged, numerous contacts were established between them and foundations were laid for the first joint projects. The managing directors of Herzog GmbH, Frank Bader and Kurt Gieseler, declared that they would have expected an even closer collaboration.

Gieseler was equally convinced of the opportunities for this new market protagonist stating, "The integration of two solid companies provides us with a new financial perimeter that will allow us to develop and expand our three production sites"[11].

miniGears grew a lot in these last years, thanks to the expansion in new markets in a more coherent and effective way and at the same time because it invested in new technologies. The Chinese plant in turn, helped to enjoy a strategic position in the growing markets of Southeast Asia. All these factors made miniGears grow broadly, as well as its number of employees which nearly doubled in four years from 138 in 2014 to 263 in 2017.

With this operation, Finatem was confirmed as a solid partner for the growth and development of medium-sized companies.

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[10] Aida database

[11] Herzog e MG MiniGears si fondono in un unico gruppo. *L'Ammonitore web* [online]. Available at: http://www.ammonitoreweb.it/herzog-e-mg-minigears-si-fondono-in-un-unico-gruppo/

Chapter 4 – SMED Analysis

This chapter presents a detailed analysis of a SMED carried out on the 050A hobbing machine of the miniGears production plant in Padova.

Hobbing is a machining process for cutting, cutting splines, and sprockets with a special type of milling machine. The teeth of the gear are progressively cut into the material (a flat, cylindrical piece of metal). The company has highly automated gear cutting machines which are integrated with a robot, whose gripper inserts the smooth piece into the gear hob and simultaneously recovers the previous piece already toothed. It is then accompanied to the chamfering, it is washed and placed on a tray, inserting it precisely into a pin. The product passes through 7 processing phases, all carried out within the miniGears production plant. They are:

1) hobbing (subject to the SMED analysis)
2) heat treatment
3) sandblasting
4) bore turning
5) teeth grinding
6) washing
7) laser marking + packaging

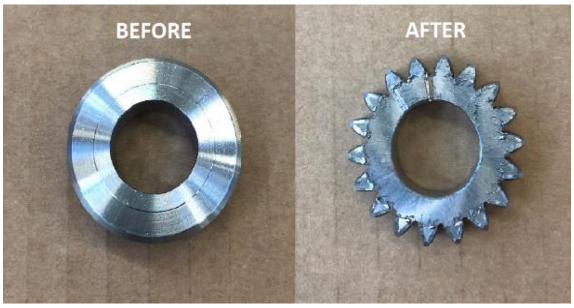


Figure 30 - The piece before and after processing into the hobbing machine (source: miniGears SpA)

In the image the piece before and after is shown after it is processed into the machine. miniGears owns two identical hobbing machines (050A and 050B), which produce the same codes. When the operator is doing a set-up in one of the two machines, the other one must be working and producing components. The operator is responsible for both the machines. Changeovers are the same for both hobbing machines and concern changes between different part numbers which are: 5780, 5781, 5782, 5785, 5786, 5790. It is important to identify the change that involves the greatest number of parts and equipment and then be able to apply the SMED improvements to all other changes without having to repeat the analysis. The instrument used is the from-to matrix and it will be illustrated in the next chapter.

It is important to conduct the analysis with the operators who know the machine, the procedures and the plant. They are therefore able to highlight all the problems during the course of the changeover and can contribute to improving it by providing adequate solutions.

Moreover, it is very important to involve the operators in all phases of the SMED analysis as the results achieved will then be applied by them. It is therefore easier to assist them immediately in the implementation of the improvement rather than to exclude them and at the end of the work, leave them with a sheet of paper to perform. SMED is an improvement procedure that requires close collaboration between the client company and the consultants.

As explained before, the set-up time is the elapsed time between the last good piece of the previous production batch and the first good piece of the next batch.
It is important to stress better the concept of "goodness of pieces". A piece is considered good when it meets all the specifications dictated by the customer. It is fundamental to verify that not only the first piece must be good but also the following ones.
This is because if the second one is defective, almost surely the changeover has been done incorrectly. The changeover, therefore, will have to be redone and all this lost time (first set-up + second correct set-up) represents 100% muda.
Set-up procedures are usually thought of as infinitely varied, depending on the type of operation and the type of equipment being used. Yet when these procedures are analysed from a different viewpoint, it can be seen that all set-up operations comprise a sequence of steps. (Shingo, 1985).
Making these steps standard and repeatable is essential. If the set-up on average takes about 5 hours if carried out by an experienced worker, the same time must be spent by a newcomer. SMED result will work well only when everyone meets the standard.
The primary objective is always to make the process standard, and only then it is aimed at reducing changeover time.
Another aspect to consider when a SMED analysis is approaching is the possibility to parallelize operations. Even though the total number of set-up man-hours may be unchanged, set-up operations are more than halved when two workers instead of one perform the changes where machines are large or processes are long (Shingo, 1985). Moreover, involving two operators instead of one is relatively less costly than involving a machine for the same amount of time. In fact, the hourly cost of the machine is on average 300 €/h while the cost of a worker is around 25€/h[12].

Why take action on set-up times?

In 2017 Considi Srl was consulted to develop miniGears' Value Stream Mapping, a useful tool to review the process of creating value for the end customer. The main activities carried out by the working team were:

- Analysis of stock and sales data (cross analysis), related to finished products, semi-finished products and raw materials, with identification of the different classes of items and of the relevant items from which to start to create the flow;
- Launch of structured numerical analysis tools;
- Flow mapping through the VSM, with determination of lead time for the selected items;

[12] Source: Considi Srl

- Definition of the status TO BE for the selected articles.

Figure 31 - miniGears' Value Stream Mapping developed on February 7th, 2017 (source: miniGears SpA)

The work process (both office and operations, such as procurement, storage, processing, shipping) is represented with post-it®. The roles of supplier and customer (internal and/or external), the phases and both value-adding and non-value activities (for the customer) is defined. It is important to mark graphically the strengths and weaknesses on which it will be essential to intervene. Furthermore, a schematization of flows can be grouped into:

- physical flows (movement of means, materials)
- information flows (communications, data exchange)
- time flows (quantification of time in each production parameter)

It is clear how dismembering every single step helps to highlight the value of each individual procedure in terms of the final result for the customer.

From the numerical analysis a very high flow index emerges. It is the fundamental indicator for assessing whether the lead time of a process is too high. It is defined as:

$$Index\ flow\ (IF) = \frac{Lead\ Time}{Technical\ Time}$$

where the numerator is formed by waiting time, VA (value added) time, NVA (non-value added) time and the denominator is given only by VA processing time for the final customer. The optimal value for this rate is 2. miniGears at the beginning of 2017 had an IF of 25. To reduce it, the numerator had to be worked on by:

1. increasing the exit speed (i.e. reducing set-up time). Often, to do that, technology is improved and therefore an investment made;

2. decreasing WIP (better managing orders by releasing them only when effective capacity is fulfilled). If WIP is kept under control at a fixed level, delivery times can be met with greater accuracy;
3. reducing the stages of the process.

Considi decided to work on the reduction of high stock value (WIP), increase of exit speed (cycle time) and improvement of set-up times.

When set-up times are reduced, it is easier and more frequent to make changes and thus be faster in delivering. A reduction of production batches will lead to a reduction of WIP, since by reducing the batch quantity, there will be necessarily less stocks in the warehouse. That is why it has been decided to apply SMED method to various production machines of the plant. In the last chapter further reasons will be explained about the improvement of the set-up time for the two gear hobbing machines.

Actual state of things – AS IS

Timer Pro Professional

The software used to analyse the video of the changeover is called *Timer Pro Professional*, an American software of which Considi Srl was the first in Italy to own the license. It is fundamental for the SMED analysis because, without it, step 1 would slow down a lot. In particular, it has a feature set that integrates video time study and process analysis capabilities to quickly visualize the work content in a process and identify and quantify the effect of changes.

Generally, consultant are in charge of recording the video, but in the case of miniGears, the video had already been recorded on July 9th 2019.

The first thing to do in the video analysis, is to insert in the "subject" section of the software all the areas, machines, departments involved in the set-up. For this changeover, the following areas were engaged:

- Hobbing machine 050A
- Robot
- Chamfering
- Island, bounded area including robot and chamfering
- CQD
- Klingelnberg
- Equipment closet
- Degausser

- Washing machine
- Vise desk
- Outside

CQD and Klingelnberg are both related to quality control of pieces. The former is a laboratory assigned to dimensional quality control of gears. The control plan includes the chamfering control by a profilometer. The latter is an evolventimeter on which measurements are made on the set of teeth (chordal measurement, toothed centre, helix and involute errors, bottom diameters, external diameter, number of teeth).

Each operation is required to be allocated in one of the areas just described, by selecting the "subject" at the moment of creation.

At the same time, each activity must be categorized with one of the following letters:

- **V**, value activity (necessary)
- **R**, required activity that can be improved
- **N**, non-value activity (not strictly necessary)

One thing to keep in mind regarding this concept is the change of perspective. In fact, if the customer and his willingness to pay were taken as a reference point, any changeover activity would be non-valued. Since it is the market that requires smaller batches and an increasingly shorter time-to-market, set-up is an inevitably necessary and increasingly frequent practice. Consequently, the progress of the set-up is assumed as a new point of view. All those activities that are fundamental to proceed with the set-up are considered value-creating. All those that have been carried out incorrectly and that can therefore be eliminated, are unlikely to be judged of any value.

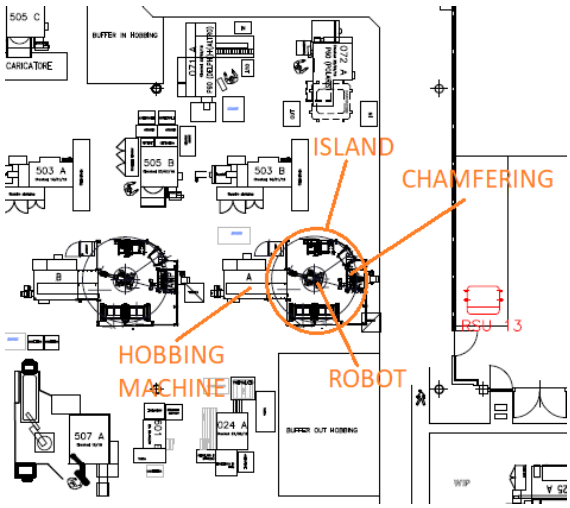


Figure 32 - Main components of the 050A machine (source: miniGears SpA)

The video analysis concerns creating a list of all the activities carried out during the changeover and their duration, aided by the operator who carried out the set-up. The level of detail used to create the list of operations may vary. The description could be very specific and detailed or it can include just the macro operations. In this case, since the changeover lasted more hours, only the macro activities were marked, reaching a total of 194 operations.

Encountered problems

Commenting together with the operator on the various activities belonging to the changeover, some critical issues emerged. Some of these come from errors committed by workers, while others should be discussed at the managers' table to get improvement. They are:

1) There is no a clear set-up scheduling;

2) An efficient quality control office checks that the required standards are always maintained. The automotive industry, for which miniGears works, requires quality control on each piece. Quality control is normally required during set-up, which must give approval for the start of production. When instead the production begins, checks take place according to the control plan. Some operators are able to perform the check themselves but there is an obligation to send the piece to the quality department. The criticality concerns the fact that the quality department works from 7 to 21, whereas production is active 24h/24. Therefore, changeover cannot occur at night. It might happen that the set-up protracts beyond 21 and the operator might need to perform a quality check. If the operator considers the product as compliant, production can start. Subsequently he must obtain approval from the quality department the next day;

3) The previous shift operator has forgotten to put the grease on the hob. If a standardized procedure had existed, it would not have happened. Furthermore, if the hob material was in hard metal (instead of steel) this activity could be eliminated;

4) Operators tighten everything by hand, which lengthens the set-up time;

5) In the preparation of the load for the washing machine, a case was missing (which is in common use for the whole company). If this is missing, you cannot proceed with washing. The washing time is 10 minutes long, during which the operator goes on with the set-up;

6) The operator lost 2.20 minutes to look for a brush that was not in place;

7) Advice to other operators represents a considerable amount of waste of time (almost 10 minutes). It is important to point out that the literature requires to exclude from the calculation of the time of changeover all those activities that somehow interrupted the development of the set-up itself (such as a colleague who interrupts the operator for help). In fact, if this interruption had not occurred, the operator could have continued to work. In this specific case, however, the company points out that consultancies are normally in the factory and that therefore even in future changeovers the probability of finding this type of interruption is quite high. It has been decided to consider them part of the set-up;

8) The operator disassembled a wrong deburring which made him lose 3 minutes because the components in the cabinet were not recognizable and not identifiable by eye;

9) The island is totally delimited by a grating to protect the operators from the movement of the mechanical arm. The operator needs to enter the area about 70 times per set-up. The entrance however, is inconvenient compared to the operator's position, so they found another way to enter (although it is dangerous because he could bang his head);

10) Gloves supplied by the company are very thick and hard. Though they protect hands, they do not allow the operator to move freely. As a result, he uses normal silicone gloves that are not suitable for the changeover;

11) The drawer unit containing screws is never ordered by the operators and there is no external description to immediately identify the pieces;

12) During the changeover, the micron's tip broke, a problem that caused more than 20 minutes of waste. The operation was recorded as N. The operator lost this time going to seek help from his colleagues (who were engaged in other activities). Moreover, it is necessary to investigate why the tip broke.

Movements and Spaghetti Chart

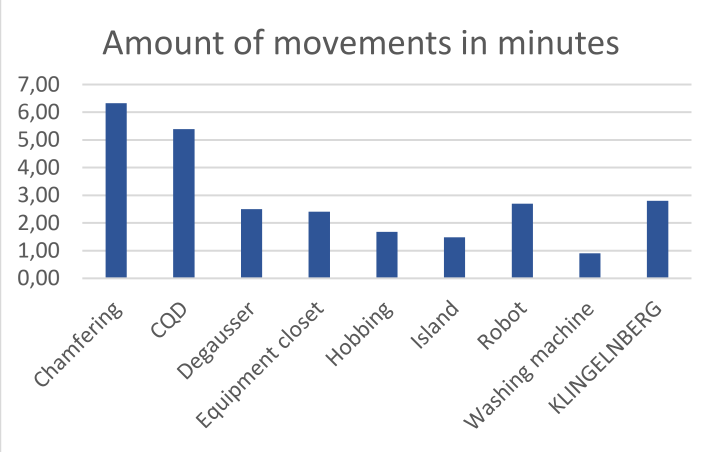
The changeover has lasted more than 4 hours (256.8 minutes), during which the operator moves throughout the department. A good amount of time is totally spent for journeys (both for worker's movements and equipment transportation).

Some areas such as the CQD or the degausser are very far from the work area and the operator travels many meters before reaching them. Moreover, he has to remember to bring all the pieces with him to avoid having to go back and waste more time.

In a lean perspective, transportation and movement are considered completely *muda*.

Transport involves goods being moved about. Taken to an extreme, any movement in the factory could be viewed as waste and so transport minimization rather than total removal is usually sought. […] Unnecessary movements involve the ergonomics of production where operators have to stretch, bend and pick up when these actions could be avoided. Such waste is tiring for the employees and is likely to lead to poor productivity and often to quality problems (Hines, Rich, 1997).

With the help of the software *Timer Pro Professional*, 54 movements have been recorded over a total of 194 operations. All the movements have been registered as R since it is a required task which can and has to be improved.



GRAPH	SUBJECT	ELAPSED TIME (m)
	Chamfering	6.33
	CQD	5.39
	Degausser	2.50
	Equipment closet	2.41
	Hobbing	1.68
	Island	1.48
	KLINGELNBERG	2.80
	Robot	2.69
	Washing machine	0.91

Figure 33 and Table 7 - Movements during 050A changeover

It should be emphasized that the movements recorded represent only the macro-movements. All those micro-shifts that took place around the workplace were not taken into consideration as it would have been difficult to intercept. Therefore, journeys lasted for a total of 26.19 minutes. The 2 main areas involved were: the CQD (for the far position from 050A) and the bevelling machine. With regards to the bevelling machine, the operator pointed out that although the machine was two years old, it already presents several problems. One of the reasons that lead the operator to make numerous trips, is linked to the fact that screws slip continuously and must be fixed on time. Results can be seen below.

Taking into consideration that the operator moves at an average speed of 5 km/h (1.39 m/s), the distance travelled during the changeover is:

$$\textit{Distance} = \textit{speed} \times \textit{time} = 1.39\ m/s \times 26.19' \times 60'' = 2184.66\ \textit{metres}$$

For this initial phase it is useful to use a visual tool called Spaghetti Chart to visualize the physical flows of materials, people and documents within the factory.

In the SMED perspective, the reference machine is taken into consideration with the flow of movements that have occurred during the changeover. Then this is traced on the layout of the plant. Operationally, it can be made with paper and coloured pens, or alternatively using a graphics software. The entire route normally done by the operator is tracked through showing on the map movements, the transportation of materials, equipment and documents. This mapping gives the ability to highlight all the movements (muda) performed, all the intersections carried out, the meters travelled during the set-up and numerous other useful information. The first step is to use the layout to easily calculate (through graphic scale), the approximate distance between the 050A hobbing machine and the other areas involved in the set-up. Results can be found below.

FROM	TO	DISTANCE ON MAP (cm)	SCALE (cm) 1:750	REAL DISTANCE (cm)	REAL DISTANCE (m)
050A	KLINGELNBERG	4	750	3000	30
050A	CQD	7.5	750	5625	56.25
050A	EQUIPMENT CLOSET	3	750	2250	22.5
050A	DEGAUSSER	7.5	750	5625	56.25
050A	WASHING MACHINE	1	750	750	7.5
050A	VISE DESK	3	750	2250	22.5

Table 8 - Distance between 050A and other machines/laboratories

In the appendix (letter A) it can be found the Spaghetti Chart tracing movements during the changeover at the initial condition (before SMED implementation). Three colours have been used:

- Red – Information flow, movements of documents to open and close the changeover;
- Green – Materials flow, used every time an object, a piece, an equipment is transported from one place to another;
- Light blue – People flow, used every time the operator is moving around the machine or walking in the ward without bringing anything with him.

An important thing to stress is the purpose of this tool. It serves to visually explain how things really are. For this reason, in the figure in the appendix, only the macro displacements have been reported. If all the real movements had been traced, probably the spaghetti chart would have been illegible.

It was decided to report it in the thesis to show the initial situation of the movements and to give a localization to the various areas involved in the set-up. Moreover, it has been created to carry out a comparison with the ideal situation suggested by SMED. During the improvement activities, in fact, some equipment or tool will be moved or duplicated in order to facilitate and reduce movements.

Analysis

The total activities are equal to an amount of 194. In the appendix (letter B) a table contains the description of each activity, the progressive numbering, the subject (area or machine where the task is performed), a definition of the activity (external or internal), the added value (letter V, R, N) which corresponds to value activities, required and to be improved activities and non-value activity. The duration of the changeover is 256.8 minutes divided as follows:

Value added	Duration [min]
V	140
N	53
R	64
Total	257

Table 9 - Subdivision of the set-up time

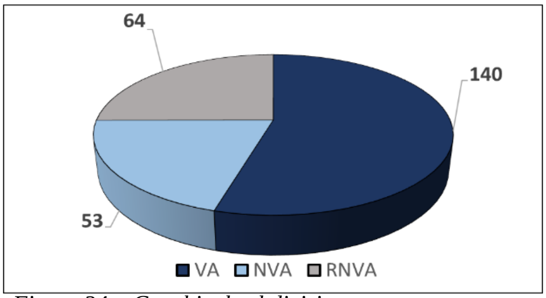


Figure 34 – Graphical subdivision

53 minutes are labelled as non-value activities. They are errors or oversights that do not create any value to the customer and will no longer have to be repeated. Therefore, they must be eliminated. In the TO BE phase, set-up time will be reduced by 53 minutes without effort. Movements last 26 minutes on total set-up time and represent almost half of the operations called R (in terms of time). As explained previously, in the TO BE phase, it is necessary to reduce the amount of movements by bringing equipment, machinery and tools closer to the 050A gear hobbing machine.

190 operations out of 194 are performed internally, therefore with the machine stopped, while only the last four are performed externally, with the machine processing. This is a datum that is surely to be improved since several activities on the list (AS IS internal) can be performed externally and therefore not going to further extend the time dedicated to the changeover. Any activity that does not have to be performed when the machine is not running should be converted to an external activity; such as preparation of documents, washing machine emptying, equipment reorganization and piece counting. This step will be seen in the paragraphs dedicated to the TO BE phase.

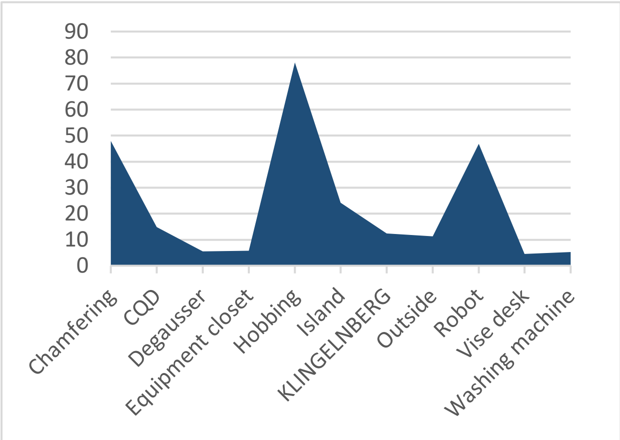


Figure 35 - Use of "subjects" during set-up

As shown on the graph, three main areas are involved in the changeover (represented in minutes): the chamfering, the robot and the hobbing machine. These three areas, belonging to the 050A hobbing machine, represent the fulcrum in which the set-up takes place.

The graph composed of histograms shows the composition of each subject, represented as a percentage. Histograms are not comparable to each other since it is not correct to say that one area performs more value-added activities than another one. What the graph can show instead, is the composition of the time spent in each subject divided into value/non-value and to improve activities.

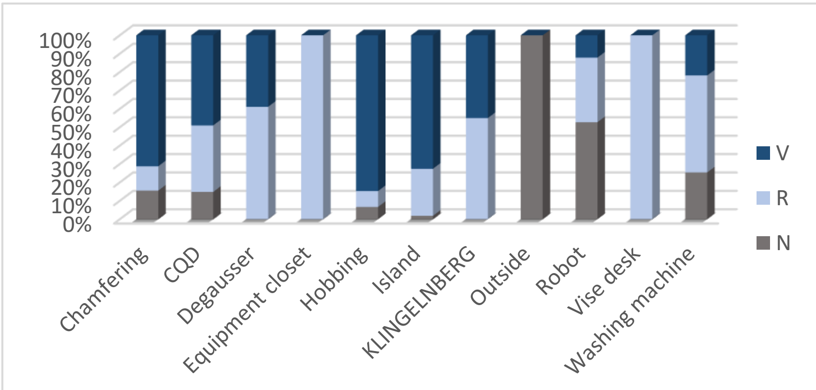


Figure 36 - Composition of each subject

In particular it identifies six areas in which non-value activities are carried out. They are: outside (100% of the time spent outside the plant), the robot (48% of the time spent in the robot), the washing machine (20%), the chamfering (10%), CQD (9%) and the hobbing machine (5%).

For example, the case in which the operator went outside can be explained. Label "outside" represents 100% muda. It is time used to do activities that do not compete with changeover. The operator in fact was stopped by a colleague who asked him for assistance and he was forced to interrupt his work to help him. As previously written, this could be considered as unrelated time to set-up time and should have to be excluded for accuracy. On the other hand, consultations are the norm in miniGears and it cannot be guaranteed that in the future there will be no longer any such pauses. For this reason, this thesis assumes these interruptions as part of the changeover.

Desired Future Situation – TO BE

The first things to do in the TO BE phase are two. The former is to scroll through all the list of operations one by one and understand together with the worker if the operations previously carried out internally, can now be moved externally. The latter is to identify all those activities that must be eliminated because they are caused by errors or interruptions that no longer need to be repeated.

In the AS IS phase, there are 190 internal operations (97.9% of all operations). In the TO BE phase, internal operations are reduced to 133 (154 minutes) and those eliminated amount to 33 (for a time saved equal to 78 minutes). On the graph it is possible to see the difference in the composition of the set-up time in the two phases. The arrow indicates the reduction in minutes of internal activities. These calculations do not include the optimization of time which will be described later.

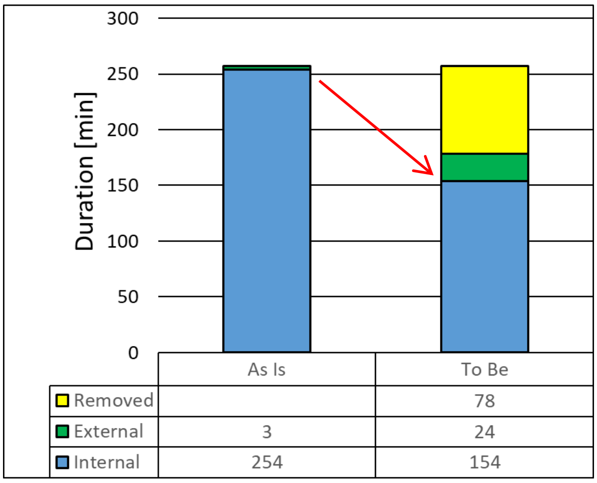


Figure 37 - Reduction of internal activities

Activities optimization

The next step involves the renovation of some activities. Some suggested improvements serve to reduce the overall set-up time. Others aim to unload or facilitate a particular operation. The operator in this helped the work team to understand which of them could be performed in a more efficient way and therefore optimized. Here is the list of improvements proposed:

1) Ensure that the production plan is defined and communicated at least one day before the set-up;


Figure 38 - Tools to disassemble bevelling components (source: miniGears SpA)

2) Prepare a check-list with all the equipment, tools, materials, pieces that are necessary for the set-up. They must be identified and brought closer to the line so as to be more comfortable for the operator who is carrying out the changeover. The same applies to the start-up documents which must already be prepared on the desk before starting;

3) Provide a small panel inside the island with all the tools needed to disassemble the bevelling components (see picture);

4) Solvent cleaning often causes delays because the brush is not in place. A proposed solution involves buying the GS200 spray solvent (operation 27 AS IS);

5) The degausser belongs to the conical department. One solution is to put it on a cart and move it throughout the department when needed (operation 41 AS IS);

6) The vise should also be brought closer to the machine. It is hypothesized to put it on a cart and move it when needed;

7) Purchase a three-story carriage on which the disassembled, to be assembled and to be demagnetized equipment can be divided. They should also be identified with a coloured adhesive;

8) Identify an area in which to store the dismounted deburring and bevelling (they are covered with metal shavings that injure hands) (operation 87 AS IS);

9) The equipment closet containing bevelling and deburring tools must be brought closer to the machine. It is a closet that serves the operator several times during the set-up, so it is advisable to approach it in a more accessible place that does not impede. Equipment inside must be identified with coloured adhesive. In the photo, the new location attributed;

Figure 39 - Equipment closet's new location (source: miniGears SpA)

10) The contribution of a second person is required to activate the solenoid valve. A pedal is proposed to activate the solenoid valve without the contribution of two people (operation 107 AS IS);

11) The operator travels many meters inside and outside the island as the bevelling control panel is external whereas the machine is inside. He would save time if the panel was duplicated on the side facing the bevelling machine (operation 113 AS IS);

12) Provide 5 types of blisters inside the machine to constitute an emergency deposit (operations 128 and 129 AS IS);

13) Test the use of electric screwdrivers to speed up disassembly and assembly times;

14) Insert a transparent folding drawer unit inside the island containing all the materials and tools useful for the set-up. In this way the tools are easily accessible and there is no risk of someone else borrowing them.

There are also two other planned improvement activities that correspond to two components of the Toyota Production System House. They are Jidoka (second pillar) and preventive maintenance (foundation).

In regards to Jidoka, quality control must be present at every stage of the production process. The aim is to make all processes visible, making the anomalies that may arise immediately recognizable. In the case of 050A, the first test product reviews two quality checks (CQD and Klingelnberg). However, sometimes it takes a long time to receive quality control feedback (production works 24h/24 whereas quality checks stop at 21). A solution is to train operators to use the profilometer (a tool belonging to CQD) to speed up the time. A consequence of doing Jidoka is certainly the fact that this methodology offers improvements on the quality of the products to avoid defective products downstream, that in reality should be stopped earlier, thus escaping unnecessary reworking (operation 125 AS IS).

The second correction regards Total Productive Maintenance (TPM). TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities (Tsuchiya, 1992). The OEE is the main indicator for the measurement of the results and it is mostly applied in capital intensive companies, where the cost of production plants is significant.

In the case of the 050A, the breakage of the micron tip is one of the problems that has extended the set-up time. This tip breaks on average once a month and it is not possible to predict when. A solution is to do preventive maintenance. Once a month, when the machine is stopped, the tip must be replaced. An alternative solution could be to perform predictive maintenance, that is, to intervene only when the machine gives signals that something is going wrong and that the tip could break in the short term. The important thing is that the replacement should always be carried out with the machine stopped and not during a changeover (operations 143 and 144 AS IS).

5S

The 5S – *Seiri, Seiton, Seiso, Seiketsu, Shitsuke* – are the basis of every improvement project. As explained in Chapter 1, it is a Japanese method for workplace organization. This tool is much more than a mere housekeeping system. It affords the opportunity to change the way people view their job, their working environment and even how they view their roles within departments. In other words, 5S Kaizen allow to change the whole method of working and develops a culture focused on continuous improvement (Scotchmer, 2008).

In a manufacturing company, as miniGears is, the two most important elements of 5S are the sorting and straightening. In a factory full of machinery and operators who work in a dirty environment in the midst of processing waste, the search for molds, equipment and components is essential for workers, especially in the set-up phase. In the daily work of a company, the habits that make it possible to maintain order and organization are essential to make the flow of activities smooth and efficient. In fact, sorting and straightening are the basis for achieving the goal of there being zero defects, cost reduction, increased safety, zero injuries (Bianchi F., 2017). The use of 5S is essential to shorten set-up time, thus generating a greater variety. In order to remain competitive, every company should reduce changeover time until it is minimised, so as to be able to increase the frequency and the variety of products. The five pillars help to minimize set-up time by reducing the time needed to search for equipment and increasing overall efficiency.

The work team focused on performing the 5S in two fundamental points. The tool four-drawer unit (Appendix letter C) and the document cabinet (Appendix letter D).
The tool drawer unit has been completely arranged using the procedure designated by 5S. All those objects not related to the changeover have been removed first. Subsequently, each piece important for the set-up, was restored and cleaned. Hobs used in the changeover, belonging to another closet, have been moved into the drawer unit. To secure and protect them, red pins, attached to the base of the drawer, have been used (see photo of drawer 1 in the appendix). It was then decided to buy new metallic pins as the current ones are easy to break. Furthermore, in order to standardize and then sustain the improvement, labels have been affixed to allow anyone to identify the equipment immediately.
Moreover, a collector belonging to the document cabinet was removed from there and approached the two gear cutters. In fact, it is extremely important during set-ups and it is more advantageous to have it close. It was emptied of all the documents that did not interest the two machines and only the related documents were kept inside it. Documents belonging to 050A and B are (for each part number): the steel and hard metal set-up cards and the piece conformity analysis. In the Appendix letter D, the related pictures can be found.

Action Plan

At this point, it is essential to draw up an action plan that programs the next moves. It identifies the set of activities to be performed after problems and corrective actions have emerged during the execution of the project, in this case the SMED. It is drafted by the work team that agrees on priorities and preparation for implementation. The document has many functions, such as:

- establishing roles and responsibilities;
- showing the progress of the work, issues and changes;

- ex post monitoring in the event of failure to perform certain actions written on the document that compromise normal operations.

The action plan compiled by the work group has the following elements, distinguished by column:

- **what**: identifies the area taken into consideration or the equipment to be improved;
- **description**: explains in detail what the improvement activity to be carried out consists of;
- **team**: who carries out the corrective action;
- **remarks**: additional notes that give suggestions about the correct execution of the activity;
- **when**: defines the priority that each corrective action has. An indicative date of the implementation period is inserted;

-**status**: current situation of the activity to be chosen from one of the following: in progress, deferred, waiting, completed.

Below there is an extraction of the action plan containing a part of the list of activities that should be performed in the short term. The more this list is completed, the more it is possible to keep track of the improvements implemented.

hGears		Improvement activities - SMED 050A		Issued by: Date: 03/10/2019 Update: 14/10/2019	Plant: Padova	
ID	WHAT	DESCRIPTION/TO DO	TEAM	REMARKS	WHEN	STATUS
1	Scheduling	Production plan defined and communicated at least 1 day in advance	Production Planning		asap	NOT STARTED
2	Vise desk	Place the vise on a wheeled cart	Work team	A resistant cart is required	November	IN PROGRESS
3	Check list	Plan to check the list of necessary equipment before starting set-up	Work team	To be prepared	October	IN PROGRESS
4	Equipment closet	Move closet to the line			20/09/2019	DONE
5	Wheeled cart	Use of a dedicated cart to identify the equipment of the previous batch and the next batch	Purchasing Dep.	Authorization received	November	IN PROGRESS
6	Degausser	Check the possibility of having a degauser dedicated to the department	Maintenance	To be put on a trolley	December	IN PROGRESS
7	Tailstock	Check the state of wear and evaluate different centering systems (cone, sphere, new tailstock)	Maintenance	Preventive maintenance is scheduled	October	IN PROGRESS
8	Deburring	Create a system to identify the different types of deburring		5S	19/09/2019	DONE
9	Island's warehouse	Provide a cabinet inside the island with all the screws and other materials needed	Purchasing Dep.	Authorization received	November	IN PROGRESS

Table 10 - Action Plan (source: miniGears SpA)

Each described activity has its own priority level but all of them are essential and must be completed. As it can be seen some are more complex than others, they require more time and above all they can be accomplished prior authorization by the maintenance office.

Analysis

In the TO BE phase it is essential to optimize activities according to two aspects. On the one hand it is necessary to reduce them in terms of time and therefore optimize the way of doing them; on the other hand, trying to bring the greatest number of activities previously performed internally, into externally.

In the appendix (letter F) it is possible to find the new standard. It is shown a new list of operations to be carried out after the SMED improvements. It is shorter because all the non-value activities have been eliminated, those remaining have been reduced in terms of time and moved where possible externally (before or after the set-up when the machine is working).

The elapsed time columns have been estimated having as starting point the AS IS time. Since many improvement and optimization actions have been carried out (including 5S in the working area), several set-up activities could be reduced. All the others have been left as they were because already carried out at full efficiency.

The changeover operations are reduced to 134 compared to 194 at the initial situation. The new set-up time is 160.07 minutes for a reduction in minutes of 96.76 (37.67%), compared to the AS IS situation where a changeover lasted 256.83'. External activities have increased because they do not affect set-up times and costs: they are in fact carried out while the machine is still working on the previous batch or when the machine has started to produce the new batch (set-up already concluded).

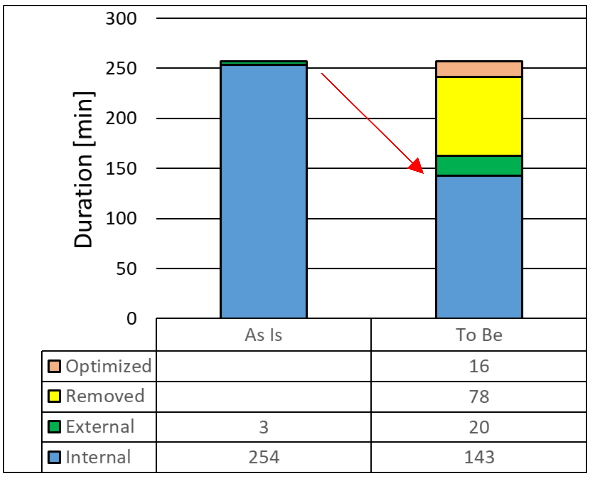


Figure 40 - Set-up time improvement

The graph shows two histograms of equal height, whose value is the duration AS IS. In the right column the new composition is shown. In addition to the yellow colour already present in the previous graph, it is used the pink colour for optimized operations (16 minutes). This data indicates that the performance of internal and external operations TO BE has been improved, favouring a time-saving of 16'. The final situation is therefore a changeover that lasts 160.07' of which 142.84' carried out internally and 17.24' externally.

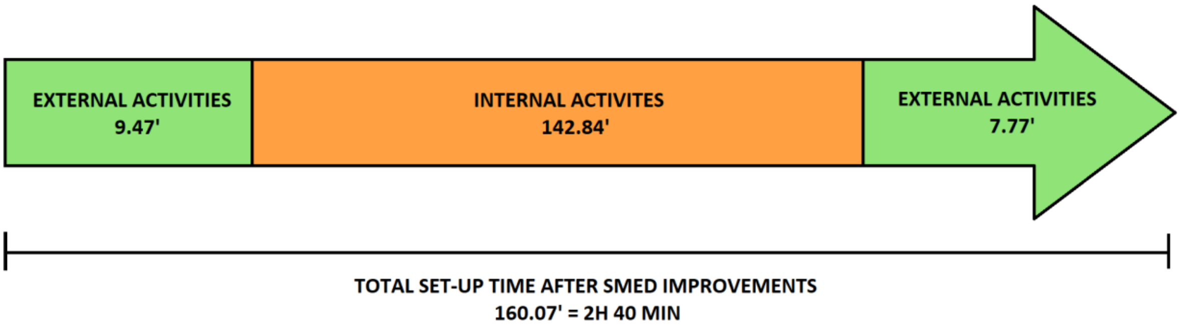


Figure 41 - 050A machine's set-up time TO BE

Spaghetti Chart TO BE

In the appendix (letter E) an optimal Spaghetti Chart can be found. It is created taking into consideration all the macro movements in the TO BE phase. It should be noted that during the redesign phase of the new layout, three important changes are made:

- The equipment closet is brought closer to the gear hobbing machine, positioned on one side of it;
- The degausser, belonging to the conical department, is put on a wheeled cart and moved to the machine belonging department;
- The vise desk in the same way is approached and placed on a wheeled cart.

Note that while the closet is for the exclusive use of the two gear hobbing machines, the other two equipment are in common with the other workers. For this reason, they are located in an easily and quickly accessible place by everyone. Journeys have been reduced by 38%. AS IS they last 26.2 ', TO BE movements last 16.29'. All equipment, tools and other materials are now on the line and movements are minimized. Moreover, in the drawing it is presumed that the quality control is done only once, therefore that the first piece coming out of the machine is compliant. In the drawing the path traced towards the CQD and Klingelnberg is one.

From-To Matrix

The from-to matrix is a preparatory tool for the calculation of the Changeover Index, created by a senior consultant of Considi Srl, Lorenzo Citran. It is used to apply SMED improvements to all other changeovers carried out with different part numbers. The first fundamental thing to do is to choose to analyse the most complete set-up, the one that uses the most parts of the machine. In this way the SMED methodology is used to subsequently adapt the results to all the other changeovers.

ChX is the type of changeover representative of all the performed activities that may be replicated even with different Part Numbers. The Changeover Index (IC) measures the level of return with which the changeover is performed.

It is calculated:

$$IC = \frac{Target\ duration\ of\ the\ changeover\ [hours]}{Effective\ duration\ of\ the\ changeover\ [hours]} \times 100$$

The objective of the IC is to compare uneven changeovers between them (different machines, different durations, operators with different experience, ...). The target duration takes into account the opportunities identified in the SMED construction sites, whereas the denominator corresponds to the actual timed duration after SMED improvements.

Methodology

To create the from-to matrix some rules must be respected:

1) Definition of the macro activities that take place during the set-up. It is important to identify and list all those macro phases that are discriminating for the various changeovers (i.e. activities that are of different duration or that are not carried out for certain types of them). A code is then attributed (a1, a2, a3…).

050A	Macro-activity	Duration [min]
a1	Opening changeover	4.3
a2	Gear hobbing equipment replacement	46.6
a3	Expander replacement	10.0
a4	Deburring replacement	19.0
a5	Washing machine	6.1
a6	Chamfering equipment replacement	17.7
a7	Robot equipment replacement	3.8
a8	Fixed pin misalignment	10.1
a9	Loading raw materials	3.5
a10	Island starting	35.2
a11	Quality check	44.0
a12	Production stat-up module	4.6

Table 11 - List of macro activities belonging to 050A set-up

2) Creation of a visual support for the operator. Post-it® are used to identify part numbers written on a post-it® each (of a certain colour) and all the macro activities written on a post-it® each of a different colour.

3) Analysis of each changeover from one code to another and vice versa; the operator is asked to think about each changeover at a time and which macro activities of the list are carried out. It is necessary to check the written duration at the bottom of the table and fill in the matrix by matching the activity with the correct change.

- ✓ If the duration is about the same as the one written, put 1;

- ✓ If the duration is *smaller (greater)* to the reported one insert a number *smaller (greater)* to 1 which will then be multiplied by the standard reported duration.

In the table there is written 0.5; it means that doing that macro activity in that particular change takes half of the time. In that case 5’ instead of 10’.

Machine	From	To	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12
050A	5780	5781	1	1	1	1	1	1	1	1	1	1	1	1
050A	5780	5782	1	1	1		1	1	1		1	1	1	1
050A	5780	5785	1	1	1	1	1	1	1	1	1	1	1	1
050A	5780	5786	1	1	1		1	1	1		1	1	1	1
050A	5781	5780	1	1	1	1	1	1	1		1	1	1	1
050A	5781	5782	1	1	1		1	1	1		1	1	1	1
050A	5781	5785	1	1	0.5	1	1	1	1	1	1	1	1	1
050A	5781	5786	1	1	1		1	1	1		1	1	1	1
050A	5782	5780	1	1	1	1	1	1	1		1	1	1	1
050A	5782	5781	1	1	1	1	1	1	1	1	1	1	1	1
050A	5782	5785	1	1	1	1	1	1	1	1	1	1	1	1
050A	5782	5786	1	1	1		1	1	1		1	1	1	1
050A	5785	5780	1	1	1	1	1	1	1		1	1	1	1
050A	5785	5781	1	1	0.5	1	1	1	1	1	1	1	1	1
050A	5785	5782	1	1	1		1	1	1		1	1	1	1
050A	5785	5786	1	1	1		1	1	1		1	1	1	1
050A	5786	5780	1	1	1	1	1	1	1		1	1	1	1
050A	5786	5781	1	1	1	1	1	1	1	1	1	1	1	1
050A	5786	5782	1	1	1		1	1	1		1	1	1	1
050A	5786	5785	1	1	1	1	1	1	1	1	1	1	1	1
	Macro-activity duration		4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6

Table 12 - From-To Matrix (part 1)

4) A code is assigned (A1, B1, C1…) for each similar change, i.e. all those changeovers that possess the same activities and therefore are performed at the same duration (last column).

From	To	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	Tot [min]	Tot [h]	Type of changeover
5780	5781	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
5780	5782	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5780	5785	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
5780	5786	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5781	5780	4.3	46.6	10.0	19.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	194.9	3.2	B1
5781	5782	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5781	5785	4.3	46.6	5.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	200.0	3.3	C1
5781	5786	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5782	5780	4.3	46.6	10.0	19.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	194.9	3.2	D1
5782	5781	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
5782	5785	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
5782	5786	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5785	5780	4.3	46.6	10.0	19.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	194.9	3.2	D1
5785	5781	4.3	46.6	5.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	200.0	3.3	C1
5785	5782	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5785	5786	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5786	5780	4.3	46.6	10.0	19.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	194.9	3.2	D1
5786	5781	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
5786	5782	4.3	46.6	10.0	0.0	6.1	17.7	3.8	0.0	3.5	35.2	44.0	4.6	175.9	2.9	B1
5786	5785	4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6	205.0	3.4	A1
Macro-activity duration		4.3	46.6	10.0	19.0	6.1	17.7	3.8	10.1	3.5	35.2	44.0	4.6			

Table 13 - From-To Matrix (part 2)

At this point it is possible to obtain the Changeover Index to calculate the level of performance of the set-up (for each part number) obtained by operators with different experience. A table like the one below will be hung in the machine and each operator, at the end of the set-up, will take care to mark the time he spent in making the changeover (denominator).

Changeover date	Operator	From	To	Changeover code	Target Duration [h]	Effective duration [h]	IC%
16/09/2019	x	5781	5786	B1	2.9	3.7	78%
24/09/2019	y	5782	5785	A1	3.4	6.2	55%
30/09/2019	z	5785	5781	C1	3.3	3.4	97%

Table 14 - Changeover Index (example)

Then it is easy to calculate the index by dividing the target duration with the effective duration of the changeover. Operators therefore are committed to achieving always a shorter set-up time. Competition between colleagues must be avoided since it can happen that an operator, in order to produce the required quantity, ignores a nascent problem that will then be faced by the colleague of the next shift. In moments of analysis, therefore, it is important to take data per day and look at the entire team of colleagues.

Chapter 5 - Results and final considerations

The idea of implementing the SMED in this machine arises in the face of an increase in the quantity demanded by the customer. An important observation to be specified is that the company has two twin gear hobbing machines 100% dedicated to one customer. All the pieces that are processed by these two machines are in fact purchased by the same customer, a leader in the automotive sector. In this work it will be called Gamma for reasons of confidentiality. miniGears SpA produces a total number of kits per month (a mix of product codes). In June 2019 without sufficient notice it has been required by the customer to increase its volumes by about 30%. Initially the increase had to be gradual and had to be continued until the beginning of 2020, then ramp-up times were almost reduced to zero.

The requests received from Gamma exceeded the actual capacity of the machines which were already working at maximum saturation. As consequence, the OEE of the hobbing machines was unsatisfactory in order to conciliate the new requests but at the same time with room for improvement.

The initial situation was therefore the following:

- potentially improvable OEE (in February it was 74%);
- saturated production capacity;

An improvement plan was therefore needed and in particular it was decided to act on two fronts:

1) **improvement of the Performance Rate**

   June and July 2019 was the period dedicated to the reduction of the cycle time. The obtained average reduction was of 2/3” for each part number’s cycle time (acting above all on the bevelling machine);

part number	cycle time before improvement [s/pz]	cycle time after improvement [s/pz]	Δ
5780	31.54	28.32	3.22
5781	32.6	30.30	2.3
5782	31.27	29.22	2.05
5785	34.87	31.38	3.49
5786	33.45	30.66	2.79
5790	30.9	29.46	1.44

Table 15 - Cycle time reduction

   By reducing the cycle time in fact, the production works at a faster pace with an improvement of the second factor of the OEE, the performance.

2) **improvement of set-up time**

   The two gear cutting machines before the improvement operation were the bottleneck of the process. This is also why it has been decided to further reduce the cycle time as seen before. The OEE also was not satisfactory and the factor to be boosted was mostly the availability. In fact, from the Pareto analysis carried out on the machine 050A it emerged that the changeover was considered the first cause of machine downtime.

The data represented belong to the period February-April 2019. The graph shows how the set-up is the first cause of machine loss.

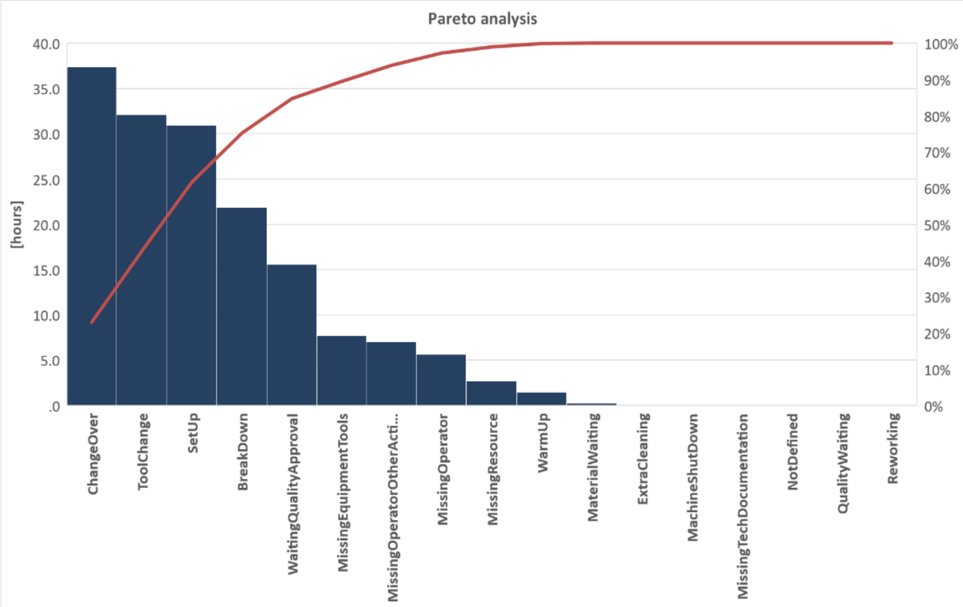


Figure 42 - Pareto analysis (source: miniGears SpA)

In fact, the first three histograms are: changeover, total change and set-up; all belonging to the same activity. The red line represents a cumulative percentage and indicates that the first three losses of the machine represent about 70% of the total losses recorded in the period under consideration. This graph it is the visual demonstration about the fact that a SMED improvement was necessary to reduce such a large percentage of losses.

High commitment

Another aspect to consider is the managerial/organizational approach that is applied in this project. It does not have to be considered as a mere technical production project but an intervention that involves the whole company, from workers to managers.

In the book '*The Fifth Discipline*', the author explains that "business and other human endeavours are also systems. They, too, are bound by invisible fabrics of interrelated actions, which often take years to fully play out their effects on each other. Since we are part of that lacework ourselves, it's doubly hard to see the whole pattern of change. Instead, we tend to focus on snapshots of isolated parts of the system and wonder why our deepest problems never seem to get solved. Systems thinking is a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively" (Senge, 1994).

This concept is largely applied in miniGears SpA where it is necessary to use systemic thinking in order to achieve common shared goals. To be clearer, the commitment of the management is very high in the company.

Going specifically, several meetings are set up because "teams can learn […] in business, there are striking examples where the intelligence of the team exceeds the intelligence of the individuals in the team, and where teams develop extraordinary capacities for coordinated action. When teams are truly learning, not only are they producing extraordinary results but the individual members are growing more rapidly than could have occurred otherwise" (Senge, 1994).

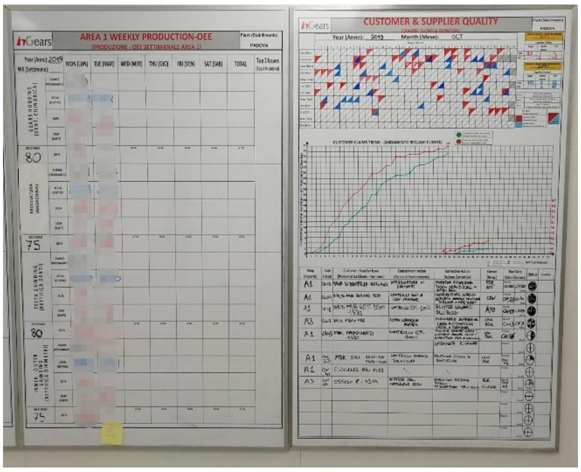


Figure 43 – Visual board example (source: miniGears SpA)

During a working day, in fact, three meetings are held in the OCR (Operative Control Room) between department heads and team leaders. These meetings are conducted with an agile management approach, through the use of visual tools such as *asaichi* or *scrum*[13].

The first meeting is at 8.30am between team leaders and it is responsible for analysing the critical issues of the day by department regarding safety, environment, quality and machine status. Countermeasures are taken to respect the production program with the customer.

At 9am there is a second meeting between function heads and Operations Director where problems emerged previously are analysed in the order: 1- safety, 2- quality, 3- machine status.

As already mentioned, therefore, there is a very high commitment by the line managers that are keen to implement a series of actions to comply with the program agreed with the client.

[13] *Typically they are morning meetings that work for the resolution of problems that occurred during the previous day. The work team should always compile a visual output (often on a board) which then becomes input for the next meeting (source: https://ithinklean.wordpress.com)*

OEE improvement

This work aims to demonstrate how an improvement in the set-up time has a direct impact on the OEE indicator. To achieve it, the work team acted on two factors of the indicator: the availability (with SMED) and the performance (with the reduction of the cycle time).

It is fair to say that the intervention on the performance rate started in June 2019 (immediately after receiving the request to increase volumes from the customer) while the SMED project started in mid-July 2019.

Machine	YearMonth	Available operating time [	Operating time [h]	Theorical quantity [pc	Produced quantity [pcs	Good pieces [pcs]	Availability Index	Performance Index	Quality Index	OEE
050A	2019/02	447.00	356.08	37,127	34,309	34,293	79.66%	92.41%	99.95%	73.58%
050A	2019/03	462.00	367.98	38,494	32,370	32,325	79.65%	84.09%	99.86%	66.88%
050A	2019/04	448.00	382.35	39,916	38,142	37,980	85.35%	95.56%	99.58%	81.21%
050A	2019/05	495.00	383.37	40,339	38,027	37,336	77.45%	94.27%	98.18%	71.68%
050A	2019/06	403.00	333.92	34,872	34,802	34,745	82.86%	99.80%	99.84%	82.56%
050A	2019/07	495.00	385.04	40,074	43,335	43,198	77.79%	108.14%	99.68%	83.85%
050A	2019/08	307.50	244.66	25,341	28,897	28,871	79.56%	114.03%	99.91%	90.65%
050A	2019/09	472.50	378.73	46,826	45,588	45,493	80.15%	97.36%	99.79%	77.87%

Table 16 - OEE calculation (source: miniGears SpA)

In table 16 it is possible to observe the elements that make up the calculation of the OEE. Starting from the first rate, the availability, it is observed that it is the one with more room for improvement. In the February-September 2019 period the average rate was around 80%.

Regarding the performance rate, the first thing that comes to mind regards some values that are greater than 100% and it is therefore necessary to explain the reasons.

First of all, it must be specified that reaching the ideal condition of 100% is effectively impossible, as it would represent a system that never stops and that never performs set-ups.

The reasons why these values are obtained is that the reference times may not be updated to the system: this happens often in contexts that have never faced a structured process of improving efficiency. The data must therefore be thoroughly validated.

Another reason could be the comparison with similar product classes in technical characteristics but not exactly equal in cycle time. This leads to enter an incorrect theoretical producible quantity. When this happens, it would be a symptom of the inaccuracy of the set model (for example, oversized and therefore inaccurate standard times).

The important thing to say and that therefore justifies a figure of this type is that the time recorded, even if not calibrated with reality, can however show an improvement of the OEE over time, which is what interests in this thesis.

The quality rate is instead perfect since it is known that the high quality of products is a distinctive and winning feature for miniGears. The value has therefore always been stable over time.

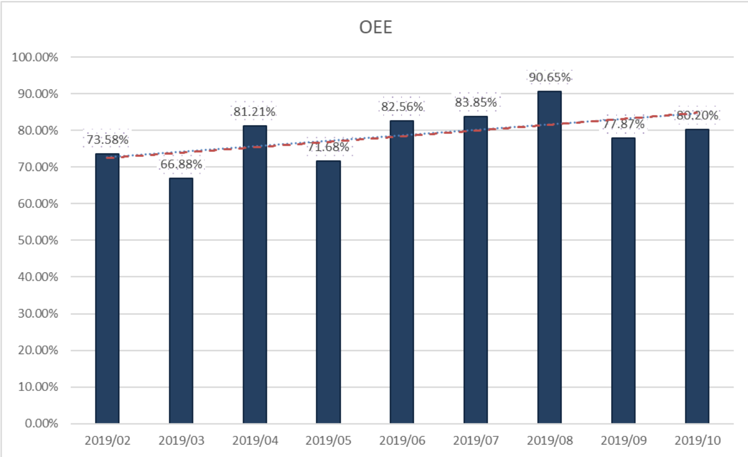


Figure 44 - OEE growth

The graph shows the trend of the OEE during 2019 and it emerges that before May 2019 (and therefore before the improvement interventions) the trend of the indicator is rather variable and does not follow a precise direction. Starting from June onwards, following the first improvements at cycle time and set-up time, the growth of the OEE appears to be quite marked, also highlighted by the trend line that is growing positive (red dashed line).

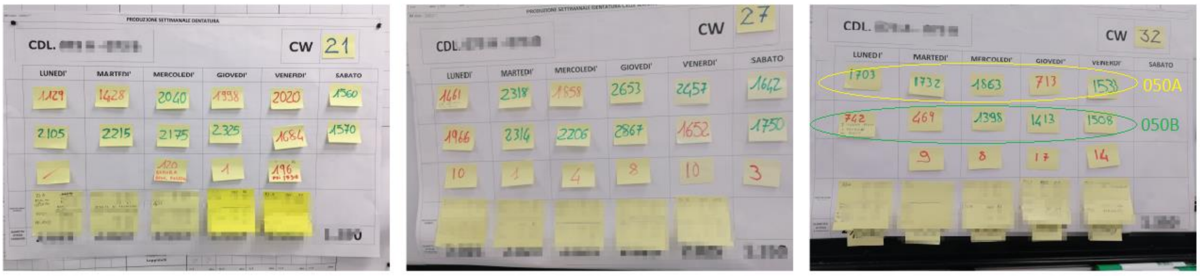
The improvement of the OEE has also allowed a shift in the bottleneck. To date, it is no longer the hobbing machine but the teeth grinding, a process further downstream.

KPI: good pieces produced per day

Competitiveness on a global scale obliges companies to exercise greater control over the entire production cycle in order to optimize it and to provide timely responses to the deaf flight required by the market. To be able to face these new challenges it is necessary to integrate the factory production reality and the company information systems. All this is feasible through logics and tools that allow the company to monitor and optimize the various activities related to the production and maintenance of the plants. Through performance indicators it is possible to optimize efficiency and a more targeted preventive and direct maintenance action.

In the case of miniGears SpA, it has been decided to start monitoring the quantity of good pieces produced every day. To do this, a weekly table has been hung on the OPC wall to record the good pieces produced during all the working days.

This action was decided in response to the request of the increase in volumes by the customer. The goal is to monitor whether the company is able to better follow the customer's requests given the improvement actions. The number is marked in green when it corresponds to the target quantity to be produced in that shift. It is marked in red both if it is not sufficient and if it is too large. In the image weeks 21, 27 and 32 are showed (total quantities cannot be shown for confidentiality reasons).



Figures 45 - 46 – 47 - Weekly production (source: miniGears SpA)

To respond to Gamma’s requests, the company must operate in a Just In Time perspective. The customer in fact requires a certain quantity at a given time and miniGears, to satisfy the request, has to supply only what is needed, when it is needed, in the amount needed.

Orders are received every three months so that the company can organize its production plan for the next three months. It is clear that the company has to be flexible enough in case it receives changes in the quantities in progress. The customer then requests for each order line a date called "KPI date" to send the order.

The component that comes out of the complete production process is highly perishable because it becomes rust in a short time. Creating a finished products warehouse is therefore counterproductive for two reasons: dissatisfaction of the customer who wants to receive the goods only on the requested date and damage of the product.

There would be technical measures to be adopted to avoid the problem such as sprinkling the finished product with oil before facing the journey to the customer. However, it is a very expensive method in terms of time, space and money.

Therefore, adopting greater flexibility represents constraints for miniGears SpA which cannot follow a free production plan since:

- the customer does not accept the product in advance: stocks take up space and lengthen the duration of production, they create transport and storage needs and consume financial resources. The finished products and the semi-finished products lying on the floor of the factory and warehouse do not produce any added value (Imai, 2001);
- greater guarantees that the product will last over time cost.

This type of production perfectly follows the pull principle, characterized by the practice of downstream work centers pulling stock from previous operations, as needed. All operations then perform work only to replenish outgoing stock (Spearman, Zazanis, 1992).

Processing lead time

With the improvement of the changeover time and of the cycle time, useful production time is recovered. If the cycle time is reduced by 3" per part number and the pieces produced per day are on average 2500, a time equal to 125 minutes a day is saved. It means that two hours a day are available to produce new pieces. And in a week, they amount to a time period of 12.5 hours. The same thing applies to the set-up, which is carried out in the gear hobbing machine every 6 days (once a week). The analysis showed that the time saved from the set-up is 37% of the initial time (256 x 0.37 = 96.76' saved)[14].

It is clear that all these improvements have allowed considerable time savings, accumulating a time saved per week equal to 14.08 hours. Surely all this has been made possible thanks to improvements in terms of both technology and organization (such as the movement of necessary equipment close to the machine). An analysis about the improvement of the processing time (intended as a single phase) is carried out.

As for the OEE, the starting point for the data collection is February 2019 while the closing point of the analysis is the last obtainable data, that is October 2019.

The lead time is given by:

$$LT = Process\ time\ +\ Idle\ time$$

In this analysis it is observed the improvement of the process time of the hobbing phase taking into account waiting and delays that can occur before, during, after production. Since it is not possible to track the entire lead time, the improvement will be calculated using a formula taken from the OEE, which takes into account all the various losses recorded by the machine.

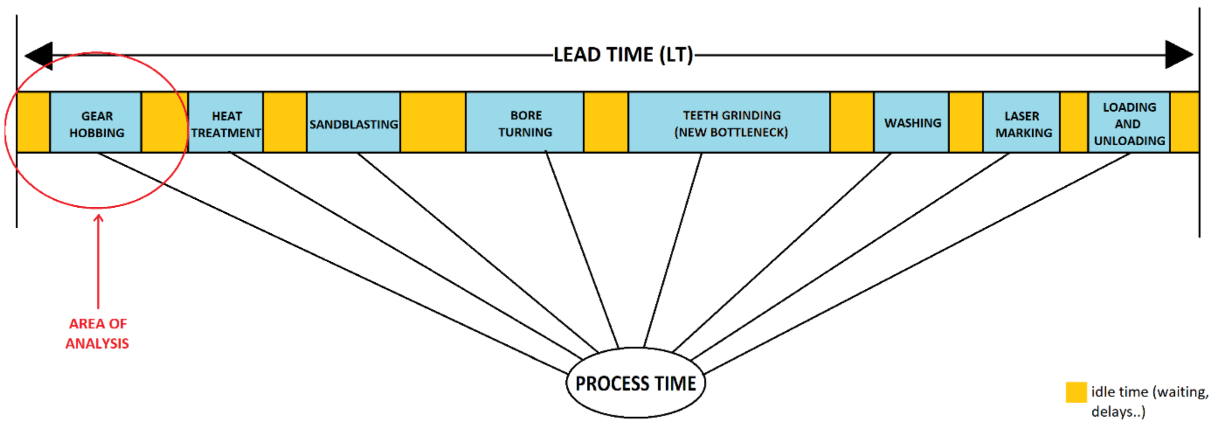


Figure 48 - Lead time for entire process

[14] Computations are referred to 1 gear hobbing machine. It is enough to multiply by 2 to get the overall effect on both machines.

From the calculation scheme of the OEE shown in figure 46, it can be seen that by reducing the losses in the process, the improvements lead to an increase in added value time that can be translated into an increase of good parts on the first try (which do not require rework) made in the reference time or, as in the case examined, to a reduction of the time necessary to complete the pieces requested by the customer.

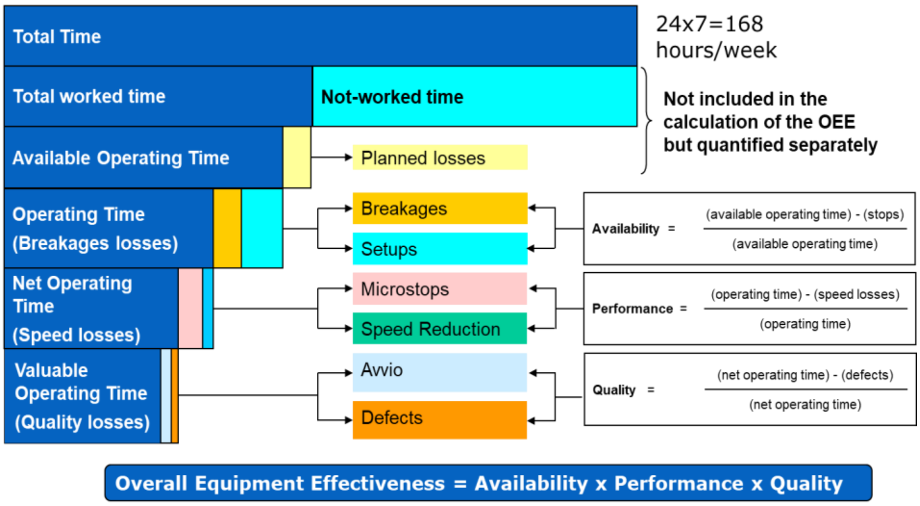


Figure 49 - OEE composition (source: Considi Srl)

The following formula is used to quantify the improvement in the time required to produce:

$$\Delta Time_{available} = (OEE_{OCT} - OEE_{FEB}) * Time_{available}$$

This formula, transformed into a percentage calculation, becomes:

$$\Delta Time_{available}\% = \frac{OEE_{OCT} - OEE_{FEB}}{OEE_{OCT}}\% = \frac{80{,}2 - 74{,}0}{74{,}0}\% = 8{,}38\%$$

This result means that in 8 months the improvement actions have made it possible to release 8.4% of the machine's production capacity. The increase in production capacity of the machine has led to many advantages:

- Respond more quickly to customer requests;
- Being able to accept further orders in order to saturate the available operating time;
- Reduce production costs as the hours of operators are reversed on a higher production.

Cost Benefits Analysis

In order to carry out this type of analysis, it is first necessary to decide how to express the monetary savings that are obtained from a reduction in the set-up time. In the case of miniGears, the two machines work at maximum saturation so they have already reached the maximum level of production capacity. Since all the pieces that are produced, if compliant, are sold, there is total absorption by the market, which in this case is represented by a single customer. It is therefore decided to measure monetary savings in terms of turnover.

Sales price	3.13 €
Hourly output	120.44 pcs
Missed production	545.60 pcs
Missed revenues	1705.91 €
Margin	30%
Missed margin	511.77 €
Machine variable cost	114.71 €
Labour cost	99.66 €
Total cost of one set-up	**726.14 €**

Table 17 - Cost of one set-up

Starting from cost analysis, the cost of one set-up represents for the company the sum of lost margin for not having produced in those hours, the cost of the operator who must perform the set-up and the variable hourly cost of the machine.

The average selling price was provided by the company. The hourly production is given by:

$$60\ sec \div average\ cycle\ time\ (29.89'') \times\ 60'$$

At this point it is easy to calculate the missed output which is computed as the hourly production multiplied by the hours of one set-up, that is 545.6 pieces. The missed turnover is therefore the lost production multiplied by the sale price. For confidentiality reasons it is not possible to communicate the mark-up calculated by miniGears on its products. For convenience, therefore, it is assumed a margin of 30% on finished products which causes the company to lose € 512 (rounded up) in sales for each set-up carried out.

At this point all the necessary elements to calculate the cost of one set-up are available. The variable hourly machine cost (€ 25.32) and the hourly labour cost (€ 22) are then multiplied by the average set-up hours (4.53h).

$$Cost = missed\ margin\ (511.77) + machine\ cost\ (114.71) + labour\ cost\ (99.66) \\ = 726.14$$

The analysis showed a set-up time reduction of 37%. Since the time and cost of the changeover are two directly proportional quantities, if the time is reduced by 37%, the costs to complete that particular set-up will be reduced by the same percentage.

Total cost of one set-up	**726.14 €**
% Reduction	37%
Saving (cost reduction of 1 set-up)	268.67
Annual savings	**15,717.30 €**

Table 18 - Annual gross savings

To calculate the annual savings, the single saving is multiplied by the average number of set-ups per month (4.8) and by 12 months, obtaining a saved amount equal to 15,717.30 €. Considering that there are two twins hobbing machines and that they are identical in the frequency of changeovers and that the other cost items are the same, the global savings can double, thus obtaining 31,434.60 €.

To put into practise some improvements brought by the SMED, some technical investments are needed (such as the purchase of new equipment or tool panels). These costs are required to be reduced by the gross benefit obtained from the reduction of the set-up time, thus obtaining a net benefit.

The list below shows all the necessary expenses to improve time. Some of them are common to both machines while others are attributable to the single machine and therefore should be doubled. Prices are an estimate:

- Spray solvent, 10 €
- Aluminium pins for drawers, 10 €
- New collector, 3 €
- Degausser trolley, 300 €
- New trolley for equipment, 150 €
- New drawer unit + panel, 50 € x 2 machines = 100 €
- Opening gap (still in feasibility analysis), estimated cost 3000 € x 2 machines = 6000 €

The total amount of these expenses is approximately € 6573, thus obtaining a net annual benefit of almost € 25,000.

However, the total amount is an investment that, even if it provides a monetary transfer in 2019, it will pay off over the next years.

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Appendix

A. Spaghetti Chart AS IS

LEGENDA:

- Information flow
- Materials flow
- People flow

B. List of operations carried out during changeover of the 050A hobbing machine (AS IS)

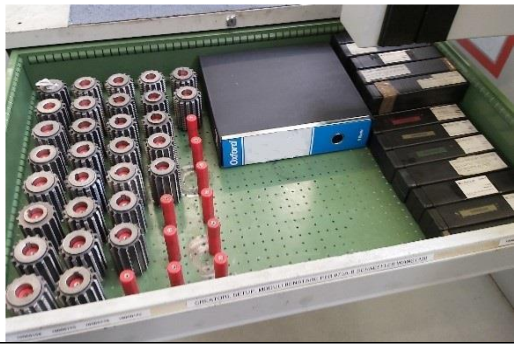
ID	Description	Value Added	Subjects	E/I	Elapsed Time (min)	Elapsed Time (s)
1	Emptying previous production	V	Island	I	0.727	43.607
2	Emptying previous production	V	Island	I	0.374	22.464
3	Emptying previous production	V	Island	I	0.291	17.437
4	Movement	R	Island	I	0.377	22.617
5	Emptying hobbing machine	V	Hobbing	I	1.850	110.973
6	Documents preparation	V	Hobbing	I	0.248	14.864
7	Movement	R	Hobbing	I	0.098	5.86
8	Opening changeover	R	Hobbing	I	0.108	6.49
9	Movement	R	Hobbing	I	0.183	10.991
10	Cleaning hobbing	V	Hobbing	I	0.604	36.251
11	Expander removal	V	Hobbing	I	1.276	76.563
12	Expander base removal	V	Hobbing	I	0.728	43.654
13	Expander base removal	V	Hobbing	I	0.081	4.854
14	Expander base removal	V	Hobbing	I	0.633	37.954
15	Tailstock removal	V	Hobbing	I	1.755	105.28
16	Hob removal	V	Hobbing	I	1.236	74.154
17	Removal of charger hands	V	Hobbing	I	1.656	99.354
18	Chele removal	V	Hobbing	I	1.220	73.223
19	Movement	R	Robot	I	0.157	9.399
20	Removal of robot hands	V	Robot	I	0.358	21.492
21	Control station removal	V	Island	I	0.166	9.954
22	Movement	R	Island	I	0.255	15.321
23	Preparing washing machine	N	Washing machine	I	1.339	80.318
24	Loading washing machine	R	Washing machine	I	1.119	67.15
25	Movement	R	Washing machine	I	0.381	22.884
26	Brush search	N	Hobbing	I	2.202	132.1
27	Internal cleaning with solvent	V	Hobbing	I	1.591	95.467
28	Movement	R	Equipment closet	I	1.682	100.895
29	Equipment recovery	R	Equipment closet	I	1.272	76.326
30	Movement	R	Equipment closet	I	0.731	43.839
31	Washing machine emptying	V	Washing machine	I	1.150	69.006
32	Movement	R	Washing machine	I	0.181	10.886
33	Hob disassembly	R	Vise desk	I	0.523	31.362
34	Hob disassembly	R	Vise desk	I	2.341	140.45
35	Equipment arrangement	R	Vise desk	I	1.673	100.365
36	Consultancy to other operator	N	Outside	I	11.322	679.349
37	Equipment arrangement	R	Equipment closet	I	2.048	122.893
38	Equipment preparation	R	Degausser	I	0.872	52.32
39	Movement	R	Degausser	I	1.251	75.06
40	Movement	R	Degausser	I	0.308	18.48
41	Degaussing equipment	V	Degausser	I	2.143	128.571
42	Movement	R	Degausser	I	0.938	56.304
43	Air cleaning	V	Hobbing	I	1.272	76.293
44	Hob measurement	V	Hobbing	I	1.118	67.091
45	Hob assembly	V	Hobbing	I	2.588	155.297
46	Hob adjustment	V	Hobbing	I	2.905	174.291
47	Tailstock assembly	V	Hobbing	I	2.811	168.645
48	Tailstock adjustment	V	Hobbing	I	3.810	228.596
49	Base support assembly	V	Hobbing	I	2.612	156.716
50	Basic support verification	V	Hobbing	I	0.397	23.81
51	Fixed plug assembly	V	Hobbing	I	1.334	80.046
52	Fixed plug adjustment	V	Hobbing	I	2.354	141.26
53	Charger hands assembly	V	Hobbing	I	2.826	169.551
54	Chele assembly	V	Hobbing	I	1.794	107.624
55	Program loading	V	Hobbing	I	2.242	134.537
56	Movement	R	Hobbing	I	0.252	15.115
57	First piece loading	V	Hobbing	I	0.134	8.033
58	Preparation for deburring dismantling	V	Hobbing	I	0.474	28.426
59	Deburring assembly	V	Hobbing	I	0.960	57.572

60	Deburring replacement error	N	Hobbing	I	3.021	181.23
61	Deburring assembly	V	Hobbing	I	5.294	317.652
62	First piece check	V	Hobbing	I	1.337	80.244
63	Replacing the fixing screw	R	Hobbing	I	4.125	247.503
64	Dimensional check first piece	V	Hobbing	I	0.680	40.802
65	Deburring adjustment	V	Hobbing	I	1.512	90.725
66	Dimensional check second piece	V	Hobbing	I	0.206	12.383
67	Deburring adjustment	V	Hobbing	I	4.270	256.213
68	Movement	R	Hobbing	I	1.064	63.82
69	Dimensional analysis	V	KLINGELNBERG	I	5.568	334.081
70	Movement	R	KLINGELNBERG	I	0.511	30.649
71	Dimensional check second piece	V	Hobbing	I	0.780	46.822
72	Robot hands assembly	V	Robot	I	0.853	51.199
73	Quality check station assembly	V	Island	I	0.355	21.277
74	Micron station adjustment	V	Island	I	0.573	34.374
75	Movement	R	Island	I	0.163	9.802
76	Equipment recovery	V	Chamfering	I	1.117	67.03
77	Chamfering's exchange support removal	V	Chamfering	I	0.916	54.971
78	Movement	R	Chamfering	I	0.285	17.122
79	Movement	R	Chamfering	I	0.215	12.902
80	Deburring removal	V	Chamfering	I	1.062	63.74
81	Chamfering removal	V	Chamfering	I	0.487	29.22
82	Movement	R	Chamfering	I	0.096	5.778
83	Gripping equipment disassembly	V	Chamfering	I	1.285	77.075
84	Movement	R	Chamfering	I	0.168	10.074
85	Gripping equipment disassembly	V	Chamfering	I	0.700	41.994
86	Movement	R	Chamfering	I	0.113	6.784
87	Loading washing machine	R	Washing machine	I	0.751	45.077
88	Movement	R	Washing machine	I	0.345	20.724
89	Air cleaning	V	Chamfering	I	0.728	43.7
90	Movement	R	Chamfering	I	0.137	8.249
91	Deburring pin disassembly	N	Chamfering	I	2.037	122.223
92	Spring pin removal	N	Chamfering	I	1.360	81.624
93	Spring pin problem	N	Chamfering	I	2.064	123.859
94	Movement	R	Chamfering	I	0.450	27.025
95	Spring pin substitution	N	Chamfering	I	1.092	65.524
96	Movement	R	Chamfering	I	0.206	12.357
97	Gripping equipment assembly	V	Chamfering	I	2.499	149.958
98	Movement	R	Chamfering	I	0.132	7.906
99	Chamfering assembly	V	Chamfering	I	0.716	42.975
100	Spring pin problem	N	Chamfering	I	0.483	29.001
101	Movement	R	Chamfering	I	0.435	26.122
102	Movement	R	Chamfering	I	1.526	91.589
103	Assembling equipment for exchanging pcs with robot	V	Chamfering	I	1.494	89.655
104	Exchange equipment adjustment	V	Chamfering	I	1.089	65.318
105	Spring pin problem	N	Chamfering	I	0.444	26.641
106	Deburring assembly	V	Chamfering	I	0.757	45.425
107	Timing sensor regulation	V	Chamfering	I	2.327	139.648
108	Loading program	V	Chamfering	I	0.204	12.247
109	Movement	R	Chamfering	I	0.110	6.575
110	Tools quota adjustment	V	Chamfering	I	0.477	28.629
111	Equipment arrangement	V	Chamfering	I	0.334	20.061
112	Loading program	V	Chamfering	I	0.532	31.923
113	Movement	R	Chamfering	I	0.100	5.978
114	Movement	R	Chamfering	I	0.316	18.952
115	First piece control	V	Chamfering	I	0.683	40.975
116	First piece control	V	Chamfering	I	0.367	22.018
117	Movement	R	Chamfering	I	0.417	25.009
118	Pin spring adjustment	V	Chamfering	I	0.218	13.072
119	First piece control	V	Chamfering	I	0.697	41.826
120	Tools quota adjustment	V	Chamfering	I	0.442	26.499
121	First piece control	V	Chamfering	I	0.616	36.949
122	Movement	R	Chamfering	I	0.192	11.539

123	First piece control	V	Chamfering	I	0.798	47.873
124	Movement	R	CQD	I	1.341	80.483
125	Operator waiting	N	CQD	I	1.949	116.94
126	Explanation to quality operator	N	CQD	I	0.262	15.735
127	Movement	R	CQD	I	0.768	46.091
128	Raw material recovery	R	Island	I	1.463	87.796
129	Blister recovery	N	Island	I	0.457	27.411
130	Preparation of blister holder carriage	R	Island	I	0.372	22.306
131	Movement	R	Island	I	0.460	27.606
132	Piece count to load	R	Island	I	0.388	23.278
133	Movement	R	Island	I	0.228	13.659
134	Piece count to load	R	Island	I	0.180	10.798
135	Start of hobbing machine in change cycle pcs	V	Hobbing	I	0.280	16.802
136	Movement	R	Hobbing	I	0.082	4.897
137	Automatic chamfering start with robot	V	Chamfering	I	0.575	34.497
138	Movement	R	Chamfering	I	0.173	10.364
139	Recall robot program	V	Robot	I	0.993	59.607
140	Resets	V	Robot	I	2.386	143.167
141	Movement	R	Robot	I	0.243	14.571
142	Cycle test	V	Robot	I	0.217	13.037
143	Micron problem	N	Robot	I	21.467	1288.045
144	Micron problem	N	Robot	I	2.716	162.974
145	Movement	R	Robot	I	0.197	11.795
146	Quota adjustment	R	Robot	I	1.907	114.442
147	Movement	R	Robot	I	0.053	3.152
148	Quota adjustment	R	Robot	I	0.857	51.41
149	Movement	R	Robot	I	0.044	2.669
150	Quota adjustment	R	Robot	I	0.228	13.691
151	Movement	R	Robot	I	0.112	6.728
152	Quota adjustment	R	Robot	I	2.963	177.761
153	Movement	R	Robot	I	1.315	78.883
154	Quota adjustment	R	Robot	I	2.175	130.473
155	Chamfering restart	V	Chamfering	I	1.394	83.648
156	Movement	R	Chamfering	I	1.256	75.348
157	Chamfering adjustment	V	Chamfering	I	1.964	117.866
158	Island safety restoration	V	Chamfering	I	0.747	44.822
159	Quota adjustment	R	Robot	I	0.481	28.884
160	Island restoration	V	Island	I	0.971	58.266
161	Quota adjustment	R	Robot	I	5.012	300.708
162	Movement	R	Robot	I	0.573	34.409
163	Quota adjustment	R	Robot	I	0.137	8.19
164	Automatic piece control	V	Hobbing	I	0.438	26.307
165	Measuring bench adjustment	V	Island	I	1.620	97.215
166	Concentricity check	V	Island	I	3.126	187.583
167	Centering pin adjustment	V	Hobbing	I	6.234	374.062
168	Thickness paper search	R	Hobbing	I	0.829	49.762
169	Centering pin adjustment	V	Hobbing	I	2.618	157.086
170	Island preparation	V	Island	I	1.539	92.347
171	Dimensional check	R	Island	I	1.674	100.455
172	Movement	R	KLINGELNBERG	I	0.539	32.353
173	Dimensional check	R	KLINGELNBERG	I	4.004	240.214
174	Movement	R	KLINGELNBERG	I	0.398	23.909
175	Movement	R	KLINGELNBERG	I	0.184	11.039
176	Creating new test piece	V	Island	I	1.240	74.391
177	Movement	R	KLINGELNBERG	I	1.169	70.13
178	Chamfering adjustment	V	Chamfering	I	5.536	332.169
179	Creating new test piece	V	Chamfering	I	2.099	125.919
180	Movement	R	CQD	I	0.816	48.933
181	Quality check	V	CQD	I	2.491	149.453
182	Quality check	V	CQD	I	2.387	143.223
183	Movement	R	CQD	I	0.864	51.843
184	Second piece adjustment on chamfering	V	Chamfering	I	1.337	80.224

185	Movement	R	CQD	I	1.604	96.226
186	Quality check	V	CQD	I	2.428	145.703
187	Island restoration	V	Island	I	2.593	155.567
188	Equipment arrangement	R	Island	I	0.627	37.618
189	Island restoration	V	Island	I	0.304	18.242
190	Compilation of documents for production start-up	V	Island	I	2.072	124.338
191	Set-up closing	V	Island	E	0.407	24.397
192	Hand-over to next operator	V	Island	E	1.237	74.196
193	Robot jam	N	Robot	E	0.509	30.525
194	Production starts	V	Robot	E	0.857	51.428

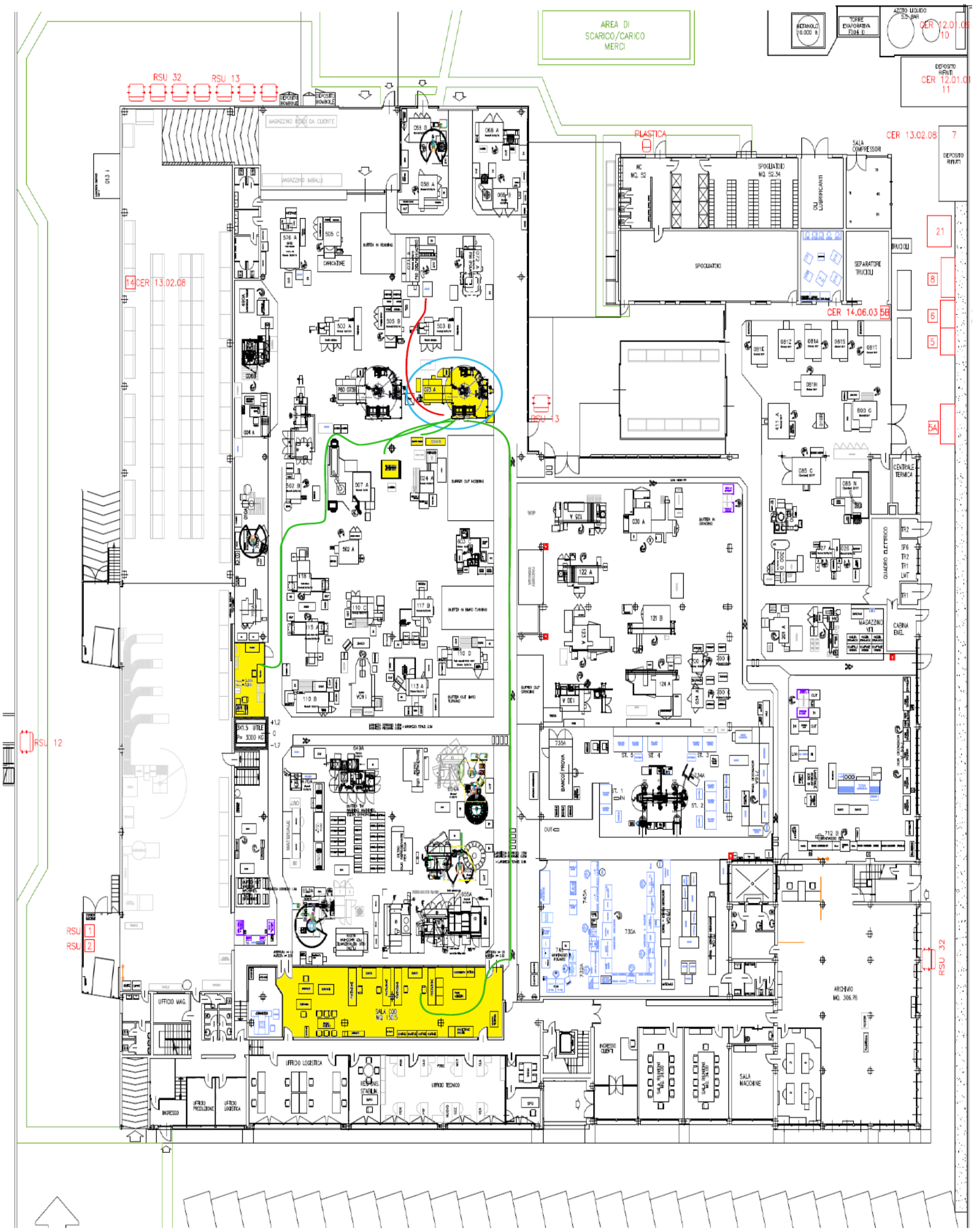
C. 5S method applied to document cabinet and tool four-drawer unit

BEFORE	**AFTER**
Drawer 1 	Drawer 1 
Drawer 2 	Drawer 2 
Drawer 3 	Drawer 3 

Drawer 4	Drawer 4
	

D. 5S method applied to a collector from document cabinet

E. Spaghetti chart TO BE



LEGENDA:

- Information flow
- Materials flow
- People flow

F. Proposed list of operations to carry out during changeover of the 050A hobbing machine (TO BE)

ID	Description	E/I	Elapsed Time (min)	Elapsed Time (s)
1	Blister recovery	E before	0.33	20
2	Documents preparation	E before	0.67	40
3	Preparing washing machine	E before	1.33	80
4	Hob measurement	E before	1.00	60
5	Equipment preparation	E before	0.83	50
6	Movement	E before	0.50	30
7	Movement	E before	0.25	15
8	Movement	E before	0.25	15
9	Counting pieces to load	E before	0.33	20
10	Movement	E before	0.25	15
11	Raw material + blister recovery	E before	1.33	80
12	Preparation of blister holder carriage	E before	0.33	20
13	Movement	E before	0.47	28
14	Measuring bench adjustment	E before	1.58	95
15	Emptying previous production	I	1.33	80
16	Emptying hobbing machine	I	1.67	100
17	Opening changeover	I	0.10	6
18	Movement	I	0.17	10
19	Cleaning hobbing	I	0.50	30
20	Expander removal	I	2.50	150
21	Tailstock removal	I	1.67	100
22	Hob removal	I	1.17	70
23	Charger hands removal	I	1.50	90
24	Chele removal	I	1.17	70
25	Movement	I	0.15	9
26	Robot hands removal	I	0.33	20
27	Check station removal	I	0.17	10
28	Movement	I	0.25	15
29	Loading washing machine	I	1.12	67
30	Movement	I	0.33	20
31	Internal cleaning with solvent	I	1.33	80
32	Emptying washing machine	I	0.83	50
33	Movement	I	0.17	10
34	Degaussing equipment	I	0.83	50
35	Air cleaning	I	0.67	40
36	Hob assembly	I	2.59	155
37	Hob adjustment	I	2.90	174
38	Tailstock assembly	I	2.81	169
39	Tailstock adjustment	I	3.81	229
40	Base support assembly	I	2.58	155
41	Base support assembly	I	0.33	20
42	Fixed plug assembly	I	1.33	80
43	Fixed plug adjustment	I	2.33	140
44	Charger hands assembly	I	2.83	170
45	Chele assembly	I	1.79	108
46	Loading program	I	2.17	130
47	First piece loading	I	0.13	8
48	Deburring assembly	I	0.83	50
49	First piece check	I	1.33	80
50	Dimensional first piece	I	0.68	41
51	Deburring adjustment	I	1.51	91
52	Movement	I	1.06	64
53	Dimensional analysis	I	5.00	300
54	Movement	I	0.52	31
55	Dimensional check second piece	I	0.78	47
56	Robot hands assembly	I	0.85	51

57	Quality check station assembly	I	0.35	21
58	Micron regulation	I	0.57	34
59	Movement	I	0.16	10
60	Equipment recovery	I	0.33	20
61	Exchange support removal	I	0.92	55
62	Movement	I	0.33	20
63	Deburring removal	I	1.07	64
64	Chamfering removal	I	0.48	29
65	Movement	I	0.10	6
66	Gripping equipment removal	I	1.28	77
67	Movement	I	0.17	10
68	Gripping equipment removal	I	0.70	42
69	Air cleaning	I	0.50	30
70	Movement	I	0.14	8
71	Gripping equipment assembly	I	2.50	150
72	Movement	I	0.13	8
73	Chamfering assembly	I	0.67	40
74	Exchange equipment assembly with robot	I	1.49	90
75	Deburring assembly	I	0.76	45
76	Timing sensor regulation	I	2.33	140
77	Loading program	I	0.67	40
78	Tools quota adjustment	I	0.42	25
79	Movement	I	0.25	15
80	First piece check	I	1.67	100
81	Tools quota adjustment	I	0.44	26
82	First piece check	I	1.33	80
83	Movement	I	1.34	80
84	Explanation to quality operator	I	0.25	15
85	Movement	I	0.77	46
86	Start of hobbing machine in change cycle pcs	I	0.28	17
87	Movement	I	0.08	5
88	Automatic chamfering start with robot	I	0.50	30
89	Movement	I	0.17	10
90	Robot program recall	I	0.99	60
91	Movement	I	0.25	15
92	Cycle test	I	0.22	13
93	Movement	I	0.20	12
94	Quota adjustment	I	8.33	500
95	Movement	I	0.25	15
96	Chamfering restarting	I	1.33	80
97	Movement	I	1.17	70
98	Island safety restoration	I	0.67	40
99	Quota adjustment	I	0.42	25
100	Island restoration	I	0.83	50
101	Quota adjustment	I	5.00	300
102	Movement	I	0.57	34
103	Quota adjustment	I	0.25	15
104	Piece automatic check	I	0.33	20
105	Concentricity check	I	2.83	170
106	Centring pin adjustment	I	6.17	370
107	Thickness paper search	I	0.83	50
108	Centring pin adjustment	I	2.50	150
109	Island preparation	I	1.33	80
110	Dimensional check	I	1.67	100
111	Movement	I	0.53	32
112	Dimensional check	I	3.83	230
113	Movement	I	0.40	24
114	Movement	I	0.17	10
115	Creating new test piece	I	1.23	74
116	Movement	I	1.17	70
117	Chamfering adjustment	I	5.50	330
118	Creating new test piece	I	2.00	120
119	Movement	I	0.67	40
120	Quality check	I	3.17	190
121	Movement	I	0.86	52

122	Chamfering adjustment on second piece	I	1.34	80
123	Movement	I	1.60	96
124	Quality check	I	2.43	146
125	Island safety restoration	I	2.50	150
126	Hob disassembly	E after	2.17	130
127	Equipment arrangement	E after	2.50	150
128	Movement	E after	0.12	7
129	Loading washing machine	E after	0.67	40
130	Movement	E after	0.33	20
131	Equipment arrangement	E after	0.50	30
132	Set-up closing	E after	0.40	24
133	Hand-over to next operation	E after	0.42	25
134	Production starts	E after	0.67	40

External activities

Internal activities

Ringraziamenti

Desidero ringraziare tutti coloro che mi hanno aiutato nella stesura di questo elaborato con suggerimenti, critiche e osservazioni.

In primo luogo, il professor Andrea Furlan, mio relatore, per avermi saputo guidare ed indirizzare. Con il suo prezioso contributo mi ha aiutata a raggiungere il mio obiettivo.

Un grazie speciale va a Considi Srl, per avermi accolta e accompagnata in questo percorso. Grazie per avermi sempre fatta sentire a casa.

Infine desidero ringraziare tutto il team di miniGears SpA per l'immensa disponibilità e aiuto ricevuti in questi mesi.