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Exploring Lean Production: Kanban Implementation in the Automotive Industry

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Sommary

Abstract

Lean Production, an approach aimed at enhancing business performance through waste reduction and quality assurance, has gained widespread adoption across various industries since its inception by Toyota in the 1950s and 1960s. This paper provides a comprehensive exploration of Lean Production, tracing its historical development over the past five decades and elucidating its key principles, methods, and benefits. Central to Lean Production is the concept of the "pull" system, which prioritizes customer demand and minimizes waste throughout the value chain. A case study is presented on the implementation of a Kanban project within a PSA production line, focusing on adjusting Work-in-Progress (WIP) while minimizing waste and increasing efficiency. The Kanban system, a visual signaling method, is deployed to facilitate production scheduling and optimize inventory levels. Through a detailed analysis of the production processes for two automotive heat shield components, HS10091 and HS10092, the implementation and results of the Kanban project are discussed. The study highlights the effectiveness of Kanban in achieving a self-feeding production line, reducing WIP, and enhancing overall productivity. By integrating Lean Production principles with the Kanban system, businesses can streamline operations, improve resource utilization, and deliver greater value to customers.

1. The Lean Production

Lean production is an effective and widely adopted approach with the aim to improve the performance of a business focus on cutting waste, whilst ensuring quality to customers. This approach can be applied at the whole chain of stream vale of and industry from the design, the production to the distribution. Developed originally by Toyota in the 1950s and 1960s, it has since become a cornerstone of modern manufacturing and has found applications in various industries beyond automotive. Lean production, often referred to as Lean manufacturing or simply “lean”, is a philosophy and a set of principles designed to optimize processes, eliminate waste, enhance productivity, and ultimately deliver greater value to customers. This articulated description of Lean production will delve into its key principles, methods, and benefits starting from its history and development in the last fifty years.

1.1. The History of Lean Production

In the subsequent paragraph, it will be briefly illustrated the main steps of the lean manufacturing history. The entire evolution is closely tied to the development of manufacturing practices, particularly in the automotive industry. Here is a chronological overview of the key milestones and historical links in the development of Lean production:

1.1.1. Henry Ford and Mass Production Era:

The birth of mass production is closely associated with Henry Ford and his pioneering work in the early 20th century. Ford has revolutionized manufacturing with the introduction of assembly lines, which have had a significant impact on various industries, especially the automotive one.

Henry Ford initiated the concept of a mobile assembly line in 1913 at a factory in Highland Park, Michigan. This innovative approach involved dividing the manufacturing process into a series of simple, repetitive tasks. Each worker was responsible for specific tasks, and the products moved along the conveyor belt, ensuring faster and more efficient production. This reduced the time required to assemble a single car from 12 hours to just 93 minutes[1]. This efficiency led to significant cost savings, which allowed Ford to make it more affordable for the masses and reduce the price of the model T car.

The key to mass production was not the moving assembly line, as many people believe, but "*it was the complete and consistent interchangeability of parts and the simplicity of attaching them to each other"*[2]. Thanks to this revolutionary manufacturing the assembly line was possible and the era of mass production began.

1.1.2. Toyota Production System:

The Toyota Production System (TPS) emerged out of necessity. The fate of post-war Japan was subject to certain market constraints, namely: high-mix, low-volume production under conditions of low demand. These limitations have become the benchmark for testing whether Japanese automakers on the mass production and mass marketing systems already established in the West.

It all began when Kiichiro Toyoda challenged the US to catch up and overtake, Taichi Ohno was one of the first to rise to the challenge. A machine shop owner, Taichi

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[1] Galitsky, C. (2008). Energy efficiency improvement and cost saving opportunities for the vehicle assembly industry

[2] Womack, J. P., Jones, D. M., & Roos, D. (2007). The machine that changed the world: the story of lean production,

eventually used his creativity and genius to develop the TPS. He realized that there was much to learn from American automakers and began to study Ford's production system, gaining a better understanding of the American inventory process. He gradually began to develop new processes, adding his expertise in spinning and weaving to what he had learned from Ford. The development of the Toyota Production System was a long and arduous process, involving years of experimentation and trial and error. As Ohno was given more responsibility, he began to spread his ideas throughout the company.

In his book, The Toyota Production System, Ohno explains that this revolutionary approach is based on two pillars: autonomation and Just-in-Time production. “Autonomation”, often referred to by its Japanese term "Jidoka," is the principle of designing and implementing automatic stops or self-regulation mechanisms in the production process. It combines the words "Ji" (automation) and "Doka" (self-regulation)[3]. Instead, the term “Just in Time” means a method that focuses on producing the right quantity of products at the right time, in response to customer demand. It aims to eliminate waste and minimize inventory levels.

These two Lean pillars, Autonomation and Just-In-Time production, work in conjunction to create a manufacturing environment where quality is assured, waste is minimized, and the production process is finely tuned to match customer demand. They

[3] Ohno, T. (1988). Toyota Production System: Beyond Large-Scale production.

are critical components of the Lean philosophy, enabling organizations to optimize their operations and deliver value efficiently and with high quality.

1.1.3. The Resistance to Mass Production

At the end of 1955, Japan entered a period of rapid growth that was rare in the world economy at that time. It was in 1962, when Japan was on a growth trajectory, that the Just-in-Time, an operational philosophy of the Toyota Production System, was adopted company-wide. It is significant that the Kanban system, which has its roots in Toyota, coincided with this period.

As Japan entered a period of rapid economic growth, and with the courageous calls for doubling in comes, Japanese businessmen seemed to have lost sight of the traditional Japanese way of doing things. They lost sight of Japan's unique economy and society itself. The cause of this "loss of sight" was the acceptance of American mass production and the growing trend toward consumption as a virtue. Large, high-performance machines such as robot or transfer machines were massively introduced into the automobile industry.

Large, high-performance machines such as transfer machines and robots flooded the automobile industry. During the high-growth period, these mass-production machines were effective because anything that could be made could be sold.

1.1.4. The Oil Crisis

The oil shock of the fall of 1973 brought a new development to the Japanese economy: Toyota, which had increased production every year since the 1930s, was forced to cut production in 1974. The entire Japanese industrial sector saw its profits plummet due to zero growth and the shock of production cuts. The results were terrible. At this time, Toyota was less affected by the oil shock and its production system came under the spotlight[4].

During the production cutbacks following the oil crisis, Toyota was confronted with a problem that had been hidden or difficult to see during the previous period of rapid growth. That problem was that of autonomous machines with a fixed number of operators.

This was a major handicap for factories that had to adapt to changes in production. Therefore, the next step in the Toyota Production System was to dismantle the capacity system. This was the "small number of workers" concept. This concept applies not only to machines, but also to production lines where people work. For example, a line with five workers is organized so that even if one worker is absent, four can work on it. However, production is only 80% of standard. To achieve this, the factory layout and equipment must be improved, and workers must be trained to become multi-skilled

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[4] Ohno, T. (1988). Toyota Production System : Beyond Large-Scale production.

workers while they are still normal. Reducing the number of workers means allow in gone, two, or any number of workers to operate a production line or machine. This concept was born out of the need to argue against the need for a fixed number of workers for a machine[5].

1.1.5. The Diffusion of Lean Approach

The proliferation of lean manufacturing in the 1990s was a pivotal time in the history of manufacturing and corporate management. There were several important factors and events that contributed to the widespread adoption of Lean in the 1990s.

One of the most important key factors was the publication of "The Machine That Changed the World" by James Womack, Daniel Jones, and Daniel Roos in 1990. This book systematically compared the Toyota Production System (TPS) with traditional mass production methods, demonstrating the superiority of Lean production in terms of efficiency, cost reduction, and product quality. "The Machine That Changed the World" introduced the term "Lean production" to a global audience, highlighted the principles and tools that underpinned Lean thinking and inspired organizations to explore Lean practices.

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[5] G. Volpato, F. Zirpoli (2011). L’auto dopo la crisi, Francesco Brioschi Editore.

Another relevant factor was the “Benchmarking Toyota's Success”. Many manufacturers, especially in the automotive sector, recognized Toyota's competitive advantage and started analysing its practices with the intent to emulate it. In fact, the 1990s were characterized by increasing globalization and competition. Companies needed to increase efficiency and reduce costs to remain competitive in the global market[6].

Lean manufacturing offered a systematic approach to achieve these goals and became more attractive to companies that wanted to be more competitive. The diffusion of lean production methods in the 1990s laid the foundations for the widespread adoption of lean principles in the following decades. Success stories, increased awareness and a support system of consulting firms, training programs and academic research have contributed to the global acceptance of Lean as a powerful approach to optimizing processes, reducing waste and delivering value to customers.

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[6] Borgatti, S. P., & Li, X. (2009). ON SOCIAL NETWORK ANALYSIS IN a SUPPLY CHAIN CONTEXT. *Journal of Supply Chain Management*.

1.2. The Five Principles of "*Lean Thinking* "

After the success of the publication of first book "the machine that change the world", previously appointed, James P. Womack and Daniel T. Jones defined the five principles of Lean manufacturing and they explained it in a second volume "Lean Thinking: Banish Waste and Create Wealth in Your Corporation", published in 1996. The reason that drove the authors to the study, refinement, and ultimately the generalization of Toyota Production System techniques was the growing interest on the part of the companies, in the ways through which to enact a reorganization process, a kind of general principles that they could leverage in order to "*Lean*"[7].

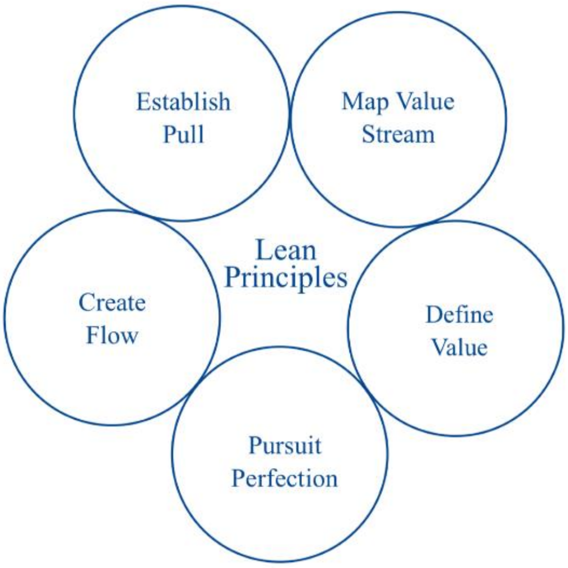

Figure 1, The five Lean Principles

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[7] Womack, J. P., & Jones, D. M. (1997). Lean Thinking—Banish Waste and Create Wealth in your Corporation. *Journal of the Operational Research Society*

Through a thorough analysis of a group of 50 companies they were able to extrapolate "5 Lean Thinking Principles" and their definitions:

- **Define Value**, "Value is what the customer is willing to pay for."
- **Map the Value Stream,** "Every product is the result of a value stream."
- **Flow,** "Make the product flow without interruption through the value stream"
- **Pull,** "Let the customer pull value from the producer."
- **Pursue Perfection,** "As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste."[8]

In the following subsections, these 5 principles will be analysed and explored in more detail.

[8] J. P. Womack, D. T. Jones, "Il pensiero snello in confronto al muda".

1.2.1. The Value

In Lean Production, the concept of "value" is central to the philosophy and methodology. It's crucial to understand what value means in this context, as it forms the basis for all Lean principles and practices. Value in Lean Manufacturing is defined as the worth a customer assigns to a product or service, which includes both functional and emotional aspects.

Lean Production is inherently “customer-centric”[9]. It starts by recognizing that the only meaningful definition of value is what the customer perceives as valuable. Therefore, any activity or process that doesn't contribute to meeting customer needs and expectations is considered non-value-added and should be eliminated or minimized.

It can easily define the value as what the customer is actually willing to pay. Therefore, it is necessary to understand which attributes of the product/service generate perceived value for the customer and aim to improve those and not think about what is most convenient for the company.

[9] Rothwell, R. (1992). Successful industrial innovation: critical factors for the 1990s. R&D Management

1.2.2. The Value Stream

The second application principle of Lean Thinking is the identification of the value stream. Once it has been determined what is of value to the end customer, what he or she is actually willing to pay for, the company will need to focus on the value stream to identify and map how it comes to be realized within the company, sifting through all the actions that lead to the formation of a given product. Value stream mapping is a method by which production plans or, even, entire supply chain systems can be reorganized and activities that do not add value eliminated.

To understand value comprehensively, Lean Production considers three key elements[10]:

1) Value-Added (VA) Activities: These are the steps in a process that directly enhance the product or service and align with customer expectations. VA activities are the core operations that create value. Examples include manufacturing, assembly, design, and other activities directly impacting product functionality.

2) Non-Value-Added (NVA) Activities: they are those that don't contribute to the product or service's quality or functionality and are deemed wasteful. Examples include waiting, transportation, inventory, and overproduction.

[10] G. Graziadei (2006). Lean Manufacturing: Come analizzare il flusso del valore per individuare ed eliminare gli sprechi, Hoepli Editore.

3) Business-Value-Added (BVA) Activities: These are activities that don't directly contribute to the product or service but are necessary for business operations and compliance, such as quality inspections, record-keeping, and certain regulatory requirements.

Value in Lean Production is often visualized through a tool called Value Stream Mapping (VSM). This technique helps organizations map the flow of materials and information from raw materials to the end customer. By distinguishing between value-added and non-value-added activities in the process, VSM highlights opportunities for improvement. Value-adding activities are those that directly contribute to fulfilling customer requirements, while non-value-added activities are waste.

1.2.3. The Flow

"The Flow" is a fundamental concept in Lean Production that emphasizes the smooth and continuous movement of products or services through the entire value stream, from raw materials to the end customer.[11] The goal is to minimize interruptions, delays, and waste in the production process, thereby increasing efficiency and responsiveness to customer demand. The concept of flow is closely related to other Lean principles, such as Just-in-Time (JIT), continuous improvement (Kaizen), and the elimination of waste.

[11] M. Ballé, D. Jones(2007) "FLOW TO LEARN", in ISE: Industrial & Systems Engineering at Work,

The essence of flow is the unimpeded movement of products or services throughout the entire production process. This involves minimizing stoppages, bottlenecks, and interruptions to create a seamless and continuous workflow.

"The Flow" is often achieved through the implementation of a pull system, where production is based on actual customer demand rather than a predetermined schedule. In a pull system, each workstation produces items only as they are needed by the next downstream process. This helps prevent overproduction and reduces excess inventory.

In essence, "The Flow" in Lean Production revolves around establishing a smooth and uninterrupted progression of products or services along the entire value stream. This entails employing tactics like adopting a pull system, minimizing batch sizes, ensuring balanced workstations, and consistently seeking improvements. These strategies collectively aim to enhance the efficiency of the production process, ensuring it is finely tuned to meet customer demand in the most effective manner.

1.2.4. The "Pull"

The core principle of "pull" in Lean Production stands in stark contrast to conventional manufacturing practices. In a pull system, the impetus for production comes directly from customer demand. Unlike traditional methods where goods are produced based on forecasts or predetermined schedules (a push system), a pull system ensures that work begins only when there is a genuine requirement for it[12]. This methodology is strategically designed to achieve several key objectives, including the reduction of waste, the minimization of inventory levels, and the enhancement of overall operational efficiency.

At the heart of the pull system is the synchronization of production with real-time customer demand. In this approach, goods or services are specifically created in response to the moment customers articulate a need. This customer-centric methodology stands in contrast to conventional practices that hinge on forecasts and predetermined production timetables. In essence, the pull system ensures that every manufacturing activity is initiated only when there is a genuine demand from customers, diverging from the predictive and preset schedules characteristic of traditional methods.

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[12] J.-C. Lu, T.-Y. Yang, C. Wang (2011) "A Lean Pull system design analysed by value stream mapping and multiple criteria decision-making method under demand uncertainty", in International Journal of Computer Integrated Manufacturing

1.2.5. Pursue Perfection

At the core of Lean Production lies the principle of 'Pursue Perfection,' which underscores the unwavering dedication to ongoing excellence and enhancement across every facet of a company's operations. This guiding principle signifies the steadfast commitment to attaining the utmost standards in quality, efficiency, and customer satisfaction, portraying an unceasing drive for improvement.

The concept of "perfection" should not be understood as a goal or a methodology that enables the design and implementation of a system that leads to the accomplishment of each set goal. Rather, it should be understood as a challenge, an incitement and stimulus to a continuous improvement process, a kind of provocation, a constant point of reference to strive for.

This path to perfection can be achieved in two ways:

- Through a "*Kaikaku*" of the value stream: through major innovations or changes in technology or organization, exploited in cases where an incremental approach does not occur sufficiently due to high amounts of muda and therefore a radical realignment of the value stream is needed initially.
- Through the principle of "*Kaizen*": taking many small steps, many small changes that allow gradual, incremental improvements to be achieved. This is the most frequently used method of keeping an active regular process of change.

Although concretely an unattainable result, perfection becomes an upper asymptote, a condition that one strongly aspires to but will never achieve. The graph below, Figure 3, represents precisely the asymptotic trend of business improvement versus perfection.

This, however, should not discourage companies, which, on the contrary, should have the will to try to approach it, continuously taking small steps in that direction, trying to keep a process of systematic change (Kaizen) active.

1.3 Muda, Muri, Mura

The above should have made it clear that, for the Lean philosophy, all resources and efforts used to create value for the end customer are justified and well desirable. On the contrary, anything that does not lead to the creation of value but to its destruction, anything that does not lead to an increase in the value perceived by the end customer, is identifiable as muda, i.e., waste, since it produces an unnecessary absorption of resources.

All the actions placed at the basis of Lean thinking, to create a lean enterprise, necessarily lead to the Identification and elimination of these forms of waste. The problem, then, lies in being able to first identify and then eliminate all such waste.

In the 1960s Taiichi Ohno, the father of Toyota Production System, theorized the 7 types of Muras, meaning “futility; uselessness; wastefulness” that can be present within a company that can lead to inefficiencies. This seven wates are:

- **Transport:** transportation waste refers to unnecessary movement or handling of materials, products, or information within a production process.
- **Inventory:** excess raw materials, work-in-progress, or finished goods that exceed what is necessary for immediate production or customer demand.
- **Motion:** unnecessary movement or motion of people within a process, such as reaching for tools or bending to access materials

- **Waiting:** delays or idle time in the production process when a worker, machine, or information is not actively contributing to the value-adding activities
- **Over-Processing:** producing more than what is needed or producing items before they are required by the next process or customer.
- **Overproduction:** performing unnecessary or excessive work beyond what is required to meet customer specifications.
- **Defects:** any errors, mistakes, or rework that result in defective products or services.

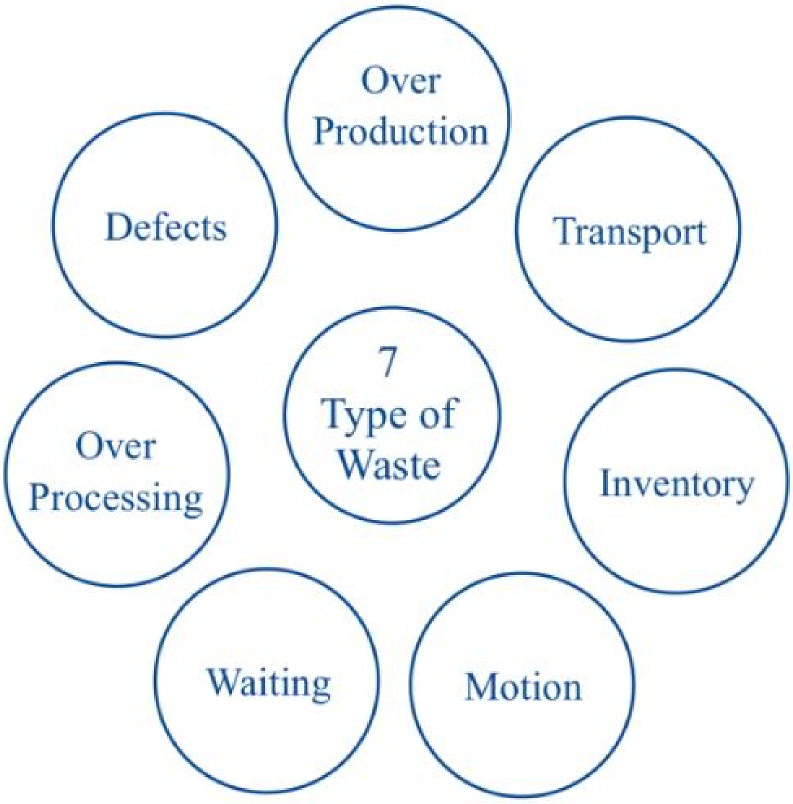

Figure 2, The seven Mudas

In addition to the 7 wastes theorized by Taiichi Ohno, J. P. Womack and D. T. Jones have identified an eighth Muda that they describe in their book "The machine that changes the world," consisting of the design of goods and services that do not meet customers' needs. This type of waste was not theorized by Ohno, as the waste identified by the Japanese engineer referred to a manufacturing company, although they were equally applicable to different realities.

Until then, in fact, the concept of muda had been defined and applied only to manufacturing realities, without proposing a more contemporary redefinition of it applicable to knowledge-based organizations as well. In this sense, a ninth form of waste can be identified, a ninth muda: "any process or activity that absorbs resources in learning, knowledge transfer and creation processes without adding value (e.g., hours of training without significant results, or investment of time and capital in R&D without valuable results)". This ninth type of muda may come into existence in all those companies that consider knowledge creation processes as integral parts of their strategy, whether they are companies operating in the manufacturing sector or considering companies operating in the service sector[13]. At the same time that processes such as learning, knowledge creation and training come to generate this kind of of waste will lose their ability to generate value. Being able to research, identify and eliminate this

[13] F. Abdi, A. Yassemi, S. K. Shavarini, S. M. Seyyed Hoseini (2005) "The 9th Muda: Using Lean thinking concepts for eliminating waste and knowledge creating flow barriers", in Knowledge-Based Economy: Management of Creation & Development

ninth waste, however, is not solely functional for this type of enterprises. The process of identifying and eliminating the "ninth muda" can also be considered useful in initiating a process of transforming enterprises traditional enterprises into learning and development enterprises, an action that is of vital importance in order to be able to reap the benefits of achieving new skills production.

We have defined the meaning of Muda but have not yet discussed the other two negative elements that Lean seeks to combat in processes and that, like Muda, are present widely within every organization: excesses or overloads (Muri) and incompatibilities (Mura)[14].

The term Muri refers to the tension or difficulty that occurs when people, equipment or resources are overcommitted or "overloaded." Emblematic in this regard may be the example of a newly hired worker. Surely the employee in question will not be able to keep up with the "normal" workflow (generating, therefore, walls); rather, he will probably have to endure too high a workload resulting in personal stress. This situation may lead him to make mistakes or, in the worst situation, to hurt himself. Inevitably on these occasions imbalances in work burdens are created. Normally in a company it is possible to distinguish between two different groups of employees: those who perform their tasks "in a hurry," due to overloaded schedules, and those who do not even have a drop of sweat falling from their foreheads, due to underemployment. Thus, overloads of

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[14] T. Southworth (2010) "Muda, mura, muri", in Label & Narrow Web

employees' commitments will occur (walls will occur) as a direct result of disproportions in workloads (also called walls). The same consideration, just made for employees, could be extended to equipment or other resources within the company.

The term mura means, instead, incompatibility. Walls are interruptions in the regular flow of materials or information that come into existence whenever there are irregularities or changes in demand. They can lead to muri (overloads) if they are due to an increase in demand for products, or to underutilization of resources if they are a consequence of a decrease in demand. Unlike muda, it is much more difficult to identify. The only way to be able to notice the presence of walls, and to be able to implement remedies to these forms of waste, is to have managers observe with their own eyes and experience for themselves the conditions their employees are enduring, that is, through the technique of "Genchi Genbutsu," which literally can be translated as "go and experience."

We will now review and elaborate on the seven categories of muda theorized by Taiichi Ohno and mentioned at the beginning of the chapter (figure 3): defective products, excessive production, inventories, unnecessary processes, the movement of people, the transportation of goods, and the queues.

1.3.1 Transport

These are all the operations of transportation from one place to another, from one department to another, which undoubtedly have a cost especially in terms of resources but not only that, sometimes they generate waste related to the handling operations themselves (which for all intents and purposes is additional processing).

Transportation waste can arise from various factors, including excessive distances, frequent material handling, inefficient layout, and inadequate communication between different stages of production. When materials are moved without contributing to the product's value, it can lead to increased lead times, higher costs, and an elevated risk of damage.

The effects of transportation waste include delays in the production process, increased overall lead times, higher operational costs due to fuel, labor, and maintenance expenses, and an augmented risk of damage to materials during transit.

Examples of transportation waste include unnecessary internal movement of materials between workstations, frequent restocking of inventory due to ordering larger quantities than necessary and opting for suppliers that are farther away when local suppliers are available.

Mitigating transportation waste involves optimizing the layout of the production facility to minimize material travel distances. To make this happen, it might be useful to leverage the Spaghetti Chart, "a map of the route that a specific product takes within the plant, so called because the product's route looks, typically, like a plate of spaghetti”[15]. The quantity of lines is plotted against the volumes of WIP (work in process) movement so that critical points of flow entanglement can be identified immediately and intuitively and the layout can be redesigned to avoid precisely these nodes.

1.3.2 Inventory

Inventory waste in Lean production refers to the accumulation of excessive quantities of raw materials, work-in-progress (WIP), or finished goods within a production system. This waste, identified by Lean manufacturing pioneers James P. Womack and Daniel T. Jones, occurs when the amount of inventory exceeds what is immediately necessary for ongoing production or customer demand.

This waste can be attributed to various causes. Overproduction, where more goods are produced than the current demand requires, is a significant contributor. Uncertain demand forecasts can lead to overordering of materials, while long lead times in the supply chain may necessitate holding larger inventories to prevent disruptions. Traditional batch processing methods, which often involve producing more than needed to meet certain batch requirements, can also contribute to inventory waste.

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[15] T. Pyzdek, P. Keller (2010) “Analyze Phase”, in T. Pyzdek, P. Keller, The six-sigma handbook: A Complete Guide for Green Belts, Black Belts and Managers at All Levels, Mc Graw Hill

The effects of inventory waste are multifaceted. Excessive inventory ties up capital that could be utilized elsewhere in the business. Maintaining large inventories incurs additional costs for storage space and associated logistics. Furthermore, it can result in the disposal of obsolete or perishable goods. High inventory levels can also limit a company's flexibility, making it challenging to adapt to changes in customer demand or market conditions.

Various examples illustrate inventory waste, such as bulk ordering of materials without considering immediate production needs, maintaining excessive safety stock levels to mitigate perceived risks of stockouts, and overproducing to meet traditional batch processing requirements.

Mitigating inventory waste involves implementing Lean principles such as Just-in-Time (JIT) manufacturing, where materials are received and goods are produced precisely when needed. Kanban systems, which use visual signals to trigger replenishment only when necessary, are also effective[16]. Reducing batch sizes aligns production more closely with actual demand, while improving demand forecasting accuracy helps in making informed inventory decisions.

Addressing inventory waste in Lean production is essential for optimizing resource utilization, reducing costs associated with excess inventory, and improving the overall

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[16] L. P. English (2005) "IQ and Muda: Information Quality Eliminates Wastes"

responsiveness of the production system to market demands. The aim is to maintain an optimal level of inventory that supports production without unnecessary excess, thereby promoting efficiency and profitability.

1.3.3 Motion

This form of waste arises whenever internal staff in a company are forced to move more than necessary to perform their work for three kinds of reasons:

- poorly designed workstations cause employees to have difficulty reaching tools or are forced to walk too far to perform their duties.
- The tools or equipment used most often are not easily accessible.
- The production line is disorganized.
- Excessive space is present between multiple workstations.

The motivation that leads employees to move more than necessary and produce muda, therefore, lies in an unsuitable arrangement of equipment, people and machinery within the corporate structure. It is possible to hinder unnecessary movement by trying to create a work environment in which men, machinery and equipment can interact in an environment of harmony and organization. Some among the solutions possible are to improve the accessibility of tools and equipment and try to not to have work areas that are larger than one's needs. The result is reduced lead time, decreased tooling time, and increased concentration on the part of employees.

1.3.4 Waiting

The waiting times are equated with the time wasted in downtime waiting for consumables or information, and are due to the unavailability of the same, plant breakdowns, defaulting workers, retooling, excessive internal bureaucracy, or problems due to not having done proper leveling of production stages, leading one stage to have to wait for the other. The timing of the waits that have thus come about are comparable to the differential value between the lead time (the time of crossing) and the actual processing time.

Waiting waste arises from unbalanced workloads, where uneven distribution of tasks results in bottlenecks and one stage of production waiting for others to catch up. Inefficient processes that are not optimized can cause delays, contributing to waiting waste. Poor synchronization between different production stages can lead to waiting as each stage waits for the completion of tasks in the previous stage. Additionally, inadequate communication may result in waiting for necessary instructions or approvals.

The consequences of waiting waste include reduced overall productivity, longer lead times in the production process and potential negative effects on employee morale as they experience frustration and dissatisfaction during periods of waiting. Examples of waiting waste include waiting for materials to arrive on time, waiting for the availability of equipment or tools, and waiting for crucial information or approvals to proceed with the production process.

To mitigate waiting waste, it is crucial to balance workloads, ensuring tasks are evenly distributed to prevent bottlenecks. Optimizing production processes by eliminating unnecessary steps helps reduce waiting times. Improving communication channels is essential to ensure timely information flow and minimize delays. The use of visual management tools, such as Kanban boards, provides real-time information on work status, helping reduce waiting times and improve overall efficiency.

Addressing waiting waste is integral in Lean production to create a smoother, continuous flow of work without unnecessary delays, ultimately ensuring that each step in the production process adds value to the final product.

1.3.5 Over-Processing

In the world of Lean production, over-processing is like going the extra mile when it's not necessary. Imagine you're adding features to a product that no one really cares about or spending way too much time polishing something that's already good enough. It's essentially doing more work than needed, and that's a waste.

This kind of waste happens when there's a bit of confusion about what customers actually want or when processes get a bit tangled up with unnecessary steps. Sometimes, it's just because things are unnecessarily complicated. The effects? Time takes a hit because you're spending longer on each product, costs go up due to all the extra effort, and you end up with less room to do the stuff that really matters. For instance, imagine inspecting a product way more times than needed - it's like checking your pizza delivery five times before it reaches your door. It's just not necessary, and it slows everything down.

To deal with this, Lean production suggests getting a clear map of your workflow to weed out the unnecessary stuff. Standardize the way things are done so there's no room for unnecessary extras. And hey, always be on the lookout for ways to make things better – it's a continuous improvement kind of vibe.

Tackling over-processing is key in Lean production. It's about delivering what the customer wants without all the unnecessary fluff. Streamlining things not only saves time and money but also ensures that what you're putting out there is top-notch. Less waste, more value – that's the name of the game.

1.3.6 Overproduction

Overproduction, a key concept in Lean manufacturing, occurs when a company produces more goods than the current demand necessitates or before they are required in subsequent stages of production.

The causes of overproduction include inaccurate demand forecasting, lengthy production runs without consideration of actual demand, and inefficient production processes. These factors contribute to the accumulation of excess inventory, leading to various negative effects. Instead, the main effects of overproduction include the presence of surplus inventory, longer lead times in the production process, increased carrying costs for storage and maintenance, and an elevated risk of obsolescence for overproduced items.

The only way to avoid its formation is to make sure that the output level of a given production stage does not exceed the capacity of the next one, so as not to "push" processing to a stage that would not be able to process the good immediately. Finally, the last stage of processing will come to be in line with the final demand, which, in this case, could be equated with the capacity of the "final production stage." Following the thrust of this reasoning, it is intuitable how, in order to remedy the wastefulness of overproduction, it is necessary to try to adopt a Pull (as explained in the paragraph 1.2.4).

Addressing overproduction is essential in Lean production as it enables companies to optimize resource utilization, reduce costs associated with excess inventory, and improve responsiveness to customer demand. The overarching goal is to produce only what is needed, when it is needed, eliminating waste and enhancing the overall efficiency of the production process.

1.3.7 Defects

The last but not least muda is the "defects" or "defective products". Taken together, they constitute the set of nonconformities to certain quality standards required for a given product that lead to its not being placed on the market or, if quality control has not done an appropriate job of verification, to receiving a return or a complaint from its customer. The product that does not meet quality standards may be the result of an employee's error or machinery malfunction. This leads, inexorably, to a burden on the cost structure because of rejects and operations performed for rework. The generation of defective products can also lead to serious image damage, to the reputation that customers have of the enterprise. In order to minimize the impact on the cost structure, and thus at least decrease the amount of muda produced, the enterprise should try not to totally discard defective products but somehow try to recover them through the implementation of accurate waste management processes, so as to reduce the impact at the economic level. The main causes that lead to the formation of defective products are misunderstanding (or inability to meet) customer needs, lack of job skills or teaching ability of managers, and poor product quality. "The secret to keeping defects under control is to continue to research what causes them and use diligence to prevent them from recurring. When problems arise, one must find the root cause of the defect and, then, try to work out its solution."[17]

[17] R. Minardi (2017) "Muda: The 7 Deadly Wastes, eliminating common sources of unnecessary excess".

1.4 The “House” of Lean

So far, we have focused on the five principles of Lean thinking, as outlined by Womack and Jones in the book of the same name, and on the seven wastes (muda) with the related concepts of overload (walls) and incompatibility (walls), identified by Taiichi Ohno. What is still missing for a more comprehensive treatment of Lean Production is the set of techniques, tools and procedures that are required to implement lean production. Some of these elements have already been mentioned briefly throughout the previous pages without, however, receiving the attention they deserve. The set of techniques that will shortly be described are based on a common prerequisite: all operators and employees must be included in an active and full involvement in every operation, production stage or decision so that they can make the most of all the skills and knowledge spread within the enterprise (and avoid incurring what Ohno termed as muda resulting from an underutilization of company personnel).

The fundamental elements of lean manufacturing can be graphically represented as a "house," a system that works efficiently and effectively only if all its component elements work well together. Just like building a good house, the implementation of lean manufacturing also requires not only to behave like a system but also to be built from the bottom up. It will need to start from a solid foundation large enough to be able to support the rest of the building, passing through strong pillars or columns to eventually be able to build a roof over it representing the result, the culmination of the efforts mad.

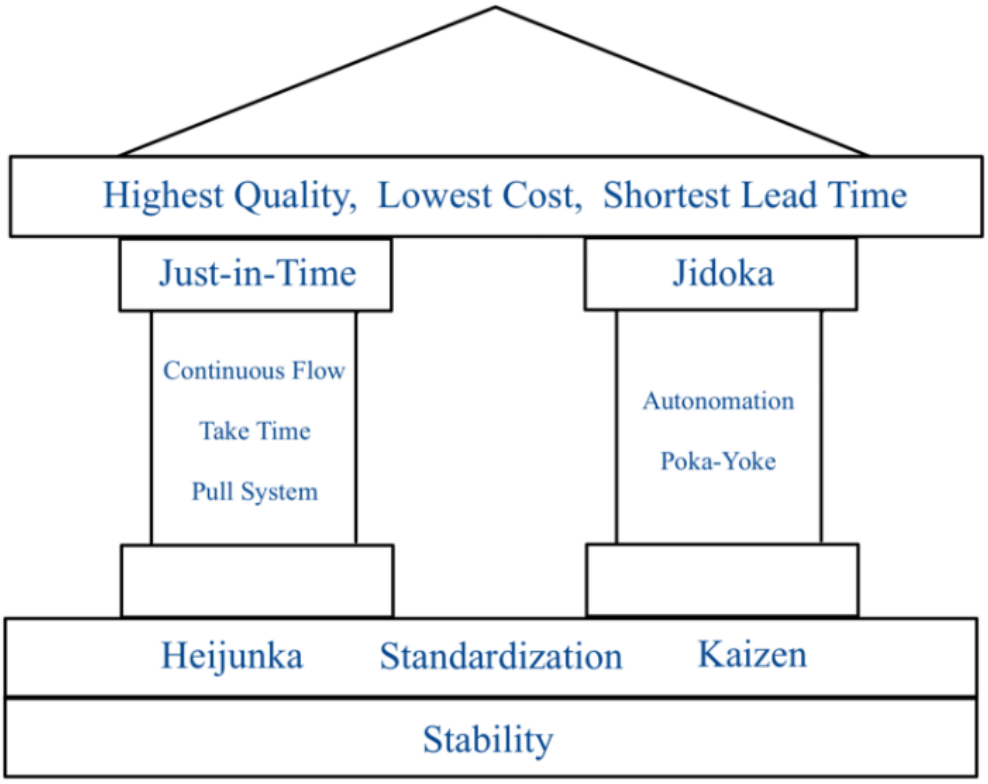

Figure 3, The House of Lean

Underneath the whole house, in order for it to stand, there is a need for stability. Stability is provided by "highly trained personnel and impeccably maintained machinery that work reliably and succeed in meeting standards"[18]. The bases are essentially composed of three basic elements:

- The leveling of production or workload (Heijunka).
- The standardization of work.
- Continuous improvement (Kaizen), which can be implemented through the use of the Cycle of Deming cycle (also called the PDCA cycle) and what is commonly called "A3," a tool that is used for problem solving.

There are essentially two pillars, or rather pillars:

- The Just-In-Time which is composed of the Pull system, the unit flow and the Takt Time (and rests on the use of Kanban).
- Autonomation (Jidoka), which can be achieved through the design of processes that stop when they detect abnormalities and the separation of human and machine work in a context where there are fail-safe systems (Poka-Yoke).

These two pillars have "zero goals" and they are the production of zero inventory (for the Just-In-Time) and zero defects (for the Jidoka). The combination of these two elements and these two zero objectives, then, should lead to the generation of zero waste, i.e. to the elimination of muda. The end result of implementing all these tools or

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[18] J. K. Liker, G. L. Convis, “Il TPS crea sfide che impongono lo sviluppo delle persone”, in J. K. Liker, G. L. Convis, L. Attolico (2016) Toyota Way per la Lean Leadership: Raggiungere e mantenere l’eccellenza in azienda.

techniques should be the creation of greater value and, in turn, lead to the satisfaction of three types of parties:

- Customers: since they will benefit from higher quality, lower costs and a significantly reduced lead time significantly reduced.
- Employees: who, on the other hand, will benefit from greater security and satisfaction relative to the workplace and remuneration as well as active participation in business decisions.
- The company: will improve from the standpoint of flexibility and profits (as a consequence of both reduced production costs and increased revenues).

The roof of our house, the overall goal of implementing Lean Production becomes, therefore, the elimination of waste (muda) and offering goods or services of high quality, at a reduced price (lower purchase price for the consumer and overall higher profitability for companies) and with very short lead times. The following discussion will start with the two main pillars of the Toyota Production System (the Just-In-Time and the Jidoka) and then dwell on the foundations (Kaizen, work Standardized and Heijunka).

1.4.1 The "Just in Time"

The first pillar of Lean Production that will be covered is Just-In-Time (JIT). The father founder of such a production system was Kiichiro Toyoda when, as a consequence of his stay in the United States, he began to organize differently the production apparatus of his own company. In later years, other companies also Japanese, and later also those located in the rest of the world, began to adopt the production system that had been developed internally by the Toyota.

The definition of JIT may have subtle differences among the various authors. All of them, however, seem to agree that it represents "a general philosophy for reducing waste and improving product quality"[19]. It is based on the concept of producing only what is needed and only when it is demanded, that is, at the moment when the end customer moves his or her demand for a specific good or service while avoiding advance production. In fact, it is the way through which lean manufacturing, through a set of techniques or tools, optimizes the supply chain and logistics by "requiring (at the same time) perfect timing between production line and suppliers to ensure that purchased materials are delivered only when needed".[20]

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[19] K. A. Brown, T. R. Mitchell (1991) "A comparison of Just-In-Time and batch manufacturing: the role of performance obstacles", in Academy of Management Journal

[20] A. Simboli, R. Taddeo, A. Morgante (2014) "Value and Wastes in Manufacturing. An Overview and a New Perspective Based on Eco-Efficiency", in Administrative Sciences

As opposed to the pull philosophy, the idea is to produce only what you have already sold, or are on the verge of selling, and not to make something that you hope to sell in the future. In fact, as we previously mentioned, JIT has as its goal the generation of "zero inventory." It is an inventory management policy that attempts to bring greater efficiency to the upstream stages of a production process, especially to supply operations, so that materials can be sourced and related processing operations carried out when the more downstream processes require it. What JIT thus enables is an alignment, a synchronization between what the enterprise offers its customers and the demands they make in the form of market demand.

The end result of using such a system is the elimination, or at least a significant streamlining, of warehousing. If we take an example of three directly sequential steps A, B and C, in fact, step B will activate the upstream process (A) only to draw on the materials it actually needs and at the time when the process (C), located further downstream, demands it. For all this to be possible, the stages located closer to the end customer will have to have a way of communicating to the sequentially preceding processes the quantity and type of materials they will need to make. It is precisely for this purpose that Kanban report cards are exploited in conjunction with the exploitation of SMED (Single Minute Exchange Of Die), a methodology through which set-up times can be reduced, thereby making the production system more flexible and versatile.

The starting point of the SMED methodology is to divide setup time into two distinct types of operations:

- Operations that necessarily have to be carried out when the machinery are stopped, called FDI (Inside Exchange of Die).
- Those operations that can take place when they are in operation, called OED (Outside Exchange of Die).

After classification and subdivision into these two categories, the possibility of carrying out IED operations when the machinery is in operation is screened out, so as to be able to speed up the timelines related to retooling. If this is possible, a redesigned a new set-up cycle (thus a new system of procedures) and advances through to a more critical analysis of the remaining IED activities to be able to see if it is possible to decrease their duration.

The combined use of Kanban and SMED leads to the elimination of "downtime" and a consequent reduction in throughput time. The result is the creation of high flexibility, the creation of a "pulsating production system" that is capable of adapting to market demands and trends. Thus, the JIT becomes the primary tool through which a Lean enterprise should relate to the market, always trying to keep in mind as its primary goal customer satisfaction and to create value for the customer. The JIT is essentially broken down into three elements, which will be explained in the paragraphs immediately following:

- The Pull System
- The One-Piece-One-Flow System
- The Takt Time

1.4.1.1 The Pull System

As previously announced, Pull logic is contrasted with traditional, mass-production-related systems that follow Push logic. The criticality of these "old" systems lies in not being able to match what is produced to actual demand since scheduling takes place prior to actual demand coming from the market. In contrast, the adoption of a Pull logic makes it possible to produce only as much as the customer, located downstream in the production process, requires a given good and/or service. In fact, in order to be able to manage production scheduling in advance of the demands coming from the market, traditional production systems made use of complex forecasting systems by exploiting historical data or mathematical models. In these cases, computer systems that absorbed a great deal of time and resources and, many times, produced results that did not live up to the effort expended proved to be of paramount importance. This type of approach required materials to arrive at the company at a time before customer requests through forecasts that, if proven wrong, led to the generation of a large amount of inventory. Push-type production models, then, exploited MRP (Material Requirements Planning) management systems through which forecasts were made relative to demand and incoming orders. First assumptions were made relative to market trends, then the components or materials needed were calculated, and finally the exact time in which these were to arrive at the company. What characterizes production systems of this type is the presence of a series of processing stages alternating with periods when material allocates in buffers.

For these very reasons, the Lean philosophy turns out to be a step forward from to the traditional approach. In fact, since it does not require the use of models forecasting, the only elements on which it relies to set up the planning of its its production are the customers, who require the goods or services according to their own needs and/or requirements, and the suppliers, who arrange the raw materials so that the production can meet as and when required by the customer. A Pull logic makes it possible to minimize the time between the request made by customers and its complete satisfaction. But this is only possible in the presence of a supply chain with high robustness and flexibility that enables the delivery of materials in great speed, even if the demands were to be characterized by both meager quantity and great variety. The flexibility and robustness of the organization that is, it should be such that it can produce the most diverse quantity of products in very small (if not unit) batches, readjust quickly and, at the same time, be able to respond very quickly to market demands. It is the high variety and speed of change that characterizes today's market that leads the same companies to lean toward these increasingly flexible Pull systems that seek to eliminate or minimize the amount of inventory.

Pull-type systems can be divided into three types[21]:

- **Sequential**: In a sequential type Pull system, most of the products are made-to-order and a FIFO (First In First Out) view is maintained throughout the production flow from downstream to upstream. The objective of production scheduling, where this type of system, is to try to determine a balance between quantity and the mixes offered. For this whole system to work properly, it is essential to the insertion of Kanban tags inside Heijunka Box at the beginning of each work shift. It is mostly exploited when the number of components that should be kept in Supermarket is excessively high.
- **Supermarket**: in this second setting between two phases there is a Supermarket, a kind of warehouse in which a certain amount of output from the most upstream phase can be found that will serve as input to the phase immediately further downstream. In a Supermarket Pull System each process will produce an amount of materials equal in magnitude to the restoration of what is taken from the downstream process. Since each process is responsible for maintaining and restoring its own Supermarket, the warehouse in which the components produced by the process are stored, opportunities for improvement or critical issues in that particular phase are more readily identifiable. When portion of this material is withdrawn by the downstream process (which will use it as its own

[21] A. Smalley, Connecting Assembly with Batch Processes Via Basic Pull Systems, in Lean Enterprise Institute

input) the upstream process will be informed of the need to restore the initial Supermarket by taking advantage of the Kanban tag mechanism.

- **Mixed**: When a combination of Supermarket and sequential system is simultaneously used, it is called Mixed Pull System. This type is the most widely used and allows the simultaneous exploitation of Kanban tag insertion in the Heijunka Box and the system of restoring the very Kanban tags used for Supermarket.

What has been described so far should have made it clear that the major discrepancy between Pull and Push systems lies in the ways in which the provisioning system is used. Push systems by exploiting the MRP technique and forecasting systems, while Pull systems by having customers "pull" the acquisition of needed materials.

1.4.1.2 The One-Piece Flow

The second element required to operate in a JIT logic is the one-piece flow system, which can be literally translated from English as "single piece flow" or "unit flow." This system makes it possible to organize production in such a way as to move a single piece at a time along a production process characterized by high flexibility, a necessary condition for being able to compete in an environment characterized by an increasing demand for customization of products with an increasingly short life cycle[22]. Flexibility is given to this system primarily through the ability to change the product model at each step while maintaining, at the same time, a continuous flow along which materials proceed without the occurrence of waiting or the accumulation of intermediate stocks. It is precisely here that being able to properly manage set-up times through proper application of the SMED methodology becomes relevant. In addition, unit flow should be facilitated through what are called U-shaped production lines, of the special cell production types used in the Just-In-Time (JIT) production system[23]. This system consists of sequentially arranging small machines in such a way as to form a horseshoe. Within this horseshoe the various operators will move while the machines will have a processing proceeding from the inside to the outside. In this way, the work of the operators and the work of the machines will be independent of each other. While the machines will be busy machining a particular part, in fact, the operators will be freer to move within the U-shaped layout and, in this way, they will be able to control the work of several machines at the same time and be able to carry out the various product control operations before it has to move on to the next stage next.

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[22] J. Miltenburg (2001) “One-piece flow manufacturing on U-shaped Production lines”, in IIE Transactions.

[23] J. Miltenburg (2001) “U-shaped Production lines: A review of theory and practice”, in International Journal of Production Economics

The main advantages of applying a unit flow system are:

- flexibility, in terms of speed of response and adaptability of the production.
- Higher quality of the products offered, as errors or defects jump to the eyes as soon as they occur (since these can be identified at the moment the product is examined and checked between two stages).
- Smaller warehouse size, freeing up resources that can be leveraged in other ways.
- Use of smaller machinery and equipment, occupying, thus, less space.
- Less handling of goods (especially large ones), which increase safety in the workplace.
- Increased simplicity in the procurement process, since the missed of processing are more easily detected.

1.4.1.3 The Takt Time

The third element that characterizes a JIT inventory management policy is Takt Time, the optimal production rate to succeed in reducing inventory quantities. It is a time indicator for linking production to demand, and the pace of realization to that of sales. Technically it is "the maximum time in which a finished product must come off the production lines to meet customer, or market, demand[24]" It is a most useful tool for being able to set the pace that production must follow to be able to eliminate, or at least try to avoid, the creation of muda in the form of waits or bottlenecks.

A proper calculation of Takt Time, should succeed in minimizing the time of customer wait and level out the amount of daily orders. That is, it allows us to understand at what speed our process should go to be able to meet the demands of customers. Algebraically, it is calculated as the ratio of work time (expressed in hours per day) and the number of customer requests (expressed in number of pieces per day), indicates the amount of time in which a unit of product must be made.

In formula:

$$Takt\ Time = \frac{Available\ working\ hours}{Customer\ Demand} \tag{1}$$

However, this indicator should not be confused with cycle time or even lead time. Lead time, in fact, represents the time between the receipt of a product request and its fulfilment (it is the total lead time). Cycle time, on the other hand, represents the actual lead time, the hours of manual labor that went into fulfilling a given order. In this regard, it is useful to note that from the relationship between cycle time and Takt Time

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[24]AA VV (2010) “Dimensionamento di massima e bilanciamento”, in Bonfiglioli Consulting, Il Lean Thinking dalla produzione alla progettazione: Pensare snello in ufficio tecnico per innovare la progettazione e diventare più competitivi.

it is possible to determine the number of operators or people required to fulfill that particular job order.

$$Number\ of\ Worker = \frac{Cycle\ Time}{Takt\ Time} \tag{2}$$

Through the calculation of cycle time, Takt Time and the resulting number of people required to fulfil a job order, it will also be possible to determine the optimal amount of people required in each production cell. It will then be possible to carry out the necessary adjustment operations in the event that there is a surplus of personnel within each cell, or if there is a shortage of personnel within that cell.

1.4.2 The Jidoka

The second pillar of Lean Production, traceable to Sakichi Toyoda, is Jidoka. The word Jidoka in Japanese can be literally translated as "autonomation," while in a looser translation it can be understood as "automation with a human touch"[25]. It is a system used to refine business quality, to be able to bring more value into the enterprise by relying essentially on two gimmicks: one mechanism to detect any errors, or defects, and another to stop production when they occur[26]. In other words, in order to take advantage of a Jidoka-based system, it is necessary for the design of the machinery to go so far as to "untie" the operators from the machinery. In this way the people directly involved in the creation process can add value of their own. In fact, if "adjustments are made (to process or product quality) only when machinery is found to be producing defects, the implementation of automatic defect control may be exactly what is needed to achieve other improvements to processes (or products)"[27].

As has been pointed out earlier, the goal of implementing Jidoka is to realize a system capable of eliminating the presence of errors and defects. It can be said that through the adoption of such a system it is possible to achieve a level of 100% quality. An organizational model that is based on the use of plants that are able to stop when the

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[25] J. X. Wang (2011) "Jidoka: Implement Lean Manufacturing with Automation", in J. X. Wang, Lean Manufacturing: Business Bottom-Line Based, Taylor & Francis Group

[26] Y. Monden (1983) "Toyota Production System: A Practical Approach to Production Management", in Industrial Engineering and Management Press

[27] 7 E. L. Porteus (1990) "The Impact of Inspection Delay on Process and Inspection Lot Sizing", in Management Science

integrity of the output is no longer assured, thus giving quality no longer the final stage of the production chain but an integral part of the process and built within it. To achieve this goal (the goal of "zero defects" or "total quality"), however, it is not enough to engineer the production so that it stops when errors occur. It also requires the presence of employees with characteristics in cognitive terms that make them suitable to these methodologies. In fact, as Kiichiro Toyoda himself said, "there are the ideal conditions for production when machines, facilities and people work together to add value without generating any kind of waste."

Whether we are talking about highly automated processes or in the case where there is a high incidence of manual labour in the operations to be carried out, the stop in case of not total quality is applied. In fact, if in the first case it is the plants that are equipped with devices to stop production in case defects are detected, in the second case it is the operators who control and have to suspend production at the same instant they reach the detection of a problem. Compared to a traditional production approach, each employee or worker becomes responsible if only in a small part for quality control generating greater motivation for workers as a result of active participation in problem solving.

The tools on which a Jidoka system is based are basically three:

- The Poka-Yoke
- The Five Whys
- Visual control systems (such as Andon signs)

1.4.2.1 The Poka-Yoke

The Japanese term Poka-Yoke refers to a set of devices or contrivances that make the work of personnel error-proof. Through the exploitation of these devices, it is possible to prevent the creation of errors in the production process and to verify whether or not what has been performed (or what is about to be performed) has been done accurately or not. This can be done in three ways: by preventing the error, by highlighting the error so that it can be corrected immediately, or by stopping the production process and preventing the proliferation of further errors.

Through the exploitation of Poka-Yoke tools, it is possible to greatly reduce working time, and costs, as you can do your work optimally from the first time you do it, limiting inspection or control operations and staff training costs.

1.4.2.2 The Five Ways

The goal of using Jidoka is to be able to separate workers and machines. In this way, the machines no longer require continuous observation during their operation, and the staff is able to generate a surplus of value. In fact, if the staff or attendants performed as their only task to observe the plants in operation, muda would be generated as a consequence of having man and machine perform a task that could likewise be performed by only one of them. However, it is necessary to develop and train personnel both in cognitive terms and in terms of their predisposition for problem solving.

A useful method for harnessing the intelligence of employees, so as to increase even more the value they bring to the company, is called the "Five Whys Method." The "Five Whys" technique consists of a series of questions to search for cause-and-effect relationships behind a given problem: when faced with a given issue, an employee should ask himself at least five times why and try to give himself an answer. According to this approach, if one stopped at the first why (the first question that searches for a cause-and-effect correlation) one would not actually perceive the actual problem and would stop at the surface finding a solution that does not always solves it completely. Instead, by asking the question at least five times why when faced with faced with a problem, one is able to identify the actual causes of a given problem and, thus, succeed in solving it completely and permanently.

1.4.2.3 Visual Control System

Within Lean enterprises it is common to adopt visual control systems such as Andon signs. The word Andon was initially used to denote a paper lantern that served the function of a signal light, while within Lean enterprises it began to "denote a light signal, or a series of signal lights, employed in signaling a problem or blockage in a production line or part of a process"[28]. Light signals, for example, could be similar to those of a traffic light in which green means that all is well, orange that there is a need to draw attention to some problem encountered (such as an example, a breakdown) and red that production is stopped.

1.4.3 The Heijunka

Having dealt with the two pillars on which the house of Lean stands, its foundation will now be explained. The first basic concept on which the construction of a lean enterprise stands is that of Heijunka, which can be defined as the leveling of production in terms of mix and volume for a defined period, dependent on the characteristics of the business, with the goal of achieving a constant flow of components. Being able to level production in a way that avoids waste, being efficient while being able to be effective with respect to market demands, is one of the biggest challenges that businesses seeking to adopt a lean-minded philosophy try to address. It is precisely being able to create a balance in workload that allows the pillars of the Lean house to be developed and implemented. The setting of a correct Heijunka allows to optimize the production planning managing to manage a lot of small quantities and, despite this, maintaining

[28] P. L. King (2017) "Strumenti Lean che necessitano di piccole modifiche: Gestione a Vista", in P. L. King, Lean Thinking per le aziende di processo: Gestire la complessità senza sprechi per essere più flessibili e veloci

unit volumes and costs lower than a traditional system based on a high exploitation of economies of scale. As mentioned above, Heijunka production requires the levelling of the type and quantity to be produced in a certain period of time to be able to improve the company's performance and to be able to better manage customer requests, while maintaining an insignificant number of products in stock[29]. This amounts to asserting that there are two different types of levelling: that of the production volume and that of the production mix (or demand). Volume levelling is the ability to produce a constant daily quantity of product over a period of weeks that is equal to the daily average of long-term demand. The levelling of the mix, on the other hand, requires that the variety of products to be produced be distributed equally over a given period of time.

1.4.4 The Standardized Work

The second cornerstone of proper lean company building is standardization, a powerful tool used to succeed in achieving excellent results. Indeed, from the earliest applications of Lean theories, Toyota executives had recognized that "the devil is in the details, [...] it must be ensured that all work is highly specified in terms of content, sequence, timing, and outcome. [...] The requirement that every activity be specified, (as well as

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[29] K. Furmans, "Models of Heijunka-levelled Kanban-Systems", in 5th International Conference on Analysis of Manufacturing Systems-Production and Management

every form of connection and communication), is the first unspecified rule of the system."[30]

The standardized work being illustrated, however, is not the one being taken to extremes by Charlie Chaplin in the film "Modern Times," in which the actor plays the role of a worker subjected to high work rhythms that produce depersonalization. It is a set of instructions that explain in a structured, but at the same time simple and immediate way, the methodology by which the various operations are to be carried out and is an indispensable tool for the proper setting of a production levelling.

Standardization proves to be very useful in channelling the production system within preset tracks and in trying to set up a set of activities designed to always seek improvements in work procedures. The lack of any form of standard, in fact, would result in continuous variations in how various operations are carried out with the consequent impossibility in being able to point out the presence of improvements or make the implementation process benefit from learning economies. Proper standardization of work occurs through the application of three basic concepts, which are Takt Time, Working Sequence and Standard In-Process Stock. The meaning of Takt Time has already been clarified when Just-In-Time was discussed. Working Sequence, on the other hand, defines the sequence of operations that must be constant and unique

[30] S. Spear, H. K. Bowen (1999) "Decoding the DNA of the Toyota Production System", in Harvard business review

for a given process. Finally, with the concept of Standard In-Process Stock, we mean the minimum amount of components or equipment that must always be present at a given workstation.

The widespread use of standardization within the enterprise is important to being able to have a constant point of reference on the work being done, the improvements made and those that can be made. In fact, by normalizing carefully the processes it is possible to be able to more easily link the cause (the work being done) with the effect (the improvements achieved). However, in order for processes are optimized it is necessary for standards to be well known within the organization and present in each department (i.e., near the workstations) so that they can be easily consulted and compared with the work performed. Each person within the organization must, that is, be able to understand whether Kaizen operations are being carried out more or less effectively.

1.4.5 The Kaizen

The word Kaizen is derived from the composition of the Japanese words "KAI"(change) and "ZEN" (better) and, on the whole, is loosely translated to mean continuous and incremental change. The term comes from Masaaki Imai, who considered it to be on a par with "the key to Japanese competitive success, [...] continuous change that involves everyone from top managers to ordinary workers."[31] It is the concept that, along with standardized work and the Heijunka, completes the foundation of the house of Lean.

Although the term Kaizen has been ascribed multiple peculiarities and characteristics by the various authors who have covered the topic, all of them have agreed that the key aspects of this methodology lie in three points[32]:

- It must possess the characteristic of continuity; it must be a never-ending path toward ever greater quality and efficiency.
- Most of the time it is incremental in nature. That is, change does not must be the result of innovations (of large technological investments), but be the result of many, small, continuous improvements that are actually sustainable in the long run. To the concept of incrementality should be closely linked also to that of cost-effectiveness. These small changes, in fact, should be the proceeds of small efforts even from an economic.
- They should be the product of a participatory process, not imposed and wanted from above but coming from the involvement of the entire workforce. It is the concept according to which decisions and suggestions must come from a bottom-up.

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[31] M. Imai (1986) Kaizen: The Key To Japan's Competitive Success, McGraw-Hill
[32] A. P. Brunet, S. New (2001) "Kaizen in Japan: an empirical study", in International Journal of Operations & Production Management

It is possible to break down the concept of Kaizen into two different approaches or types: flow Kaizen and process Kaizen. The term Flow Kaizen refers to improvements that affect the enterprise as a whole, thus affecting the entire flow of materials and information. The procedure begins with mapping the current flow by trying to identify the presence of any waste and then looking for a better solution that allows an undisturbed flow of value that eliminates, that is, the presence of obstacles or interruptions. The concept of Process Kaizen, on the other hand, relates to more particular aspects of the enterprise as it produces improvements concerning specific workstations. This approach is decidedly more operational and relates to the Japanese concept of Genba Kaizen. It is through this type of Kaizen that concrete changes and adjustments to the flow take place through tools such as the Single Minute Exchange of Die (introduced earlier) and the TPM methodology (aimed at increasing plant efficiency, activating a program of thorough plant maintenance, designing new equipment and, finally, developing a training and education program to disseminate the innovations to be introduced). The implementation of a quality and efficiency optimization process following a Genba Kaizen-type approach should, therefore, bring continuous improvement to individual workstations. The Genba Kaizen process (translatable to Kaizen on site) has four distinct phases[33]:

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[33] D. Dysko (2001) "Gemba Kaizen- Utilization Of Human Potential To Achieving Continuous Improvement Of Company", in The International Journal of Transport & Logistics

- The first phase consists of "Go To Genba," properly go to the site. In fact, you need to physically go to the place where you want to make an improvement and not try to find a solution while sitting in an office chair.
- The next step consists of "Observe Genbutsu," which can be translated as observe the reality around you. It consists of observing machinery, equipment and people to try to understand the motivations behind the encountering a particular problem.
- The third step is to look for and find the wastes, which, through careful observation, should now be visible and identified in the form of muda, walls or walls.
- Finally, the last step is to perform Kaizen, to eliminate these wastes and thus make an improvement to the individual station.

These four steps should then be followed by standardizing the solution that has been found with the aim of preventing a given problem from recurring in the future. A proper approach of constant and continuous improvements from a Lean perspective should reach a daily frequency and succeed in having positive impacts in the work environment: eliminating work overloads (walls) and involving workers belonging to all organizational levels (even the lowest) in eliminating waste (muda). Although great emphasis has been placed on the fact that the change process should follow the pace of "a slow but steadily advancing turtle," it is worth reiterating how this is not the only phase of improvement that can affect a Lean enterprise. In fact, the concept of Kaizen is complementary to that of innovation, which consists of a high magnitude of improvement that takes place in a very short time interval.

As can be seen from the chart, business improvement can go through two different phases:

- The first, Kaizen, in which there is continuous change over time and gradual, carried out in small steps.
- The second, that of innovation, in which profound changes occur (big leaps) in a very short interval of time. It leads to an improvement suddenness that remains so until the introduction of a subsequent innovation.

The two forms of business improvement possess a major difference. Innovation requires large investments, comes from the management body and, therefore, follows a top-down logic. Kaizen, on the contrary, requires a better use of resources in order to eliminate all sources of waste and comes from anyone who is in the position of having to solve a given problem (it therefore disregards the hierarchical level). A company that wants to implement an effective management system will need to use both of these forms of improvement. While innovation will lead to the introduction of sudden improvements in standards, Kaizen will lead to small and continuous refinements of standards.

2. The Tenneco Case: Kanban on PSA line

2.1 A group TENNECO Overview

Headquartered in Lake Forest, Illinois (USA), Tenneco is a leading designer, manufacturers and global distributors of automotive equipment products original and aftermarket, with sales of $17.5 billion in 2019 and about 78,000 team members working at more than 300 sites worldwide. The multinational corporation is divided internally into four main business groups: Motorparts, Ride Performance, Clean Air, and Powertrain, and each provides technology solutions for diverse global markets, including light vehicles, commercial trucks, industrial off-road vehicles, and aftermarket parts.

Tenneco's history as a stand-alone entity began in 1999, when the current company emerged from an earlier multinational entity consisting of a few core businesses: shipbuilding, packaging, agricultural and construction equipment, gas transportation, chemical, and automotive. Beginning in the 1980s, through public offerings, sales, acquisitions and mergers, the company divested all its businesses, leaving Tenneco Automotive as the remaining part of the original company. It is precisely the remaining automotive entities that have allowed Tenneco to be defined for what it is today. About 16 years ago, in 2005, the company took on the official name by which it is still known today, to better represent itself in the marketplace international market.

To support the growth of light vehicle production and new segments of the company's market, the organization decided to greatly expand its global presence during the early 2000s, becoming one of the leading automotive suppliers in China.

At the same time, it has considerably improved its engineering and manufacturing operations worldwide, becoming a leader in developing clean air solutions to help its customers meet stringent emission control regulations worldwide. In fact, the U.S. multinational was one of the first companies in the world to commercialize diesel filters in Europe in the early 2000s and continues to lead the industry today with important after-treatment technologies for both gasoline and diesel engines. Beyond that, the company's advances in driving performance technology have helped provide better comfort, increased performance and control to differentiate its customers' vehicles.

After nearly two decades of growth, mainly due to product deployment and geographic expansion, Tenneco has completed two acquisitions, helping to position the company for continued success in the future. One of these occurred in October 2018, when Tenneco acquired the multinational American company Federal-Mogul, also a leading global supplier of components automotive, thus doubling its size and expanding into other countries around the world.

To this day, Tenneco describes itself as the proud steward of more than 30 brands automotive brands among the most well-known and respected in the industry including BMW, Mercedes, Ford, CNH, and Fiat Stellantis.

The Chivasso plant, within which the study was conducted, belongs to the Powertrain business division and before it was acquired by the U.S. giant in 2018, it was manufacturing factory signed Federal-Mogul. Today, the plant is known as "Federal-Mogul Powertrain - Tenneco Group" and belongs to a of several existing business units called Sealing & Gasket, as its main business is gaskets.

Figure 4, The Tenneco Chivasso Plant

Tenneco's Powertrain business group, designs, develops and manufactures components of original equipment and innovative technologies that help engine designers meet increasingly demanding customer, regulatory and market requirements in every region of the world.

Worldwide, Tenneco has 21 Technical Research and Development Centers and 144 production facilities. The Powertrain sector, specifically, is characterized by 14

Technology Centers and 97 production plants, among which the Chivasso plant is included.

The plant in question, presents itself as a "glocal" reality: it, in fact, has medium-small size because it includes a total of about 150 employees between workers and clerks, contributing to a family-friendly and welcoming atmosphere; at the same time, inside it one fully "breathes" the dimension of the multinational company, due both to the weekly inspections of foreign representatives of important foreign companies who come to verify the procedures of making of products, as well as the company policy that requires daily confrontation with the line, establishing a broader, international dimension.

There are six production departments within the plant, each specializing in a specific work cycle:

1. Gasket: production of static steel gaskets.
2. EMG: rubber metal and fiber production coupled with steel.
3. Unipiston: production of rubber gaskets for automatic transmissions.
4. Dynamic Seal: production of rubber and PTFE oil seals for crankshafts.
5. Heat Shield: production of heat shields for engines.
6. Kitting: packing gaskets.

In addition to these, there are tooling, maintenance, and main offices: HR, EHS, Supply Chain, Customer Service, Value Stream, Finance, Purchasing, Sales, Quality and Information Technology.

Following a climate survey conducted during 2020, Tenneco has recently revised and updated its corporate vision, mission and company's core values. As specified on the organization's official website, the mission of the multinational corporation is "To support Tenneco's performance by building a high-performance culture with capabilities and processes to execute now and in the future." The company's vision is, instead, "Creating more business opportunities to achieve excellence through continuous improvement and by paying attention to the safety and well-being of workers" (Tenneco, 2021).

Among the key values, the first of these is integrity, a fundamental part of the corporate culture that translates into the call to do the right thing in the right way, communicating and owning actions with high honesty, fairness, and integrity; another value is to make tomorrow better by turning problems into solutions, creating opportunities, and being willing to learn and learn. In addition, one way to make tomorrow better is through ongoing commitment to customers, employees, and communities to build a more sustainable future, as Tenneco strives to operate in a socially responsible and honest manner, regardless of the challenge. Willingness to win is another corporate value, understood as the ability to aim for impeccable performance, build customer loyalty and make a difference in the competitive market; finally, the last major value is the one defined as "one team," which calls for workers to take care of each other, welcome each other's differences as a strength and achieve success together.

2.2 Kanban project on PSA Production Line

The project under study aims to implement a kanban system for adjusting the WIP of a production line. It has been previously described the foundations of lean production, and the "pull" system is precisely one of them. The main goals are to achieve a self-feeding production line (without a person having to schedule each process step) while minimizing wip, reducing waste, and increasing efficiency. The following paragraphs will explain the theory behind kanban and the implementation of the project with its results.

2.2.1. Production process description

In order to better understand the kanban system implementation is essential to know the products and their processes. In this section will be illustrated the two products main characters of this case study. The two objects in question are Heat Shield, a component design to protect the car component from the possible damage caused by heat and overheating. Also called heat deflector are often made of metal or ceramic materials and are responsible for reflecting and dissipating the heat produced by the car engine.

The two products are identified with a specific part number (used within the company): respectively HS10091 and HS10092. Following they will be analysed individually.

Figure 5, HS10091 exterior view

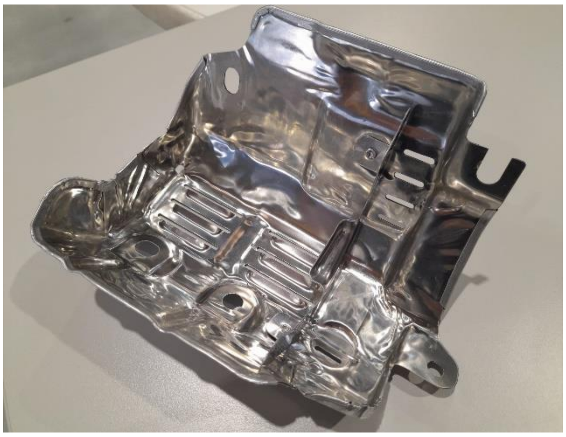

Figure 6, HS10091 interior view

Figure 7, HS10092 exterior view

Figure 8, HS10092 interior view

Let's start with the HS10091. In the image below, *figure 9,* it is represented the process flow chart. At the first step there are the raw materials:

- The material coil, a sheet of steel or iron rolled around a circular core.
- The isolation, a layer of insulating material placed between the two main metal components. It is purchased from the outside and is ready to be assembled without further processing.
- Rivets, a mechanical fastener that cannot be disassembled, it Is used to hold the two sheets together.

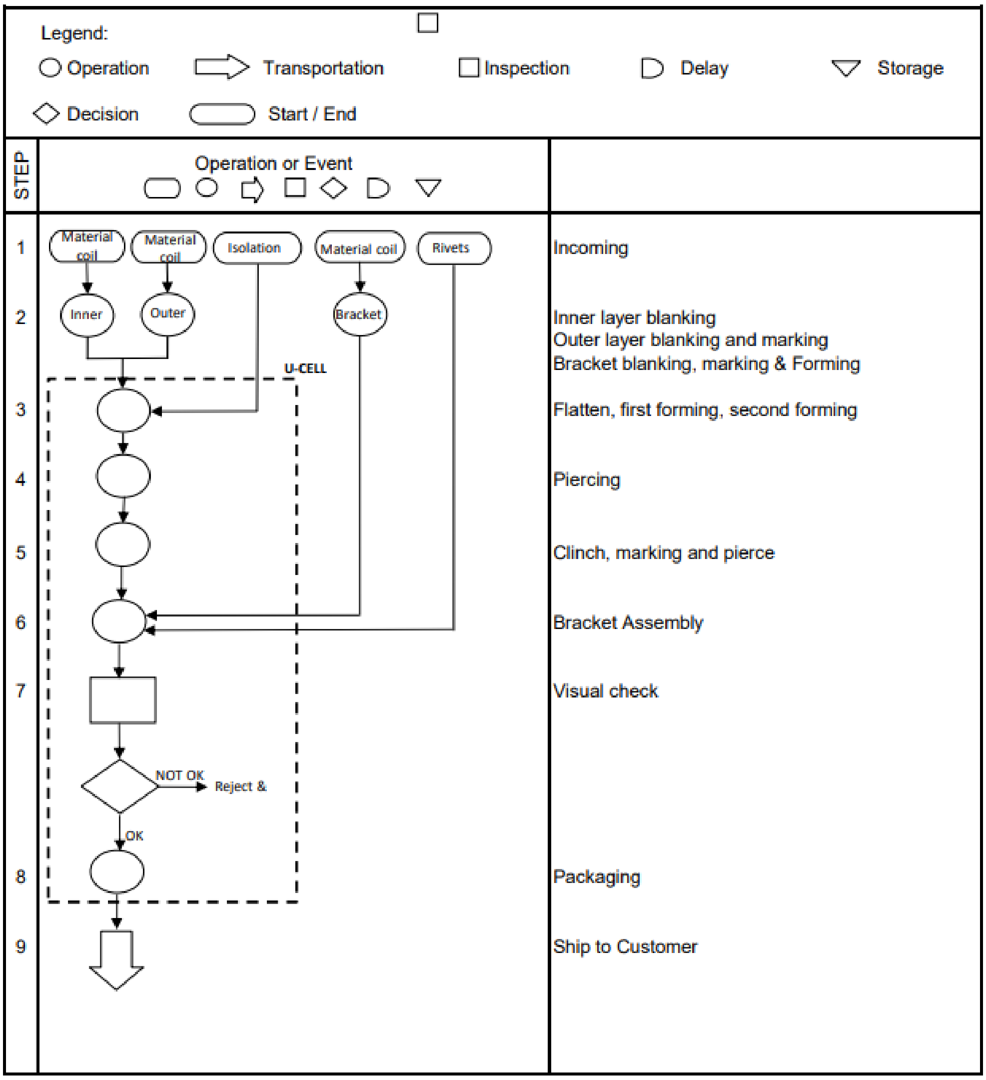

Figure 9, HS10091 Process Flow Chart

In the second phase, there is the transformation of the raw material into the main components that make up the heat shield. The inner and outer layer are produced in-house by a press called the Rocher. So, this step consists of blanking the two layers: the WIP that will feed the U-cell, the automated line that takes care of the second transformation. Bracket is made by shearing, forming and marking the raw material. This component is processed by an external supplier.

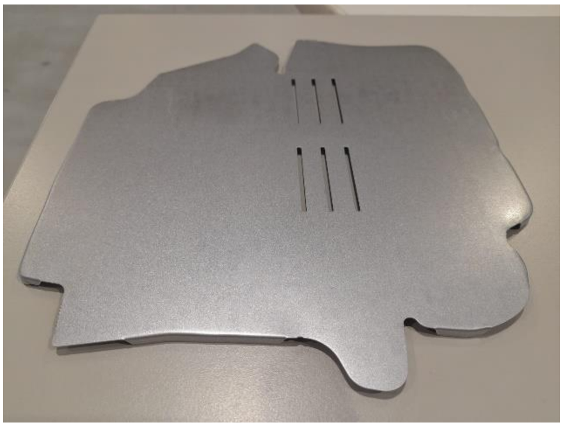

Figure 10, HS10091 outer layer

Figure 11, HS10091inner layer

These components are then processed within the U-cell where 2 operators work. Initially inner layer, isolation layer and outer layer are stacked in their respective order and placed on a conveyor belt, thus entering the automated line. Here the component is moved thanks to robotic arms, placed inside a press to be formed. This operation is repeated three times on different presses for a total of three forming operations. After leaving the automated line, the component is taken by the same operator who initially inserted the 3 layers and placed in another press, called GIGANT, where it will be drilled to obtain the motor head grids. At this point, the second operator takes over the assembly operation. Using a machine, called a VTS, the component is riveted to hold the various layers and bracket tightly together. In the last step, the finished product undergoes a visual check that checks the quality of the part and discards it if the parameters are not met. Good components are packed at the edge of the line according to the customer-specific packing sheet. Finally, they are prepared for shipment and sent to the customer.

The second heat shield in question, HS10092, is similar to the previous one, but is important underlining the differences. Below it is reported the Process Flow chart, *figure 15*.

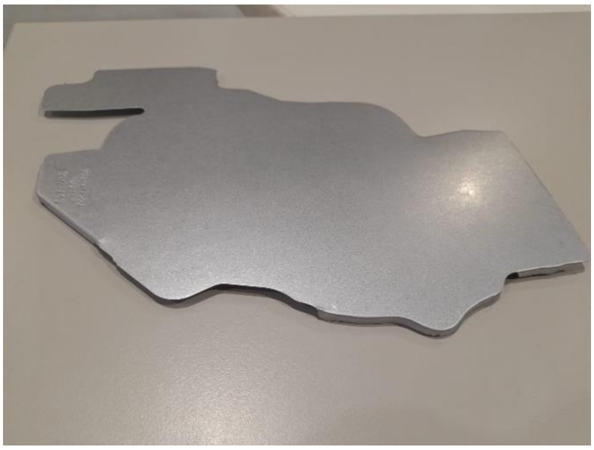

Figure 12, HS10092 outer layer

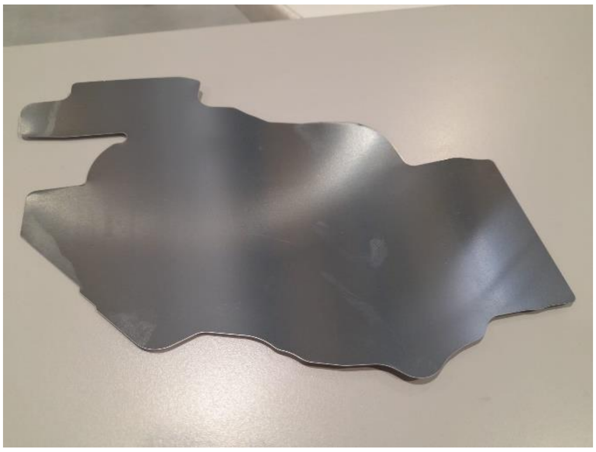

Figure 13, HS10092 inner layer

Figure 14, HS10092 Gasket FL1

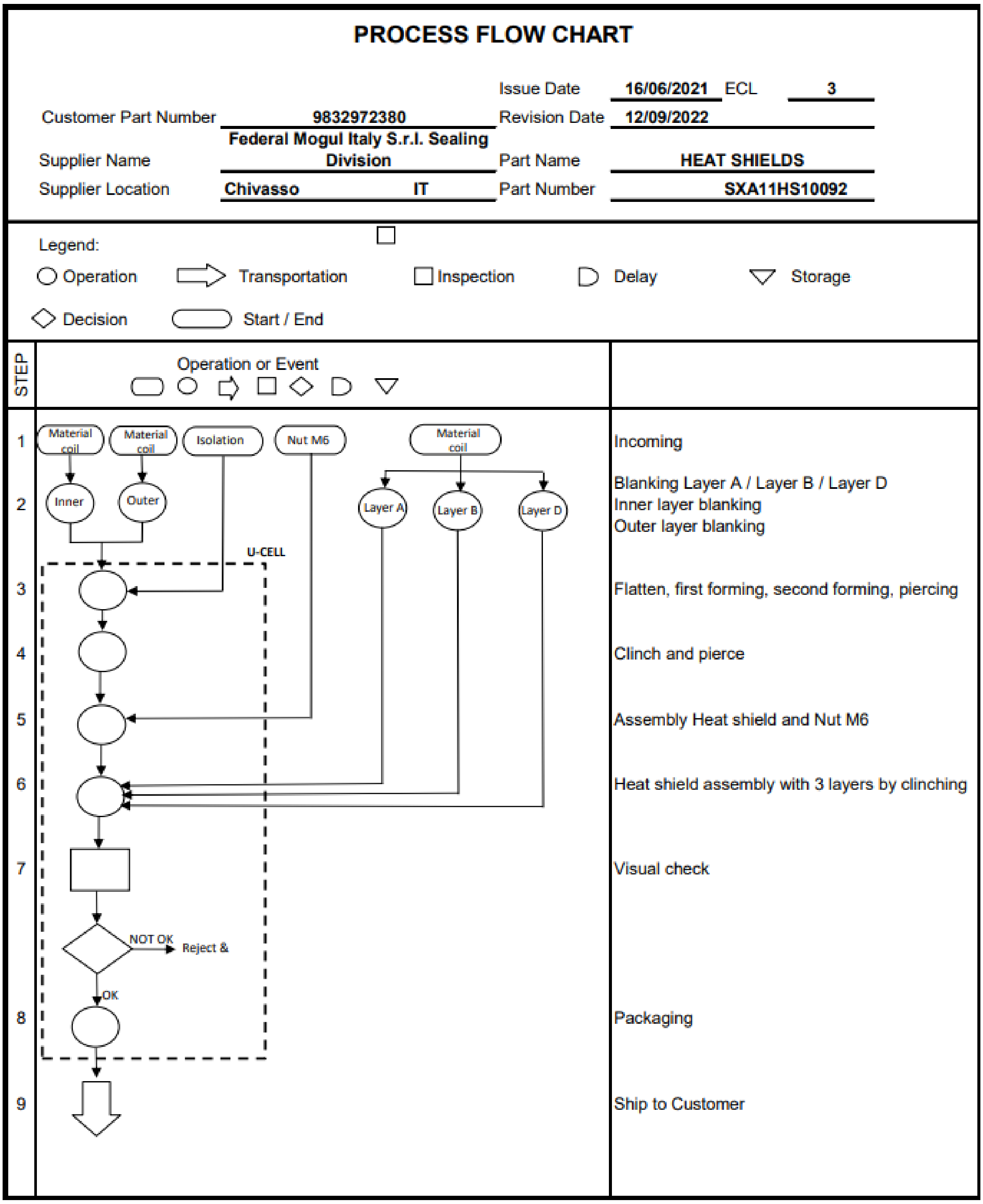

Figure 15, HS10092 Process Flow Chart

The initial part of the processing is virtually identical to that of HS10091, what changes, of course, are the shapes of the layers that are punched by Rocher and then processed by the automated line. after which the component is not riveted together with a bracket but is assembled with three gaskets. These parts are also produced by Rocher, thanks to a single mold that simultaneously blanks the three layers A, B, and D. Within the factory these three gaskets are identified by the initials FL1-FL2-FL3. The assembly of the 3-layer heat shield by fixing during the second processing step. The end of the process is similar to the previous one, including visual checking and packing.

2.2.2 The Kanban System

The tool most used by lean enterprises to succeed in getting the value stream flowing is Kanban, a Japanese term meaning "signboard" or "name tag." It is a visual system that, more often than not, consists of a tag that is affixed to a container and allows information to be communicated regarding the production, purchase, picking or movement of determinant components/materials (it is a tool that allows production scheduling and replaces MRP functions). The strengths of a Kanban system are essentially threefold: it produces a reduction in information processing costs, data acquisition becomes at the same time faster, and, finally, it limits the production capacity of the most upstream stages, thus reducing the possibility of overproduction.[34]

The primary benefit of implementing a Kanban system is the elimination of overproduction as a result of identifying the quantity and type to be produced at each stage of the production process. The resulting secondary benefits range from the reduction of inventory and labour to the elimination of the presence of defective products, failures or interruptions along the manufacturing process. In fact, precisely for these purposes, a whole range of information is applied to the tag such as: the part/material code and a description of it, the number of parts/materials needed to fill the container, the origin, destination, location in the warehouse.

A Kanban system can essentially take advantage of four types of tags: the production Kanban (also called P-Kanban), the handling or picking Kanban (called C-Kanban), plus two "special" Kanbans called the supplier Kanban and signal Kanban[35]. Whether or not these cards are used depends on the production technique chosen within one's company, which can be basically of two different types: the Single-Card Kanban and the Dual-Card Kanban. The Kanban system that Toyota exploits is Dual-Card Kanban and is based on the use of two different tags, one representing a production Kanban and one representing a handling Kanban. P-Kanbans are the methodology through which the

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[34] Y. Sugimori, K. Kusunoki, F. Cho & S. Uchikawa, (1977) “Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system”, in The International Journal of Production Research

[35] R. J. Schonberger, (1983) “Applications of Single-Card and Dual-Card Kanban”

most downstream stage authorizes the production of a particular component by the stage located further upstream by specifying its type and quantity. Before a container moves on to the next stage, in fact, the P-Kanban is detached from the container and attached to a bulletin board, thus authorizing a new production of that predetermined amount of material or component. C-Kanbans, on the other hand, indicate quantity and type that a particular downstream stage needs to withdraw from the upstream stage; they are purchase or withdrawal authorizations. For example, if there is a need to produce a container of PA-Kanban at a particular stage (which will be deposited downstream in the production process) there will have to be recalled or withdrawn at the beginning of that stage the CA-Kanban within which all the materials from the previous stages that are required for the production of component "A" will be conveyed. Once the production of component "A" is finished, the CA tag is detached and attached to the bulletin board, becoming authorization to produce more "A" material. In contrast, the easiest technique to apply and the most widely used is Single-Card Kanban. The operation of this production technique, compared to the previous one, is based on the use of only one card, without any distinction between C-Kanban and P-Kanban. When a container is emptied, it is deposited in a buffer and its tag is peeled off which is affixed to the appropriate bulletin board, thus giving permission for the production of that particular component. The appropriate process worker immediately up upstream will see the tag in which is specified the type and quantity of material that the immediately upstream process is to proceed to produce. Once the production of that particular component, the tag is re-hung on the container which is re-deposited in the warehouse causing the cycle to begin again.

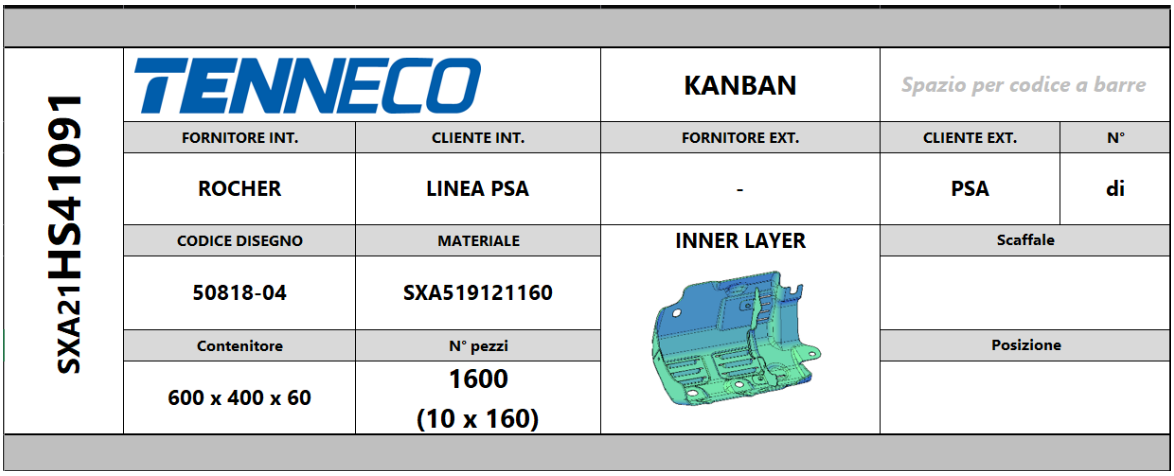
To succeed in having positive impacts within the enterprise, and for the whole system to be simple and effective, a Kanban-based system must be subject to a set of rules:

- No phase may produce until the relevant P-Kanban authorizes it. Employees of that phase may perform other tasks (e.g., maintenance) or help employees of other phases but not produce other components of that type until there is a P-Kanban on the bulletin board.
- The number of containers, for each of which there is only one C-Kanban and a single P-Kanban, comes from a careful business decision and should remain unchanged.
- The containers are standard and should always be filled with the quantity predetermined that should remain constant.
- The tags, when not posted on the bulletin board, must necessarily be affixed to a container.

2.2.3 How the Kanban System works

Now let us focus on the operation of the single card kanban system; this type will be the one used in the project to adjust the WIP between the Rocher press and the U cell.

Each Kanban tag represents a so-called handling unit; the quantity of these depends on the size of the components, their containers so that they are easy to carry and count. Let's see an example: a kanban for the inner layer of HS10091 inner is shown in the figure below.



SXA21HS41091	TENNECO		KANBAN	Spazio per codice a barre	
	FORNITORE INT.	CLIENTE INT.	FORNITORE EXT.	CLIENTE EXT.	N°
	ROCHER	LINEA PSA	-	PSA	di
	CODICE DISEGNO	MATERIALE	INNER LAYER	Scaffale	
	50818-04	SXA519121160			
	Contenitore	N° pezzi		Posizione	
	600 x 400 x 60	1600 (10 x 160)			

Figure 16, a Kanban Card of HS10091 inner layer

As you can see the part number for this component is SXA21HS41091. The Kanban tag shows some information such as:

- The supplier, i.e., the machinery, in-house, involved in the production of the component.
- The customer, what will process the part in the next stage of production.
- The drawing code of the component.
- The identification code of the raw material from which it is made.
- The dimensions of the containers.

- The quantities of the handling unit, i.e., in this case each kanban represents a unit of 1600 inner layers, arranged in 10 boxes of 160 pieces each.

The KANBAN CARD is placed in visible places on the container dedicated to the component, when it is full, and also on a sort of "blackboard", when the container is empty. When the operator picks up the components and the container is emptied 100%, he or she will find the KANBAN CARD and place it in a kanban board where to place the tags while waiting for reorder. The kanban board is divided into three sections:

- **GREEN ZONE**: Corresponds to the *"production lot size"* defined by customer demand. There is no need to produce when there are only Kanban cards on the green zone.
- **YELLOW ZONE**: Represents the "*lead time of reposition"* of a production batch. You need to produce the item, the line needs to finish what it is doing, run the setup, produce a transfer batch, and move to the supermarket.
- **RED ZONE**: Corresponds to the "*safety/protection zone"* to be absorbed against any sudden customer changes or problems in the process of the supplier.

So, in this way the production supervisor is able to immediately decide what and how much produce thanks to a visual representation of WIP. In fact, As the KANBAN CARDS reach the frame they are inserted into the sequence: GREEN→YELLOW→RED as shown in the adjacent figure.

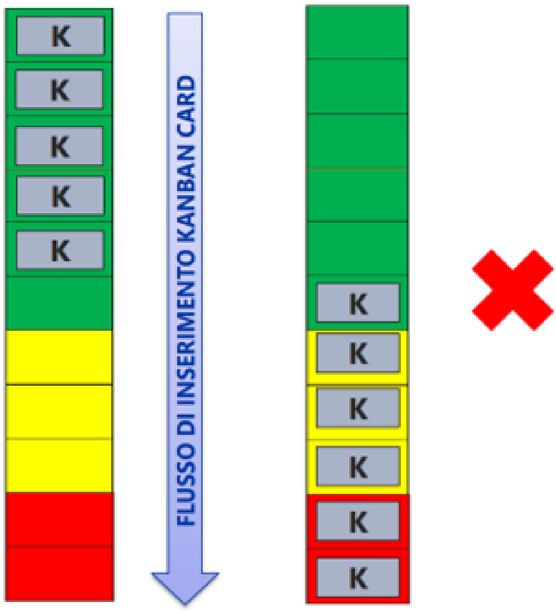


Figure 17, The right flow of Kanban Card input

In Chivasso plant, it was realized that for a total of five component that are necessary to produce the two heat shields previously described:

- SXA21HS41091, the inner layer for HS10091
- SXA21HS42091, the outer layer for HS10091
- SXA21HS41092, the inner layer for HS10092
- SXA21HS42092, the outer layer for HS10092
- SXA214140092FL1-FL2-FL3, the three gaskets for HS10092

These five components all produced by Rocher and their production alternates frequently (1-2 times a week) so that the work in process is relatively low, but at the same time always enough to feed the automatic PSA line.

Figure 18, the Kanban Board in Chivasso plant

2.2.4 Kanban Calculation

Kanban sizing is done upstream in the process with the goal of producing with economical batches, justifying the set-up times of the machines and their production speed, and at the same time limiting the amount of WIP and reducing them as much as possible. The kanban size is influenced by several factor, such as:

- Container size.
- Production batch size at the supplier's stage.
- Weight limitations for manual movement.
- Dynamics of customer "demand'/pull.
- High setup times and cycle times

The formula used for the number of kanban tags is as follows:

$$N = \frac{D * LT * (1 + \alpha)}{C}$$

N = number of kanban

D = average piece consumption (e.g. number of pieces processed in a day)

LT = Total average lead time calculated as the time between the highlighting of the requirement (the tag) and the actual availability of the corresponding material.

α = safety coefficient (0,15-0,25)

C = container capacity

But calculating the total number of kanban tags is not enough. The next step is to size the kanban board and figure out how many places it should have for each colour band, green, red and yellow. Following are the respective formulas:

- N° GREEN BAND = $D * \sqrt{\frac{LT}{C}}$
- N° YELLOW BAND = $\frac{D}{1+\alpha} * \sqrt{\frac{LT+LT*D}{C}}$
- N° RED BAND = $\frac{D}{1+\alpha} * \sqrt{\frac{LT}{C}}$

2.2.5 Demand Analysis

Obviously, the production is scheduled based on customer demand. In the Chivasso plant, customer orders are received via EDI and are entered directly into the SAP business software. In this way it is simple and immediate to go and see the current demand and its forecast for a specific product. The customer of the two heat shields under thesis is Stellantis: shipments are arranged for 4 different plants thus defining different "ShipTo", i.e., respective destinations. Each ShipTo is identified with a different letter at the end of the part number. In addition to the destination, each ShipTo has a specific packaging so depending on the plant to the components are to be shipped these will be packaged differently. The 4 ShipTo are:

- HS10091 Madrid-Spain
- HS10091K Kenitra-Marocco
- HS10091T Tichy, Poland
- HS10091S Saragoza, Spain

The HS10092 has only one ShipTo and it is Tichy in Poland.

Generally, orders are weekly for each plant and shipments occur on different days during the week. The goal is to produce the quantity required by customer on time and at the same time have at most one stock of finished product covering a time horizon of at most 10 working days to avoid overproduction and maintenance costs.

The table below will show the demand and respective forecast thanks to a data extraction from SAP.

Part Number	October	November	December	Genuary
SXA11HS10091	720	960	480	480
SXA11HS10091K	5520	8880	8160	5760
SXA11HS10091S	4880	4400	4800	5200
SXA11HS10091T	630	6500	3300	4800
HS10091 TOTAL	11750	20740	16740	16240
SXA11HS10092	22.050	19.530	16.380	20.160

Performing a demand analysis is essential to be able to observe a possible trend and be able to adjust in terms of production capacity. In this case, demand remains mostly constant; a slight decline can be seen in December (probably given by the possible closure of factories during the Christmas period). In total, the average monthly quantity is around 35’000 pieces considering both heat shields.

In addition, demand analysis and respective production volumes are essential for sizing the kanban system. In fact, the demand for the next four months will be a starting point for being able to calculate the quantity of kanban tags for each component.

2.2.6 Project Implementation

The first step in implementing the project was to size the kanban board. In the previous section, the customer's demand was analysed in order to figure out the average daily quantity of finished parts that will need to be produced (data that will be used in the formulas in section 2.2.4 for the calculation of the actual kanban). The other two essential data for sizing the system are the quantity of which is represented by a kanban tag for each component and the production lead time of each batch. The former is identified by the letter C (i.e., container capacity) this quantity is chosen arbitrarily, depending on the size of the component, that of the container. In practice, a trolley was chosen as the handling unit on which several boxes with the various semi-finished products inside are stacked. To each trolley corresponds a kanban and, as seen above, when the trolley is full the kanban will be attached to it, while when the trolley is emptied the kanban tag will be inserted into the respective kanban board. The following table shows the quantities and sizes of containers, and the number of total components per handling unit.

Part Number	Description	Dimension (mmxmmxmm)	N° of container	Container Capacity	Pieces per Kanban
SXA21HS41091	inner layer	600x400x60	10	160	1600
SXA21HS42091	outer layer	600x400x200	6	80	480
SXA21HS41092	inner layer	600x400x60	10	180	1800
SXA21HS42092	outer layer	600x400x200	6	100	600
SXA214140092FL1-2-3	Gasket	rack	1	2000	2000

The latter is the lead time of a production batch, identified by LT. This time is not easy to calculate you have to start with the measurement of machining cycle times, to understand the time it takes to produce a single part, and you also have to consider all the setup time needed to prepare the machinery. The latter, setup time, is calculated as the time between the last part produced and the first component produced in the next batch: in simple terms, the downtime between production batches.

$$LT = ST + PT$$

where ST= Setup Time and PT = Production Time of a single batch.

Cycle time and set up measurements are shown in the table along with related calculations for production lead times for each individual semi-finished product.

	Setup Time		Cycle Time		Kanban Production Time	
Part Number	ST (min)	ST (min/pz)	CT (pz/h)	CT (min/pz)	Qk	PTk (h)
SXA21HS41091	60,00	0,04	1030	0,06	1600	2,6
SXA21HS42091	60,00	0,13	590	0,10	480	1,8
SXA21S41092	120,00	0,07	1160	0,05	1800	3,6
SXA21HS42092	120,00	0,20	765	0,08	600	2,8
SXA214140092FL1-2-3	240,00	0,12	1540	0,04	2000	5,3

The last column shows the production time of a kanban for each component in hours. The calculation was done by multiplying the quantity of the individual kanban by the sum of the cycle time and the "unit setup time." Finally, to obtain the kanban lead time as the production batch repositioning time, the waiting time must be added to the production time. This waiting time has been estimated as ten production shifts that on average are already scheduled on the Rocher for blanking of other codes.

Once the results just discussed have been obtained, the formulas in Section 2.2.4 can be used to determine the size of the kanban board: that is, to determine how many spaces to devote for the green, yellow and red areas of each individual semi-finished product.

Part Number	G	Y	R	G	Y	R
SXA21HS41091	1	2	1	1600	3200	1600
SXA21HS42091	3	4	3	1440	1920	1440
SXA21HS41092	1	2	1	1800	3600	1800
SXA21HS42092	3	4	2	1800	2400	1200
SXA214140092FL1-2-3	1	1	1	2000	2000	2000

The last step in implementing the kanban system is to set up an area for WIP storage. A floor plan of the plant is shown in the *figure 19*, with the area for the semi-finished products of the two heat shields in question highlighted in light blue. Obviously, the chosen area is located between the Rocher press and the automatic PSA line so as to minimize the movement of material within the plant and be immediately available at all times.

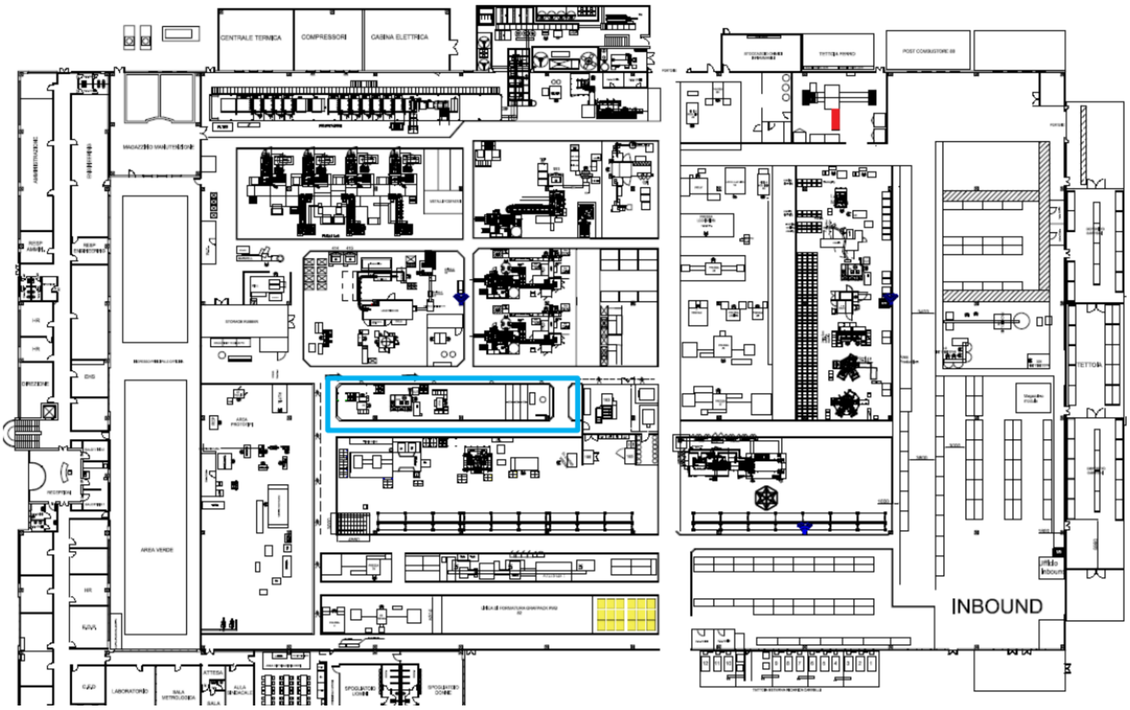


Figure 19, Chivasso Plant Chart with WIP zone identification

The kanban board will be hung in front of the storage area so that it is easily accessible by operators moving kanban units and also by team leaders supervising production.

2.3 Results

The latter section of the paper will discuss the results of the project. First, the management of the WIP and the size of the production batches will be analysed, and then the key role of the workers and the autonomy obtained by the team leaders will be discussed. Finally, minor problems encountered in implementation and resistance to change will be reported.

2.3.1 The WIP management and batch size

As previously mentioned, one of the primary benefits of Kanban in WIP management is its ability to minimize overproduction. By using visual cues such as Kanban cards, the system ensures that production only occurs when there is a demand for it. This prevents excess inventory buildup and reduces the risk of producing goods that may not be immediately needed, thereby optimizing resources and minimizing waste. In fact, following the implementation of the kanban project between Rocher and the PSA automatic line the WIP was reduced and had a more constant trend in the following months. This was made possible by reducing the production batches of components that are produced by Rocher. The table below shows the average batches per component for the year 2023. Consider that the kanban system was implemented in August.

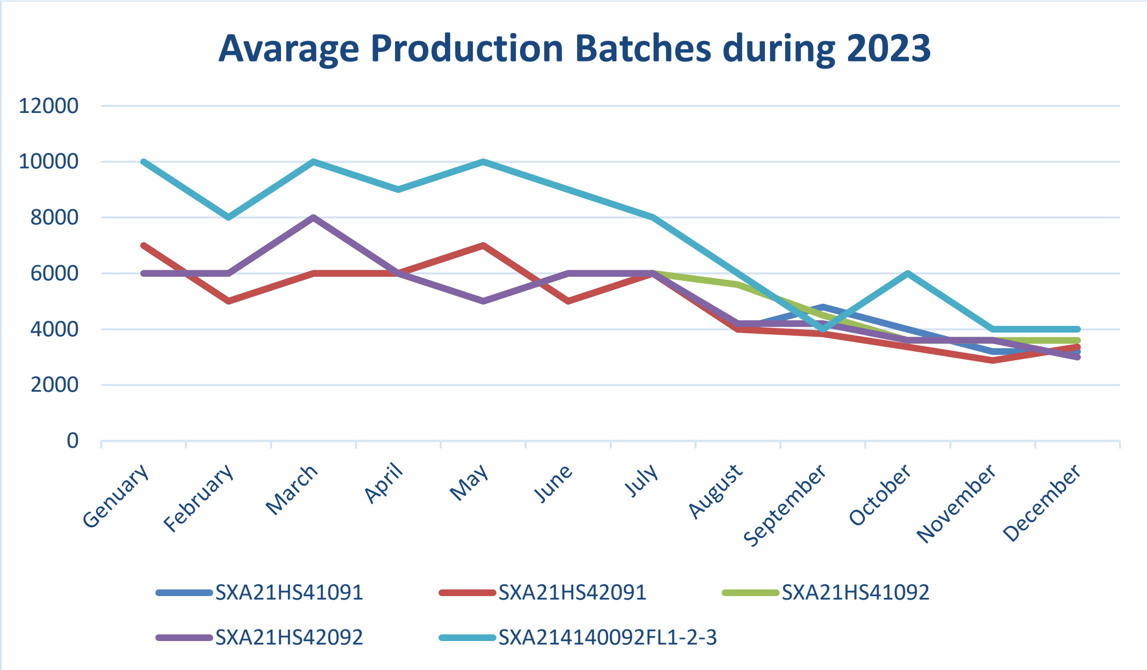


Figure 20, Avarage production batches graph

It can be seen that in the first half the lines representing the inner and outer layers of the same heat shield are superimposed. This is because without the kanban system the launch of production batches was studied simply based on demand. So, they were the same for HS10091 and HS10092. Whereas for the three Gaskets (SXA214140092FL1-FL2-FL3) they are produced simultaneously by Rocher and having short cycle times tended to make very large batches. From the graph it can be easily seen that after August the average production batch for each component decreases. Certainly, to produce the same quantities will require more production batches which implies more setup and thus more time when the Rocher press is not actually producing. At the same time, the advantage of having a smaller WIP allows you to cut down on capital equipment costs and avoid overproduction.

Another great advantage of having a kanban system going to the automatic PSA line, which is saturated in terms of production working all shifts, is to avoid line stops due to lack of components. Sometimes it has happened to stop U-Cell production due to running out of layers of the respective Heat Shield. This obviously leads to serious inefficiencies that could have been easily avoided. Why can such situations arise? Without an orderly and visual representation of the WIP it is easier to fall into these errors. Also, by producing large batches the Rocher press is occupied for so long with the same component lengthening the repositioning time. The implementation of the Kanban system makes it much easier to avoid downtime due to missing components. The trend of the amount of WIP over time is much more regular and hardly reaches low or zero levels. Next, WIP trends in July and November are depicted in the two graphs.

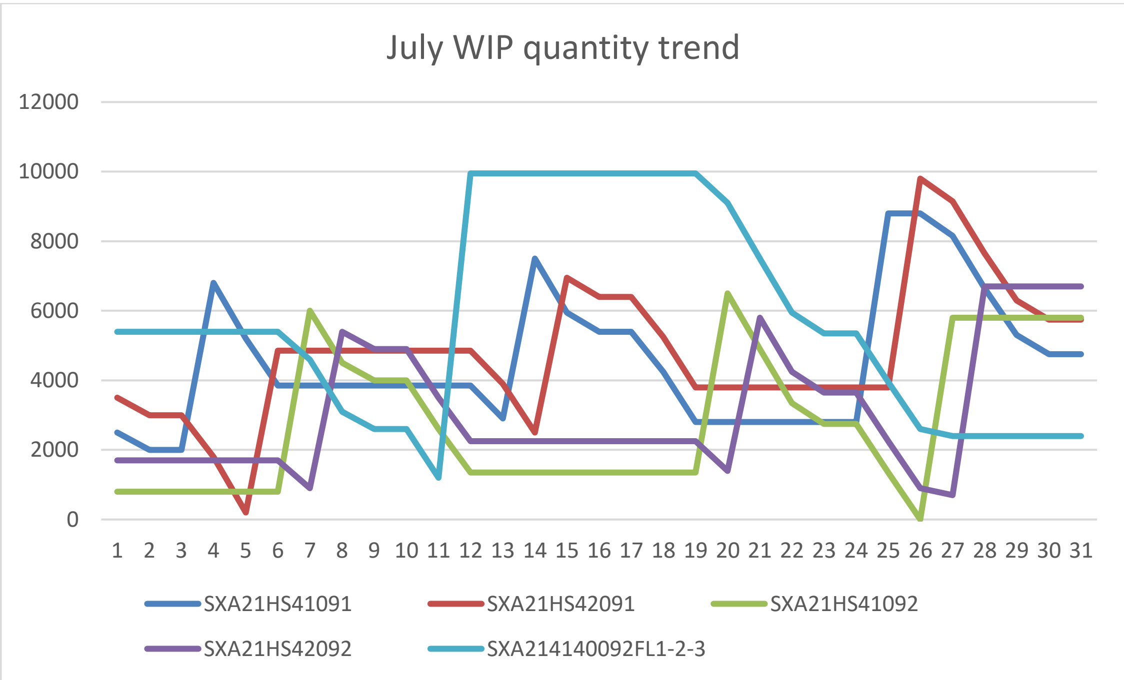


Figure 21, July WIP quantity trend graph

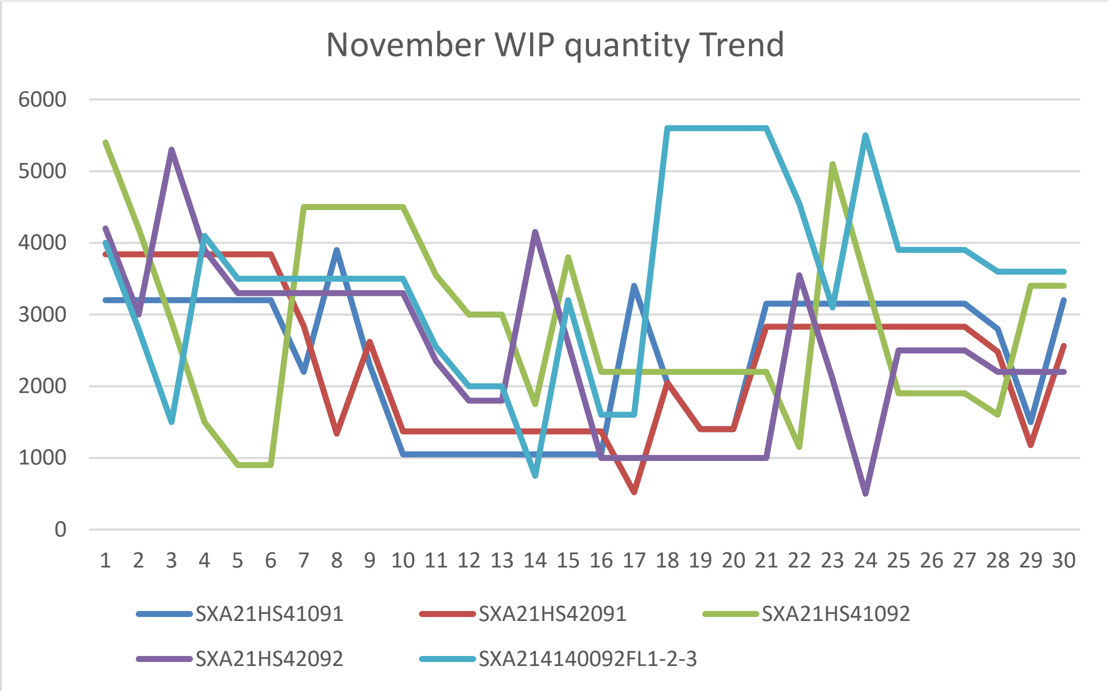


Figure 22, November WIP quantity trend graph

Comparing the two graphs, it can be seen that WIP in November is reduced compared to that in July. The latter fluctuates in a much wider range than the other. Without differentiating between components, in July some people's quantities touched 10000-piece peaks. In some cases, they even went into depletion. In November, on the other hand, the range in which WIP quantities fluctuate is greatly reduced: between about 500 and 6000 pieces. This confirms the thesis of a smaller WIP and at the same time always available pe production of the finished product.

2.3.2 Empowering Operators

An important point for project implementation is the training of operators and team leaders. The former, that of operators, is the simpler of the two. In fact, the workers have the task of using the Kanban tag by moving them from the Board to the handling units and vice versa. The operator working at Rocher, the so-called presser, has the task of producing the various components and moving the kanban tags from the Board by placing them on the handling units, obviously one for each unit produced. Similarly, the worker who works on the automatic line and picks up the WIP components will transfer the tags to the blackboard once the respective container has been emptied. This role, while simple and trivial, makes the operator critical to the management of the WIP and the operation of the Kanban system. Therefore, the operator no longer has only the task of "producing" but is also empowered for a management role by feeling integrated into the project and more involved in the company's value stream.

Instead, the role of the team leader becomes even more important within the Kanban system. Previously, production scheduling was done by a "Production Planner" who decided production batches upstream by simply analysing customer demand. Now, it is directly the team leader who, looking at the "Kanban Board" decides what and how much to produce. This decision greatly empowers the Team Leader since he is not only limited to organizing the work so that the schedule "imposed from above" is adhered to but he himself schedules the production. The role of the production planner is virtually replaced. Demand analysis in order to modulate the Kanban Board to the customer's demand de be done only once a month (in the case of constant demand in the short term).

3. Conclusions

The studies carried out provided an in-depth look at the theory of "Lean Thinking" from its origins to the present day with an application case. Initially, the 5 fundamental principles of Lean philosophy are described: the value, the value stream, the flow, the pull and the pursuit of perfection. These five pillars are activities that a company's management body must focus on in order to make it more competitive. The general idea is to understand and analyse the Flow of Value within the company to be able to avoid possible waste and inefficiencies, making the whole process smoother and more linear. The perfect visual representation of the study theory is, the so-called, "House of Lean." As previously described, on the roof are the goals to be achieved in order to achieve a more competitive business, essentially three elements: highest quality, lowest cost, shortest lead time. These three characteristics allow for a higher gear in the market and give the possibility of higher profits. Instead, the two supporting columns represent the two methods to be pursued with the aim of reducing waste to zero. The first is "Just-in-Time," production that mirrors, in quantity and timing, exactly the customer demand; reducing, or rather zeroing, overproduction. The second is "Jidoka", or “Autonomation”: the implementation of automatic systems that detect errors, avoiding the production of defective products. This method is key to raising the level of quality while avoiding waste. Finally, there is the foundation of the "House of Lean" consisting of three lines of thought to be pursued to have a solid foundation on which to build all Lean processes within a company. These three elements are: Heijunka, a balanced volume and mix of production; Standardization of work; and Kaizen, the continuous improvement.

In the second part of the study, an application of lean production, specifically the "Pull" philosophy, was analyzed, namely the implementation of a Kanban system. The implementation of the project aimed to better monitor and manage the amount of semi-finished products that go into the automatic production line of two heat shields. In fact, thanks to the Kanban system, the management of the WIP is much more immediate: the orderly arrangement divided into the respective handling units gives a visual idea of the quantity of the components. This clear and immediate visual representation allows the team leader to be able to schedule production activities by looking at the Kanban board.

As a result of the implementation of the project, production batch volumes are greatly reduced; this leads to a more regular WIP trend, within a smaller range without having an excessive amount of a component that may not be needed in the immediate future and at the same time with the security of always having it available. it is also true that this implies a larger number of batches to produce the same quantities, thus a larger number of set-ups where there is no actual production. This disadvantage is offset by reducing the "immobilized value" in the WIP and having a more linear and waste-free production flow management, certainly avoiding overproduction.

In the future, there is the possibility of expanding the Kanban project by implementing a similar system for both the supply of raw materials and the finished product. As far as the raw material side is concerned, the main constraint could be the MOQs imposed by the supplier and its responsiveness in delivery, which would not allow the system to function perfectly. On the other hand, as far as a kanban system between the production of the finished product and the customer's demand is concerned, it would certainly be more interesting. At the same time, it would imply having a minimum stock for the handling of kanban cards. At the moment, however, the company is structured with a completely Just in Time policy, so it produces exactly the quantities of the shipment without making a minimum of stock.

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