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Lean Manufacturing: Tenneco case study

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Introduction

The thesis is the result of a corporate experience in Tenneco, inside the Chivasso plant, Torino, Italy. The company, previously part of the Federal-Mogul Powertrain division, is a leading automotive Original Equipment Manufacturer (OEM) and aftermarket supplier, which is producing heat shields, gaskets, seals, and other products for clients like BWM and DAF. The goal of automotive suppliers is to be competitive in the evolving automotive landscape, adapting their capabilities and production systems to the digital shift changing the industry. To do so, companies use Lean Manufacturing techniques to improve the efficiency of their industrial plants. The thesis aims to describe two Lean projects carried out inside Tenneco. The first chapter presents a theoretical introduction about Lean philosophy and its principles, describing some tools connected to the continuous improvement carried out in the production activities. Tenneco corporation is introduced after a brief description of the industry and its complex value chain, to understand the company's role and the new trends and crises it faces. The first project described in chapter 3, regarding the losses analysis, is strictly connected to the Total Productive Maintenance (TPM), the Lean process of using machines, equipment, employees, and supporting processes to maintain and improve the integrity of production and the quality of systems, reducing production losses. The need originates from the introduction of a digital production tracking system, which makes it easier to manage losses and problems. The aim is to create a new standard methodology to accelerate problems' solutions and useful to operators, working on the machines, team leaders, who manage the departments, Supervisors, who help the previous roles, and finally the management. The outcomes are standard reports for the weekly and monthly losses analysis in Tenneco, created with the involvement of the workers. The graphs show the losses for every machine and every department, to easily understand which ones to focus on to identify and possibly solve the problems. Keeping track of wastes is not only very important both on a weekly and monthly basis, but also in the daily production activities. For this reason, the losses project finds continuity in chapter 4, which describes the way the company manages and escalates daily problems, starting from the *gemba*, which means the "actual place", the starting point for all corrective actions. An effective escalation plan is based on the Andon tool, which notifies real-time problems to workers and managers, to immediately solve problems, improving the productivity of the plant. Daily *KAIZEN*™ steps guide the escalation of the problems from operators to managers. The general results of the two Lean projects are promising, the first one helps the company deal with accurate results to identify the starting point of the corrective actions, for problems that are not easily identifiable in real-time activities or that are not solved yet, while the second one helps workers first hand, creating a more efficient and effective communication system, to intervene faster and in a better way to solve problems.

1. Lean Manufacturing

In this chapter Lean Manufacturing will be presented. This philosophy, with its principles and tools, is the starting point of the projects followed during the thesis. After the explanation of this production method and its features, a benchmark activity will compare the company case study, Tenneco, with the other automotive ones, in the adoption of Lean.

1.1. History

The term Lean Manufacturing was coined in 1991 in the book *The Machine That Changed the World* (Womack, Jones, & Roos, 1990), which first highlighted Japanese production methods as compared to traditional Western mass production systems and the superior performance of the former. The birth of Lean was in Japan within Toyota in the 1940s: The Toyota Production System was based around the desire to produce in a continuous flow that did not rely on long production runs to be efficient; it was based around the recognition that only a small fraction of the total time and effort to process a product added value to the end customer. This was the opposite of what the Western world was doing, with mass production based around materials resource planning (MRP) and complex computerized systems developing alongside the mass production philosophies originally developed by Henry Ford. (Melton, 2005). The fathers of the system were Sakichi Toyoda, his sons: Kiichiro Toyoda and Eiji Toyoda as well as Taiichi Ohno, a manufacturing engineer. Sakichi Toyoda, who then worked in textile industry, invented a motor-driven loom with a specialized mechanism, devised to stop in case of breaking off the thread, and the mechanism became later a foundation for Jidoka. The then Japan suffered from reduced demand, therefore diverse automobiles were necessarily produced in smaller numbers on the same assembly lines. In order to compete in the mass production automotive industry, which had already been introduced in European and American companies, Toyota was forced to change the methods of production. Kiichiro commenced preparatory work to produce in the Just-in-time system. The objective of the latter was to elevate the production capacity and reduce waste. In the 1950s Eiji Toyoda visited the Ford company. It seems that owing to the visit Toyoda together with Taiichi Ohno were capable of creating a system linking the two pillars of the TPS, Jidoka and Just-in-time, with the Ford assembly line. Shortly after the previous improvement Taiichi Ohno advanced another concept called "pull-flow production", an old practice in American supermarkets. The pull-flow production allowed to generate as many products as could be exploited in the successive process. In turn, it would facilitate the reduction of overproduction (Dekier, 2012). In the 1980s, most of the companies lacked in a toolbox of techniques on how to improve their businesses and successfully conduct a transformation process. Therefore many companies have taken Japan, as a rising manufacturing nation, as an example. Companies like Toyota, Nissan, Sony or Honda started to gain market leadership not only in the Japanese market but also in North America and Europe. The origins can be traced back to the American fear that the Japanese manufacturing companies within the car industry would take over and gain an unbeatable competitive advantage. The American contribution resulted in a spectacular productivity growth and decrease in price; this lead to wider product accessibility for customers. On the other hand, the Japanese contribution lead to the elimination of waste and reducer of resources within the automotive industry. Differences in culture, industry and infrastructures make it impossible for managers worldwide to implement the same Lean tools and principles that once worked in Japan. The approach must be held under continuous improvement and must be tailored to the realities of each specific company, industry and country. Lean nowadays, continues to spread not only to every country worldwide, but has settled its roots in Europe, in companies like Porsche or Daimler. Moreover, there is valid market information about further investment strategies of automotive suppliers in countries from Eastern Europe (Pranav, 2020).

1.2. Lean Manufacturing principles

Lean approach, targeted at improving operational performance and attaining customer satisfaction, is permeating into the manufacturing industry globally where business leaders are implementing the approach at different operational areas in their organization for operational improvement purposes. Originating from the automobile industry, the captivity of Lean approach has considerably extended from the heavy manufacturing industry to numerous industries such as banking, mining, public service, hotel, and health care. In the book "*Lean Thinking: Banish Waste and Create Wealth in*

Your Corporation", (Womack & Jones, 1996), both authors approached the Lean concept from a general perspective by extending the base of the concept from a functional level to the business level. The authors referred to Lean thinking as the "way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively". Lean incorporates a collection of principles, tools and techniques into the business processes to optimize time, human resources, assets, and productivity while improving the quality level of products and services to the customers. The principles guide management in the process of developing a Lean based enterprise and create a continuous journey towards waste elimination by working together and revisiting each activity in a value stream to identify opportunities for further improvements. The level of innovation and improvement driven by the Lean thinking in manufacturing industry eventually have encouraged management teams from other industries to consider and implement the key principles in their organization. The five Lean thinking principles introduced are: define value from the customer perspective, identify the value streams, make the value flow, implement pull-based production and strive for perfection continuously. They are summarized in figure 1. The first key principle emphasizes defining value from the way customers perceive it as they ultimately decide the value of a product or service. This means designing products to meet the needs of customers, eliminating wasteful steps that may have been required for unwanted features. The second principle regards the value stream, which is a focused view on the value-adding process and it is defined as a set of all actions required to bring a specific product through the three critical management tasks of a business unit: problem-solving, information management, and physical transformation. The process requires firms to identify and map the product's value stream. Lean tools like Value Stream Mapping (VSM) can be used to visually map the entire product flow, in order to find and minimize the steps which do not add value. The third principle is creating flow. Efficient product flow requires items to move from production to shipping without interruption and can be achieved by strategically organizing the work floor. Every factor, from people and equipment to materials and shipping, must be taken into account to ensure products seamlessly move through the production process. A well-organized work floor will result in reduced production time, inventory size, and material handling. The fourth principle of Lean thinking is the pull-based production one, which ensures customers receive their desired product or service when they want it. Pull assures continuous flow in the production process by associating actual customer orders with the production rate. The upstream operation in a value stream reacts only to the demand laid by a downstream operation. Lean manufacturing tools like Kanban can help businesses establish a pull system to control the flow of materials in a production system. The last principle is constantly pursuing perfection. The principle basically indicates that enterprises need to continuously iterate their way through the first 4 principles until all the non-value-added activities and wastes are removed from the value stream. With the principle, the culture of constantly searching for opportunities to improve operational efficiency, reduce costs and improve product quality is induced in an enterprise. *Kaizen*, a philosophy of continuous improvement, can help businesses with this shift by creating a culture where workers seek perfection (Thangarajoo & Smith, 2015), [1].

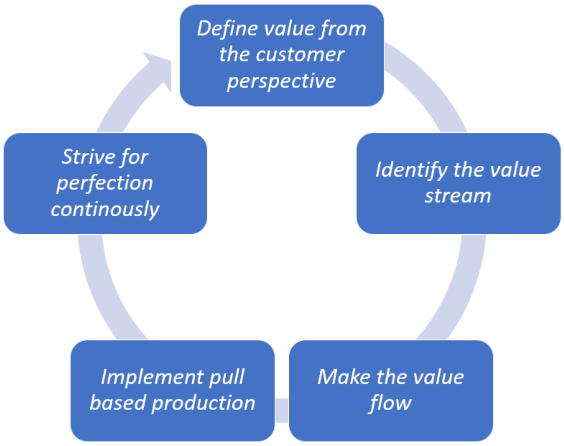

Figure 1: Lean principles (Thangarajoo & Smith, 2015)

1.3. Kaizen

Today, organizations worldwide from manufacturers to hospitals, to banks, to software developers, to governments are making a difference by adopting *kaizen* philosophies, mindsets, and methodologies. In Japanese, *kaizen* means "continuous improvement." The word implies improvement that involves everyone, both managers and workers, and entails relatively little expense. In the context of *kaizen*, management has two major functions: maintenance and improvement. The first refers to activities directed toward maintaining current technological, managerial, and operating standards and upholding such standards through training and discipline. Improvement, instead, refers to elevating current standards. The Japanese conception of management can thus be reduced to a single precept: maintain standards, and improve them. *Kaizen* fosters process-oriented thinking because processes must be improved for results to improve. Failure to achieve planned results indicates a failure in the process. Management must identify and correct such process-based errors. An important concept related to *kaizen* is the importance of *gemba*. Cambridge Business English Dictionary is one of the few sources that provide a definition of this word in the English language: "in Japanese business theory, the place where things happen in manufacturing, used to say that people whose job is to manufacture products are in a good place to make improvements in the manufacturing process". In Japanese *gemba* means "the actual place", meaning the place where the action occurs. From the perspective that the *gemba* is where all actions take place, it becomes the location of all improvements and the source of all relevant information. There are two main types of resource management activities that occur on a daily basis in the *gemba*: maintenance and *kaizen*. The main components of an effective *kaizen* strategy are Total Quality Control (TQC) and Total Quality Management (TQM), a Just-In-Time (JIT) production system, Total Productive Maintenance (TPM), a policy deployment process, a system of suggestions and small group activities. TQC is the Japanese quality control delegated to the entire company organization, while TQM is its extension to all other management aspects related to quality. The JIT aims at reducing any kind of activity that does not bring value and realizing a "Lean" production system, flexible enough to be adjusted according to the fluctuations of customer orders, using a pull system. The *kaizen* activities that contribute to customer satisfaction declined according to the objectives of Quality, Cost, Delivery (QCD) are mainly three: standardization, 5S and elimination of inefficiencies. Those activities are easy to implement and understand for workers and do not require particularly advanced knowledge or technologies (Masaaki, 2015).

1.3.1. Muda

Muda is a Japanese word that denotes waste, inefficiency, and more. Production activities are composed of a series of processes that start from raw materials and other inputs up to the final products. Every process adds value to the product (or service) and it transfers this value to the downstream process. Taiichi Ohno classified seven types of *muda*, occurring inside the *gemba*. The first one is overproduction and it depends on the mindset of production Supervisors. It is created by the tendency to move ahead on the production schedule, or produce more than needed, to increase the utilization of expensive machinery. Overproduction derives from fallacious assumptions and inadequate policies, such as producing as much as possible in each production process, without considering the optimal speed of the downstream process; allowing operators a certain margin; making each production process have an interest in increasing its own productivity; increasing the shortage of production, by virtue of the useful yield and few stoppages; saturating the productive capacity of machinery, even producing more than necessary; using machinery according to its depreciation schedule. Another *muda* is represented by the stock. Finite products, semi-finished products, components and raw materials do not add value, they represent an operative cost, take space and need specific equipment and additional services, such as forklifts or internal systems. Warehouses also require qualified personnel for movements and documents. Excess inventory deteriorates over time and is at risk of being destroyed by fire or other casualties. Defectives also represent a *muda*, because they interrupt the production and need expensive re-work. Many times the parts are to be discarded completely and with them the resources and efforts that produced them. In today's mass production environment, the malfunction of a machine can result in a large number of defective parts before stopping. In turn, scraps can damage expensive equipment and machines. Therefore, machines should be equipped with a rapid stop device as soon as they produce a defective part. Any movement of people is unproductive if it is not directly related to the provision of value. Any action that requires the operator to exert physical effort should be avoided because of its inherent difficulty, but also because it is an example of *muda*. Once these types of *muda* are identified, it is necessary to intervene and add more appropriate equipment or change the layout of objects. Processing *muda* is due to technological or design deficiencies in the single workings of the process. In many cases, these inefficiencies are the result of synchronization failures in production processes; other times, they result from operators' insistence on refining machining beyond what is necessary. Eliminating machining inefficiencies is often achievable with low-cost, common-sense techniques. Waiting *mudas* originate when the operator has idle time because he or she has to stop for line unbalancing, missing parts or machine stops. They also include the time the workers spend in waiting for the end of the machine action. Finally, transport wastes mean all the activities to move parts or components around the plant, with the use of specific equipment such as forklifts. Transport is an essential part of the productive activity but by itself, it does not bring value. Worse, it can cause damage. The physical distance between two processes in the same flow means that transportation is required; to reduce these inefficiencies, isolated processing cells must be eliminated as far as possible by bringing their operational processes back to the main production line. Alongside the seven *gemba* wastes identified by Ohno, there is the time *muda*. Time misuse leads to inertia, materials, products, information and documents staying where they are, without adding value to the process. The three main areas of weaknesses in a company are, besides losses and wastes (*muda*), overloading and exertion (*muri*) and imbalances and deviations (*mura*). There is *mura* whenever the regular course of operations is interrupted or disturbed, in the arrival of parts to be machined, in the scheduling, in daily work activities. *Muri* means overload or boundary condition in operators as well as in machines and production processes. *Mura* and *muri* are often cited in relation to the *muda* they generate and for that reason, they need to be minimized (Masaaki, 2015). In figure 2 it is possible to see a scheme of these weaknesses, to better understand their different meanings. A simple illustration shows how *muda*, *mura*, and *muri* often are related so that eliminating one also eliminates the others. Suppose that a firm needs to transport six tons of material to its customer and is considering its options. One is to pile all six tons on one truck and make a single trip. This would be *muri* because it would overburden the truck, which is rated for only three tons, leading to breakdowns, which also would lead to *muda* and *mura*. A second option is to make two trips, one with four tons and the other with two. But this would be *mura* because the unevenness of materials arriving at the customer would create jam-ups on the receiving dock followed by too little work. This option also would create *muri*, because on one trip the truck still is overburdened, and *muda* as well, because the uneven pace of work would cause the waste of waiting by the customer’s receiving employees. A third option is to load two tons on the truck and make three trips. This would be *muda*, even if not *mura* and *muri*, because the truck would be only partially loaded on each trip. The only way to eliminate those weaknesses is to load the truck with three tons, its rated capacity, and make two trips [2].

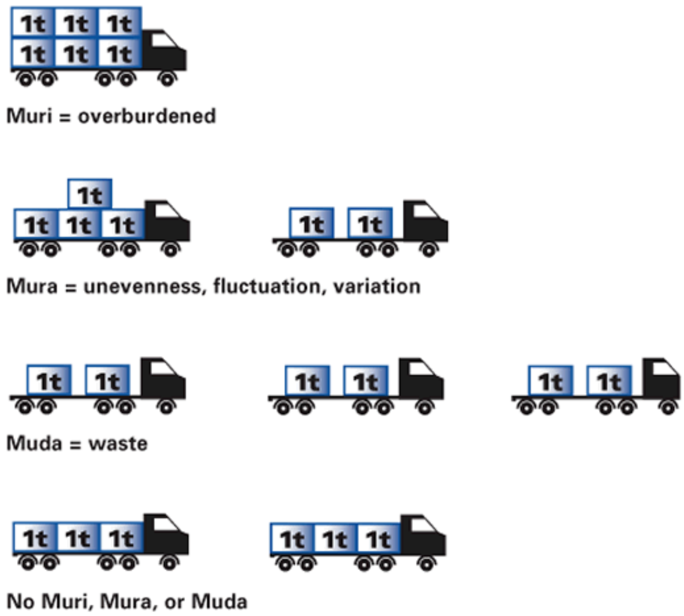

Figure 2: Muri, mura, muda scheme [2], 2021

1.4. Standards

The company's activities take place every day in accordance with established procedures which, when expressed in written form, form the so-called standards and define best practices for the implementation of the work. Management, in its daily routine, can be traced back to a single lesson: maintain and improve standards. If something goes wrong on the production line, for example, defective parts are produced or customer complaints are received, management must always research the root causes, take corrective action, and modify operating procedures to prevent the problem from recurring. In *kaizen* terminology, managers must implement the Standardize-Do-Check-Act (SDCA) cycle, to stabilize the company's current processes and bring them back to a standard. The production process can be defined as being under control when it is equipped with standards, the operators respect them, and no anomalies are found. In order to improve processes even more, managers instead apply the Plan-Do-Check-Act (PDCA), which will be presented in chapter 3. It is possible to distinguish between management standards and operating standards. The first type includes administrative regulations, human resources policies and rules, while the second one is the methods with which to carry out operations aimed at achieving QCD objectives. Management standards relate to the internal purpose of personnel management, while operational standards relate to the external purpose of customer satisfaction. Standards in a company also have a role to minimize the three main area of weaknesses cited before, *muri*, *mura* and *muda* (Masaaki, 2015). Standards must be of maximum brevity, containing only the necessary instructions for operators or workers, simple and easy to visualize, so that every person in the company can understand them properly. Another important aspect is the monitoring of their impact on process parameters. With proper implementation of standards a company prevents defects in production and at the same time constitutes procedures to prevent the occurrence of other errors that could have an impact on production. The benefits of standardized work include documentation of the current process for all shifts, reductions in variability, easier training of new operators, reductions in injuries and strain, and a baseline for improvement activities. Standardizing the work adds discipline to the culture, an element that is frequently neglected but essential for Lean to take root. Standardized work is also a learning tool that supports audits, promotes problem solving, and involves team members in developing poka-yokes (Mlkva, Prajova, Korshunov, & Tyurin, 2016).

1.5. Total Productive Maintenance

Total Productive Maintenance (TPM) is considered a Lean manufacturing tool increasingly used within the current industrial environments and the automotive industry has been considered the first one to report its usage and application. The purpose is to maintain the equipment and machinery used in the production of goods and services in optimal conditions to be able to provide products and/or services that achieve and even exceed customers' expectations. In addition, it also seeks to reduce waste, minimize equipment inactivity, and improve quality, but mainly focus on equipment maintenance programs to optimize efficiency and performance through activities to improve preventive and predictive maintenance. The traditional approach to TPM was developed around the 1960s and it is based on the 5S, alongside eight supporting maintenance activities, which are: autonomous maintenance, focused improvement, planned maintenance, quality maintenance, education and training, office TPM, safety, hygiene & environment and developed management. The benefits provided by the correct usage of TPM can be divided in advantages for the company, productivity ones and safety ones. The work environment quality is enhanced, changing the employees' mindset and increasing their morale. TPM then helps the management to develop new policies for a better operations control. From the benefits mentioned, also a significant improvement is acquired in the equipment availability and performance within the plant, as well as from a better communication between the employees. As regards the productivity, the elimination of losses can be included. Another objective of these processes is the equipment improvement reliability and availability, which leads to a decrease in the maintenance costs. Avoiding equipment breakdowns and standardize the process also improves the final product quality and consequently fewer spare parts will be produced, resulting in a lower cost. The results obtained with the TPM implementation allow the development of a culture that promotes a sense of psychological ownership, which guarantees the workers' commitment and, at the same time, generates higher productivity levels. Safety benefits of TPM regard the environmental conditions and the preventive effects on health. A safe environment is guaranteed also because the prevention and elimination of potential accidents causes (Diaz-Reza, Garcia-Alcatraz, & Martinez-Loya, 2019).

1.6. Main Lean Manufacturing tools

Lean tools provide frameworks to solve problems, measure performance, analyze and optimize work processes while helping to manage people and change. Lean Manufacturing tools are intended to help drive out waste, simplify everything, create efficient flow, improve quality control, and make the most of factory resources. Adopting Lean Manufacturing tools guides manufacturers to continuously improve processes through waste elimination and decrease process variability in quality and flow rates. Another advantage is expanding production flexibility to enable build to order method. Reduce manufacturing costs by increasing productivity, reducing labor hours, lowering inventory, decreasing consumables usage, and contracting factory footprint/space are other key benefits. Using tools is also good to optimize CAPEX investments. Furthermore, it improves production throughput, cycle time, and delivery to meet customer demand and it enhances product quality and reduces defects, rework and scrap, and related costs [3]. In this chapter 5S, Andon system, 5W2H and *gemba* walk, some important Lean tools connected to the project, will be presented.

1.6.1. 5S technique

The so-called 5S are the five phases of housekeeping, which means the reorganization of production sites. Along with standardization and *muda* elimination, it forms the pillars of *gemba kaizen*. Those activities are low cost because they do not need technologies or new management theories to be applied. The first “S” is called *Seiri*, meaning to separate what is necessary to what is not, and therefore needs to be eliminated. *Seiton* represents arranging in good order everything that remains in the *gemba* after the first phase. The next activity is *Seiso*, which is to cLean up the machines and the operating environment. *Seiketsu* means apply the previous three steps to yourself and practice them continuously. The last “S”, *Shitsuke*, consists in maturing self-discipline and make the application of the 5S stable, through the introduction of standards. Employees must be mentally prepared to accept the 5S, because *kaizen* encounters the resistance to change inherent in human beings. Time needs to be spent discussing their theoretical underpinnings and practical benefits, such as cLeaner, more pleasant and healthier working environments or reduced inefficiencies and easier and less exhausting operations. Among the various benefits of using the 5S technique there is helping employees gain self-discipline. They thus consistently engage in the 5S, take an active interest in *kaizen* and become reliable in meeting standards. Their adoption brings out the many types of *muda* found in the *gemba*. Recognizing these problems is the first step in solving them. Using the 5S method also makes anomalies evident, like defective parts or excessive stock, reduces unproductive movements and unnecessary efforts, allows to detect at a glance the problems associated with material shortages, production imbalances, machinery unavailability and delivery delays. Other advantages are the fact that it makes quality problems visible and improves operational efficiency, reducing costs (Masaaki, 2015).

1.6.2. Andon system

Andon in Lean Manufacturing is a system designed to alert operators and managers of problems in real time so that corrective measures can be taken immediately. It originates from the Jidoka methodology used in the Toyota Production System, which empowered operators to recognize issues and take the initiative to stop work without waiting for management to make the decision. Using the Andon system in Lean manufacturing yields many benefits both in the short and long term. In the short-term, it provides visibility and transparency in the production process, increased productivity and efficiency and decreased waste. Long term benefits include improvements to the production process, as reduced costs and downtime, enhanced value to the customer because of better quality products. Another advantage is responsible operators who are accountable for the line running as efficiently and effectively as possible, empowering them to act when problems arise, rather than waiting for management. Originally, the operator would pull the Andon Cord, which was a rope located above the line, but the system can take many forms. It can be activated by an operator pulling a cord or pushing a button, or it can be automatically activated by equipment when a problem is detected. Whether used because of part shortage, equipment malfunction, or a safety concern, the point of Andon in Lean Manufacturing is to stop work so that the team can gather together, perform a real-time root cause analysis, and quickly apply a solution. The system takes the position that stopping work in the moment will save the organization from major and costly issues in the future. This fits nicely with the Lean principle of “Respect for People.” If an operator doesn’t feel trusted enough in the environment to stop the line based on their own judgment, huge problems could occur later by not resolving the issue. Once the problem is resolved and work continues, the occurrence is logged as part of a continuous improvement system. Like most principles in Lean manufacturing, the Andon cord itself does not add value. Likewise, if action is not taken immediately when the system is alerted, it defeats the purpose and can actually detract from the value you are targeting [4].

1.6.3. 5W2H

5W2H is the tool used to understand a problem or opportunity for improvement from different perspectives. Of a Japanese origin, it was initially created for management projects by professionals who carried out quality studies, and, currently, it is used in the most varied business projects, such as Lean Six Sigma projects, regardless of their context and operating scenario. With the problem being understood from different points of view, decision-makers can analyse which decisions are most cost-effective to take, so that the end result is the best and most coherent possible with the stated objective in the project scope. It is only by understanding the problem efficiently that it is possible to act on it and obtain as a consequence an effective result. The 5W2H can be applied in a simple Excel worksheet as a means of facilitating to those involved a clear and precise understanding of the problem they are seeking to solve. The seven points are summarized in figure 3 and are presented below:

- **What:** in this section the description of what the problem is about should be noted, the purpose of the project and / or the improvement goal being proposed to achieve;
- **Who**: who is responsible for solving the problem or opportunity for improvement. The team assigned to solve it and who are the internal or external clients are some of the ways to respond this part;
- **Where**: in this space, the information of the place involved by the problem must be recorded, that is, where it is inserted. It will be defined if it is a specific sector or even in which operation or production machine it operates;
- **Why**: at this stage it is important to define the reason why solving this problem or reaching the proposed goal is important. Discuss under which financial and qualitative aspects is worth pursuing with the resolution of the problem and / or the achievement of the goal;
- **When**: the information is linked in time, that is, from when the problem occurs and what the deadline for resolution, as well as the delivery dates and schedule to meet the project objective;

- **How:** how the process by which the problem is involved works is the question to be answered. What steps, activities and relevant variables can affect it. One tip here is to use a flowchart to better represent it;
- **How much**: here, information can be linked to quantity and cost, that is, how much this problem has already generated expenses for the area involved and / or for the whole company. How much investment is necessary to solve it, as well as how many processes and products it has already affected [5].

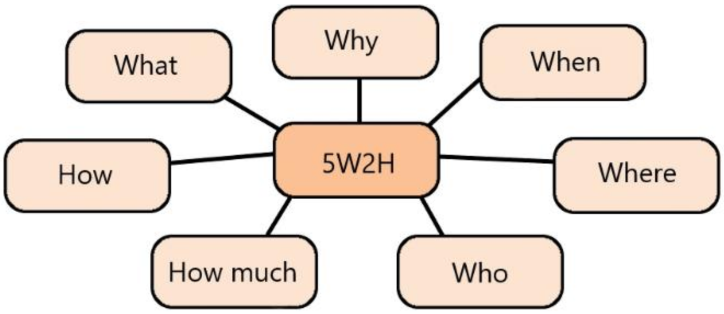

Figure 3: 5W2H [5]

1.6.4. Gemba walk

The *gemba* walk is an essential part of the Lean management philosophy. Its initial purpose is to allow managers and leaders to observe the actual work process, engage with employees, gain knowledge about the work process, and explore opportunities for continuous improvement. The first elements of this tool is for managers and leaders on every level to take regular walks around the shop floor and be involved in finding wasteful activities. A *gemba* walk's objective is to explore the value stream in detail and to locate its problematic parts through active communication. One technique used to identify problematic parts of the process is the 5W2H tool, presented in section 1.6.3.. Another important aspect is to collaborate with the team and find problems together, without blaming people. Some basic steps for the *gemba* walk application are schematized in figure 4 and the first one consists in picking a theme; this helps focus and be effective. Then, the team must be prepared for what is going to happen, making it more willing to collaborate. Another point is to focus on the process and not the people involved and to follow the value chain to understand areas with high wasteful activities. Another step is to write everything down, leaving the analysis for later purposes, in order not to base observations on gut feelings. People coming from different departments or less familiar with the process can help as well, because they have a fresh perspective. The last step is to share the observations with the team, to involve them. Usually during *gemba* walks some checklists are used, to guide the process [6].

Figure 4: Gemba walk steps [6]

1.7. Lean Manufacturing in the automotive sector

1.7.1. Different suppliers' roles

As explained in section 1.1., Lean was founded and developed in automotive companies, especially car makers. To keep up with the manufacturers' requests and be competitive, suppliers need to align their production facilities to this production method. There are many ways in which automotive manufacturers guide their suppliers to apply Lean principles to their production facilities. Supplier development, a company's undertaking to improve its supplier's capabilities, has been taken for granted in the Japanese automotive industry for several decades, and has received attention in the US only recently. Automakers may send their own engineers to the supplier's shopfloor to help solve a problem with a specific component in order to meet the product launch date. They may provide training courses for suppliers' or they may also ask a supplier to work on a specific production line for an extended period with a view to learning heuristics to achieve cost reduction, inventory reduction or quality improvement. In 'Japanese-style' supplier relationships, suppliers are given a consistent set of incentives to learn and acquire organizational capability from their customer companies. Each automaker has an array of supplier development programmes, ranging from individual assistance to group-based assistance, from seminars or lectures to joint-problem solving in concrete settings, but also with different aims (Sako, 2004). In some companies, such as Tenneco as regards the Chivasso plant, there is not a strong supplier development and there is less vertical integration and the company serves more clients at once. Manufacturers simply check the suppliers' capabilities, by asking them to apply Lean principles, especially the 5S methods, to be more efficient as possible. Suppliers to the automotive industry are likely well-versed on the concepts of layered process audits (LPAs), since these audits are typically required as a condition of doing business with major automakers. LPAs differ from generic process audits in that they require multiple people, including management, to conduct an ongoing chain of simple verification checks to ensure that a defined process is followed correctly. This powerful audit management methodology can improve quality and deliver cost savings by boosting problem-solving systems and making continuous improvement nearly routine [7]. LPAs are not confined to the Quality Department, but involve all employees in the auditing process. Supervisors conduct frequent process audits in their own area, while higher-level managers conduct the same audits less frequently and over a broader range of areas. These audits also typically include integrated corrective and preventative actions taken either during, or, immediately after the audit. Layered process audits help manufacturers and service providers take control of processes, reduce mistakes, and, improve both work quality and the bottom line [8]. To remain competitive in the evolving automotive landscape, automobile manufacturers need to fundamentally ensure that production remains highly optimized. In this regard, another way to ensuring efficiency and Lean on the assembly line is the seamless collaboration between the Original Equipment Manufacturer and its suppliers along the supply chain. To facilitate just-in-time (JIT) and just-in-sequence (JIS) processes, a large number of individual components need to be fitted correctly and punctually throughout the production chain. Crucially, these parts all need to be delivered on time and to the right location. The conventional warehousing of components must be avoided as far as possible to eliminate additional costs, capital lockup and storage risks. These highly optimized Lean production processes tend to be extremely complex and in the automotive sector they are facilitated, or even made possible, through EDI integration. EDI is a high-performance, robust method of exchanging data, which has been tried and tested over many decades. It has become indispensable in the automotive business, where suppliers offering a professional EDI connection enjoy huge benefits. The automotive sector exploits the substantial advantages offered by EDI integration on a large scale [9]. Another aspect to consider is the product development. This has become a critical process within Supply Chain Management, especially in the automotive industry, which carries a high degree of complexity and usually involves a significant diversity of materials and technologies. For such, the involvement of key suppliers in the early stages of the product development process, by the practice of ESI, can promote reduction of development time, quality improvements, and innovations into the products and the production processes, as well as can leverage costs and time-to-market reductions to the entire supply chain, by incorporating into the project the knowledge and skills of suppliers. ESI is also aligned with the principles of Lean Manufacturing, as both aim to reduce waste, risk, cost, and time-to-market. The degree of involvement of each supplier in the PD depends on a series of factors, among which stand out the degree of responsibility of the supplier in the project and the degree of risk involved (Silva, Pires, & Argoud, 2019).

1.7.2. Lean applications among automotive suppliers

Valeo, an important company among the tier-1 suppliers , values operational excellence, which reflects their commitment to customer satisfaction. To meet customers' expectations in terms of product and service quality everyone must deliver total quality. Valeo has developed its own production system which implements a set of methods, tools and state-of-the-art production processes within a working environment that promotes quality, performance and employee motivation. In order to deliver the highest quality products and services while remaining competitive, the company has set up a supplier base integrating the most efficient suppliers in terms of innovation, quality, cost, delivery and risk management. Operational excellence cannot be achieved without the ongoing commitment of all of the Group's employees. Valeo, therefore, implements processes aimed at creating a safe working environment that fosters employee well-being. To develop its products and systems, Valeo's highly qualified Research and Development teams work within an optimal organizational structure that combines professional skills and product expertise with first-rate methodology and best-in-class project management tools aimed at ensuring product robustness and competitiveness [10]. Bosch started applying Lean thanks to a global initiative called Bosch Production System, similar to the TPS, in which all factories had to meet the same stringent standards. The first steps were to change the company's vision, to establish a continuous improvement mindset not only in manufacturing but in all organizational support functions, including management. For example, when they applied the 5S method, they involved the managers in the process, because *kaizen* methodology does not distinguish between company hierarchical levels. Another golden rule in Bosch is the importance of the self-improvement (Masaaki, 2015). Denso, one of the world's largest automotive suppliers and one of Tenneco's competitors, has been applying Lean almost since the beginning of the company. That dedication to Lean management led to receiving the Shingo Prize, which was awarded to two of Denso's North America units, one in 2007 and another in 2008. Their early challenge was to empower and engage the workforce in applying *kaizen* principles to their own processes. The key to Denso success is the common language established in the organization, with training at each level that worked from top to bottom [11]. Tenneco is applying the principles following its clients' guidelines, but the Chivasso plant case study is relatively new to a structured Lean methodology, as will be presented in chapter 3. This facility has been part of Tenneco only since 2018 and it needs to align to what other suppliers do in the automotive landscape. The main objective of the thesis project are to pursue operational excellence and to reduce wastes, by creating some standard procedures, as will be explained starting from chapter 3. As the other automotive companies, Tenneco uses Lean Six Sigma, which is a structured approach resulting from the integration of Lean thinking and Six Sigma, born and developed by Motorola and later by General Electric. The latter is an approach to improving quality and reducing process variability using powerful statistical methods. Its goal is to achieve a process control such that there are only 3.4 defective parts per million parts produced, bringing the variability of the production process to very narrow limits. Lean Six Sigma as a whole aims to reduce or eliminate wate, make the materials and information flow, optimize the process as a whole and not locally, involve resources and cultivate a culture of continuous improvement, improve quality through major improvement projects, use statistical analysis tools to reduce variability [12]. Tenneco is continuously proposing new training to its employees, to align them with Lean principles. The Chivasso plant, as many other companies, is helped by the *Kaizen* Institute. *Kaizen* Institute was founded in 1985 by Masaaki Imai and has grown to a global leader in Business Improvement consulting with offices in 55 locations around the globe. Their mission is to support organizations to develop people-based business excellence systems and create sustainable competitive advantage. For example, the Institute provides two-day *kaizen* activities. The two-day *kaizen* process was developed in 1977 by Nissan Motor Company and its suppliers, where the companies used two days to optimize their production lines. Akio Takahashi, who was Nissan's suppliers' consultant for many years, asserted that objectives are more easily achieved if the constructed line is capable of self-regulate on the takt time and it is flexible enough to manage its deviations, *muri*, *muda*, and *mura* are eliminated, factors disturbing the operational cadence are eliminated, operating procedures lend themselves to being transcribed into operating standards and line operators are reduced to the minimum number (Masaaki, 2015).

2. Tenneco

This chapter will describe Tenneco corporation, with special regards to the Chivasso plant and its product portfolio. An introduction about the automotive industry and its new trends and challenges has been added to underline the company's role in the evolving landscape.

2.1. The automotive industry

As (Binder & Rae, 2020) affirm, the automotive industry includes all those companies and activities involved in the manufacture of motor vehicles, including most components, such as engines and bodies, but excluding tires, batteries, and fuel. The history of the automobile industry has exceptional interest because of its effects on history from the 20th century onwards. Although the automobile originated in Europe in the late 19th century, the United States completely dominated the world industry for the first half of the 20th century through the invention of mass production techniques. In the second half of the century the situation altered sharply as western European countries and Japan became major producers and exporters. In the United States it is the largest single manufacturing enterprise in terms of total value of products, value added by manufacture, and number of wage earners employed. One of every six American businesses is dependent on the manufacture, distribution, servicing, or use of motor vehicles; sales and receipts of automotive firms represent more than one-fifth of the country's wholesale business and more than one-fourth of its retail trade. For other countries these proportions are somewhat smaller, but Japan, South Korea, and the countries of western Europe have been rapidly approaching the level in the United States. The trend toward consolidation in the industry has already been traced. In each of the major producing countries the output of motor vehicles is in the hands of a few very large firms, and small independent producers have virtually disappeared. The fundamental cause of this trend is mass production, which requires a heavy investment in equipment and tooling and is therefore feasible only for a large organization. Once the technique is instituted, the resulting economies of scale give the large firm a commanding advantage, provided of course that the market can absorb the number of vehicles that must be built to justify the investment. Figure 5 shows the manufacturing leaders in terms of market share; data refer to 2020.

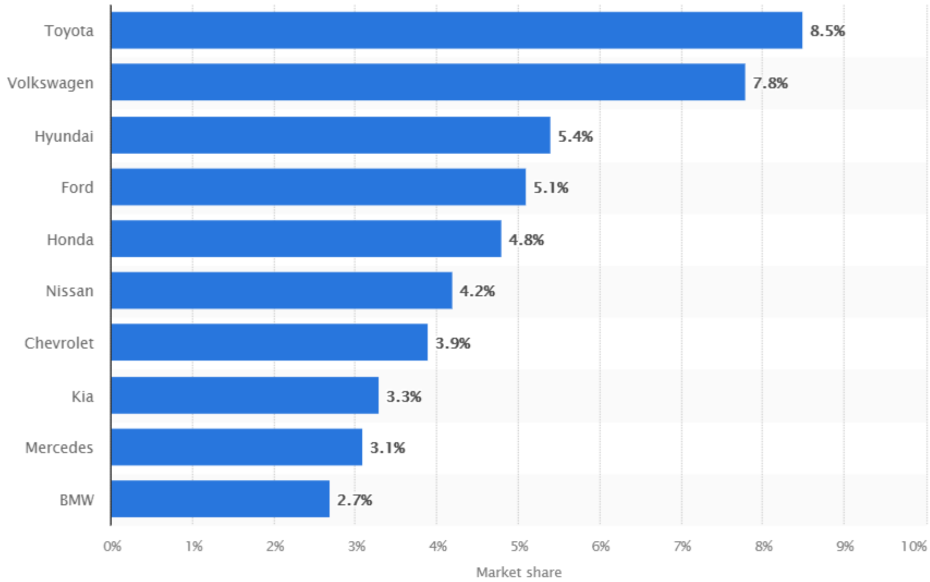

Figure 5: Leading car makers worldwide [13], 2021

2.1.1. The value chain

As presented in (Ambe & Badenhorst-Weiss, 2011), the automotive supply chain is highly complex and consists of many processes which, when linked together, form a supply chain from the customer back to the various tiers of suppliers. The structure of the supply chain consists of physical components, operational and planning processes and strategies. The physical flow of the supply chain, as shown in figure 6, consists of the suppliers, inbound logistics, production, outbound logistics, dealers and finally customers.

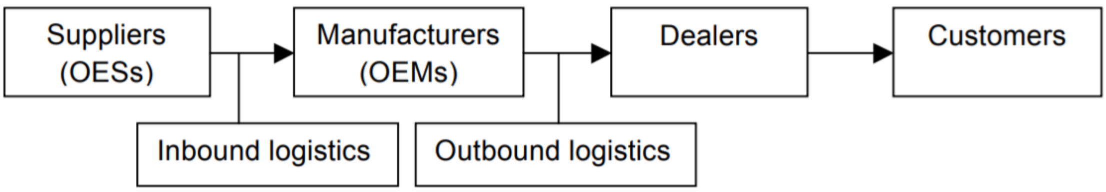

Figure 6: Physical flow of the value chain (Ambe & Badenhorst-Weiss, 2011)

Dealers are responsible for selling the vehicles produced by the manufacturers to the customers. They also have a significant influence on customer satisfaction. Dealers are involved in aftermarket activities such as order management, vehicle sales, customer relationship management, spare part sales, workshop management and service schedules Suppliers provide thousands of parts and components that go into the vehicle, received via an outbound logistics network from hundreds of Tier 1 suppliers. The so-called Tier 1 suppliers are companies that supply parts or systems directly to the OEMs, such as Tenneco. The major suppliers of the company are raw materials ones. These suppliers usually work with a variety of car companies or OEMs but they are often tightly coupled with one or two of them. The more complicated the product is, the more tiers of suppliers are there in the supply chain. Tier 1 suppliers, in turn, get their materials and components from Tier 2 and 3 suppliers. Another area among suppliers is represented by replacement parts, usually made by the same manufacturer as the OEMs. Finally, suppliers take care of the aftermarket parts, used to replace damaged parts. An original equipment manufacturer (OEM) is defined as a company whose goods are used as components in the products of another company, which then sells the finished item to users. The second firm is referred to as a value-added reseller (VAR) because by augmenting or incorporating features or services, it adds value to the original item. The VAR works closely with the OEM, which often customizes designs based on the VAR company's needs and specifications. Traditionally, OEMs focus on business-to-business sales, while VARs marketed to the public or other end users. An OEM is the opposite of the aftermarket. An OEM refers to something made specifically for the original product, while the aftermarket refers to equipment made by another company that a consumer may use as a replacement [14]. The increasing complexity of the car designs, due to the digitization and the improving technologies, is increasing the number of specific components manufactured by suppliers rather than by the manufacturers. In a single car it is possible to find more than 30,000 parts and that is the reason motor vehicle producers rely on key suppliers to assist in bringing these parts to market and to manufacturing them. OEMs supply components to produce new cars and the right parts need to be in the right place at the right time for the assembly line to continue operating efficiently [15].

2.1.2. New trends

The study by McKinsey & Company (Gao, Kaas, Mohr, & Wee, 2016) proposed different ways in which the automotive industry may be affected by the digital world and this is useful to understand how the industry is going to change. The automotive revenue pool will significantly increase and diversify toward on-demand mobility services and data-driven services. Connectivity, and later autonomous technology, will allow the car to become a platform for drivers and passengers to use their time in transit to consume novel forms of media and services or dedicate the freed-up time to other personal activities. The increasing speed of innovation, especially in software-based systems, will require cars to be upgradable. Consumers today use their cars as all-purpose vehicles. In the future, they may want the flexibility to choose the best solution for a specific purpose, on demand and via their smartphones. This customization possibility will create new segments of vehicles, and consequently specialized suppliers. Another trend in mobility is the electrification, also associated to environmental concerns. By 2030, the share of electrified vehicles could range from 10 percent to 50 percent of new-vehicle sales. More and more companies, and customers, are shifting to electric vehicles because of their advantages and improvements in the technology is lowering production costs, to compete with traditional cars. The new digital shift will disrupt the industry, causing new actors to enter it. First, suppliers may change and mobility providers, such as Uber, tech giants, like Google, or other specialized OEMs, for example Tesla, might emerge in the automotive industry. Therefore, OEMs are looking for new ways to differentiate themselves from their competitors. Upstream in the value chain, numerous components will disappear, and new components will be added to the car design, as the battery. To embrace the new trends, OEMs should start investing also in the new technology, increasing their vertical integration, especially as regards the battery production, the most important component of the future. Another strategy to keep up with the changing industry could be to align skills and processes investing in the knowledge, by hiring new technical experts or new graduates. To succeed, OEMs or other actors in the automotive value chain could for alliances, for example with startups proposing the new technologies. In this way, they would share the success by using the new science and exploiting the competitive advantage that established incumbents have, both with respect to network externalities and cost advantage. The last strategic step is to reshape the value proposition, offering differentiated products and services and creating integrated mobility services.

2.1.3. Covid-19 and crisis

The European automotive market, along the global one, is on its way out of the crisis due to the COVID-19 Pandemic occurred from 2020 onwards. In April 2020, new cars registration of the main European markets reached their lowest since World War II. What started off as a supply crisis, which temporarily constrained access to parts and raw materials sourced from China, turned into a full-fledged demand shock that saw sales tumble in the face of mass unemployment and financial uncertainty (Papi, 2020). As the chart in figure 7 shows, the world's largest automobile markets suffered significant sales declines in 2020, with the Chinese market furthest along on the road to recovery. Looking at European sales figures in more detail reveals that things were particularly bad in some of the region's largest markets. France, Italy and Spain, all heavily affected by the COVID-19 pandemic, suffered above-average sales declines of 25.5, 27.9 and 32.3 percent in 2020, respectively, while Germany, the EU's largest automobile market that had a good handle on the pandemic for long stretches of 2020, saw registrations drop by "only" 19.1 percent according to the ACEA. COVID-19 has accelerated and amplified the dynamics already existing in the automotive sector, with its challenges due to new technologies and mobility trends [16].

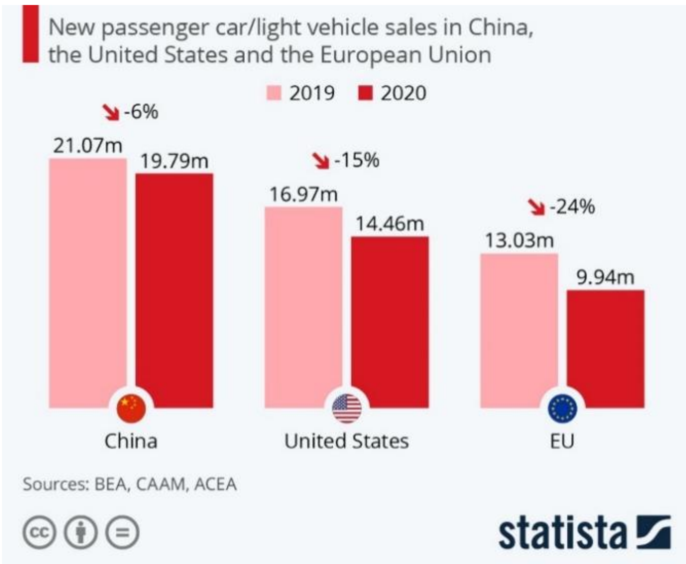

Figure 7: Sales data for passenger cars and light vehicles [16], 2021

During 2020, worldwide motor vehicle production fell sharply, dropping 15.4% from the previous year, because of travel restriction measures and an overall decline in economic activity. Aftermarket was the most recession-resilient part of the automotive industry, since its growth primarily depends on the size of the car parc, rather than the new vehicle sales. Used cars business was less impacted and showed a quicker rebound if compared to new sales, as during times of economic distress and weak consumer confidence many customers tend to delay purchasing new cars. OEMs need to focus on five business imperatives to mitigate the short-term impact of COVID-19. At first, they should help distressed suppliers enhance liquidity position and operations, alongside helping troubled dealership improve financials and secure business continuity. Then, they should reshape their value proposition by planning demand based on customers' needs, pushing towards electrical mobility to tap the potential of a rising demand, and embracing new technologies to remotely engage with customers (Papi, 2020).

2.2. Tenneco history

Tenneco is one of the world's leading designers, manufacturers, and marketers of automotive products for original equipment and aftermarket customers, with 2020 revenues of $15.4 billion and approximately 73,000 team members working at more than 270 sites worldwide. Headquartered in Lake Forest, Illinois, it is primarily an automotive components OEM and after-market ride-control and emissions products manufacturer. In 1930, the Chicago Corporation, a small investment firm and bank subsidiary, was formed. Around 1940 the Tennessee Gas and Transmission Company was founded as a separate entity. Tenneco was formed in 1943 as the Tennessee division of the Chicago Corporation to build a natural-gas pipeline and it was incorporated after World War II as the Tennessee Gas and Transmission Company. In 1966 the company was incorporated as Tenneco, Inc., expanded into many business ventures for diversification purposes. Starting from the 1980s the company divested all its businesses through various public offerings, sales, spin-offs, and mergers, leaving Tenneco Automotive as the remaining part of the original company. The automotive entities that remained, including a strong original equipment business and legendary aftermarket brands like Monroe and Walker, each with historic roots reaching back more than 100 years, showcase a rich history that helps define Tenneco today. Tenneco's history as a stand-alone entity began in 1999, when the current company emerged from a conglomerate formerly consisting of six businesses, shipbuilding, packaging, farm and construction equipment, gas transmission, automotive and chemicals. On October 28, 2005 Tenneco Automotive was renamed Tenneco, to better represent the expanding number of markets it served. Tenneco significantly expanded its global footprint during the early part of the 21st century, becoming one of the first automotive suppliers to establish operations in China. At the same time, Tenneco significantly enhanced its engineering and manufacturing operations throughout the world, becoming a leader in developing clean air solutions to help its customers meet stringent emissions control regulations throughout the world. Tenneco was one of the first companies to commercialize diesel particulate filters (DPFs) in Europe in 2000, and today continues to lead the industry with important aftertreatment technologies for gasoline and diesel engines. The company's advances in ride performance technology helped deliver comfort, performance and control to differentiate its customers' vehicles. In 2018 Tenneco acquired Federal-Mogul, a leading global supplier to original equipment manufacturers and the aftermarket. Federal Mogul Corporation was an American company founded in 1899 that started as a seller of mill suppliers, rubber material and metals for bearings. The firm operated two independent business divisions: Federal-Mogul Powertrain and Federal-Mogul Motorparts. The acquisition of Federal-Mogul doubled the size of Tenneco and allowed the company to add more than 25 aftermarket brands and a strong OE powertrain business to its portfolio. In Italy the company has three industrial plants in Piedmont, Courgnè, Chivasso and Mondovì. Today, Tenneco is a proud steward of more than 30 of the industry's most widely known and respected automotive brands and part of the Fortune 500 companies publicly traded on the New York Stock Exchange. It is made up of four diverse and complementary business groups: Ride Performance, Motorparts, Clean Air and Powertrain, each with their own heritage, strong identity and distinct value proposition. The company is composed of 201 manufacturing plants and 33 distribution centers. In figure 8 Tenneco logo is shown [17].

TENNECO

Figure 8: Tenneco logo [17]

2.3. Vision, mission, and values

Tenneco vision is to create more business opportunities for their plants, working for excellence through the continuous improvement, paying attention to safety and well-being of all employees. The mission is to support Tenneco's performance by building a high-performance culture with capabilities and processes to execute now and in the future. All business groups within Tenneco are united in the mission to preserve the environment and conserve resources. Tenneco’s environmental strategy is focused on reducing the environmental footprint of the facilities while developing and delivering quality products that enable fuel-efficiency to the customers. In figure 9 it is possible to see the effects of the environmental policies on energy and water use, overall waste and GHG emission intensity, compared to the previous years.

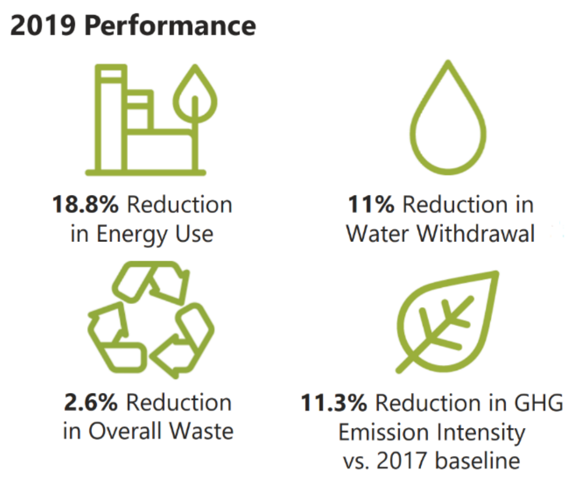

Figure 9: 2019 Environmental performance (Tenneco, 2019)

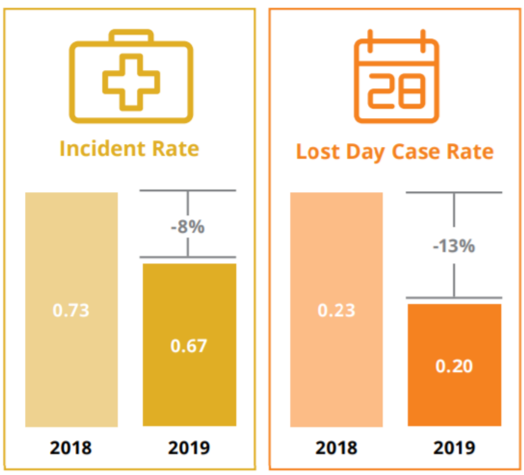

Figure 10: Rates reduction 2018-2019 (Tenneco, 2019)

The Code of Conduct sets high standards for Tenneco and enhances the way employees work together as one global team. The goal is to be recognized as a company that builds and grows its teams through a strong and positive culture. The standards are rooted in the values and are vital to their reputation and success. This Code serves as a daily reminder of what is expected from every member of the Tenneco team. The first value is integrity, which means being honest and fair. Accountability is related to accepting responsibility and trust to relying and having faith in one another. Every employee should then be result oriented and have passion and a sense of urgency, all guided by perseverance in pursuit of goals. Other key values are represented by the teamwork and innovation, which means discovering new solutions keeping up with advanced technologies. The last value is represented by the will to win, meaning making a difference and creating customer loyalty. Employees are periodically asked to complete compliance training on topics such as the Code of Conduct, ethical decision making, respect in the workplace, privacy, information security, anticorruption and competition laws. Tenneco has an Environment, Health & Safety policy, committed to excellence in these fields. The global impact of this policy is evident, as the case and incidents rates have been decreasing over the years. In figure 10 it is possible to see the reduction in the rates (Tenneco, 2019), [17].

2.4. Suppliers, clients and investors

In 2020 fiscal year, Tenneco generated 15,4 billion of U.S. dollars revenues, among which $ 3,7B can be attributed to Powertrain technology, $ 3,48 B to Clean Air, $ 2,7 B to Motor parts and $ 2,2 B to Ride performance. In figure 11 it is possible to see a sales breakdown into the different markets. Aftermarket revenue is generated from providing products for the global vehicle aftermarket to warehouse distributors, retail parts stores and mass merchants. Original Equipment (OE) substrate includes the catalytic converters and diesel particulate filters or components on behalf of its customers which are used in the assembled system. Original equipment value add category revenue is instead generated from providing original equipment manufacturers and servicers with products for automotive, heavy duty, and industrial applications [18]. Powertrain supplies products to a diverse customer base, including all major OE manufacturers in the automotive sector, light, medium and heavy-duty commercial vehicle, off-road, agricultural, marine, rail, aerospace, power generation and industrial equipment segments. No single customer represents more than 10% of Powertrain's global revenue and less than 5% of Powertrain revenue is sold into the aftermarket. The Motorparts department, global aftermarket leader, owns more than 30 brands and provides seven product categories with value-added services for customers. The Ride Performance one offers vehicle ride and NVH management solutions. Since Tenneco is an incumbent among automotive suppliers, it is accelerating growth on light vehicle Battery Electric Vehicle (BEV) platforms and it is investing in autonomous vehicle trends, to be ready to face the shift of the automotive sector and to maintain its leadership position. Clean Air department offers engine emissions control and acoustic performance solutions and it is a strong cash generator. Furthermore, Powertrain technology offers engine component solutions for improved efficiency and durability. The four departments try to align with automotive trends and provide solutions for light vehicles, commercial trucks, off-highway and industrial applications. Tenneco Global Purchasing is responsible for procuring all goods and services used by the facilities and joint ventures around the world [17], [19]. The markets served are light vehicle, commercial truck off-highway, energy, industrial, marine, power generation, railway, aerospace and small engines.

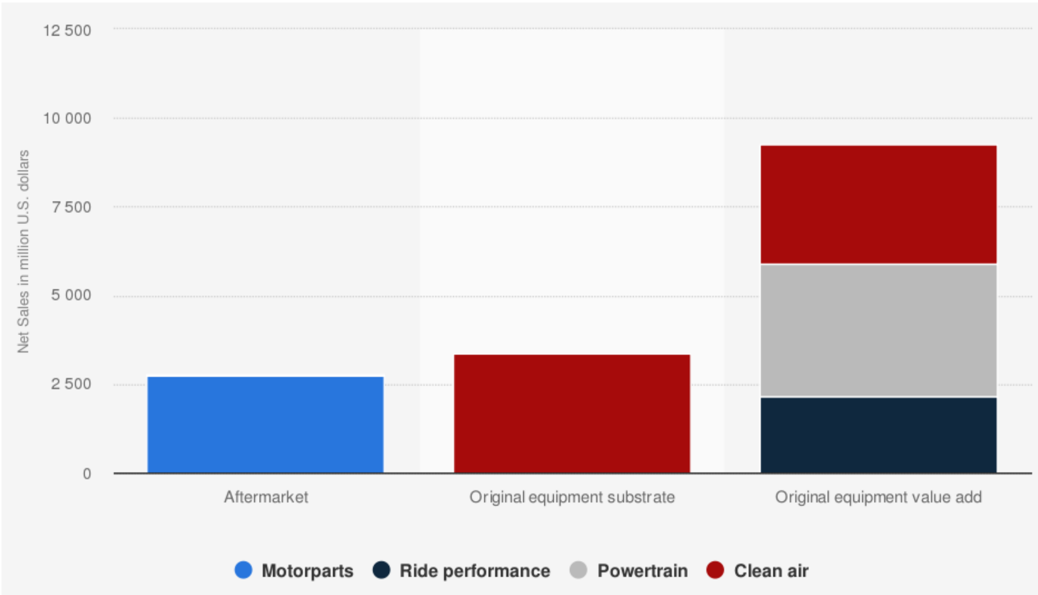

Figure 11: Tenneco net sales by market [18], 2021

The main customers at the global level are General Motors, Ford, Volkswagen, Daimler, Toyota and Caterpillar. Tenneco has a region and market diversification with a strong presence near all major customers, which are presented in figure 12.

Figure 12: Tenneco main customers (Tenneco, 2021)

In 2020 General Motors recognized Tenneco as a 2019 Supplier of the year winner, among other companies that exceeded GM's expectations, created outstanding value or introduced innovations to the company (Tenneco, 2021). To face the digital shift and satisfy the requirements of their clients, Punch Powertrain, Tenneco and Bosch have agreed in 2018 to set up a 'smart network', in which they, all being suppliers to the automotive industry, will exchange knowledge and resources. The network will mutually strengthen the partners and anchor South-Limburg region as the focal point of automotive industry. The main goal of the agreement is knowledge exchange around "Lean & smart manufacturing", to enable the next step in evolution of manufacturing - industry 4.0. For this purpose, best practices on topics such as automation, digitalization, logistic flows, and other organizational processes will be shared. In this way expertise and insights from different companies will be brought together to build an optimal scenario, from which all partners can benefit [20]. Tenneco has raised a total of $800M in funding over 1 round, during a Post-IPO Debt round raised on Mar 17, 2021. The company is registered under the ticker NYSE:TEN at the NY Stock Exchange, at a value of around $ 22.27 per share (June 16th). It has 433 institutional owners and shareholders that have filed 13D/G or 13F forms with the Securities Exchange Commission (SEC). Major shareholders can include individual investors, mutual funds, hedge funds, or institutions. These institutions hold a total of about 68 million shares. Largest shareholders include Icahn Carl C., an American entrepreneur and philanthropist, and Vanguard Group Inc and BlackRock Inc., the biggest investment firms in the world [21].

2.5. Chivasso Plant and units

The thesis experience has taken place inside the Tenneco Chivasso plant. The factory, which was part of Federal-Mogul Powertrain division, was acquired in 2018 by Tenneco. The building was constructed in 2000 and it now has a total area of 20,000 m^2, with a covered area of 12,100 m^2. The location is considered strategical, it is based in Chivasso industrial area, which is close to Turin-Milan motorway and it is also close to Caselle Airport in Turin and Malpensa Airport in Milan. The organizational chart is composed of the Plant Manager at the first level, then Plant Controller, Value Stream Manager, Maintenance Manager, Supply Chain Manager. Other managers take care of Human Resources, Health and Safety, Purchasing and Quality. It is composed of four main production departments: Unipiston, Heat shield, EMG and Gasket. In addition to those, in the plant there are some areas dedicated to logistics, both inbound and outbound, and maintenance. The latter is divided in tooling and a part dedicated to machine maintenance. In the next figure the various parts of the plant are shown, highlighted with different colors. The different parts of the factory are visible in figure 13. The plant counts around 170 employees and it works on three-shift operations. In the different departments there are the operators and each department is guided by a Team Leader, who oversees the operations and helps the workers. Team Leaders report to the Supervisors, who are in the offices and report directly to the management. There is one Supervisor managing EMG, Gasket and Heat Shield departments, one for Unipiston, including Injection, Compression and Dynamics departments, one for the Maintenance activities and finally one Supervisor for the Tooling department. These employees report to the Value Stream Manager, who is also the head of Production inside Tenneco and will be described in section 3.7..

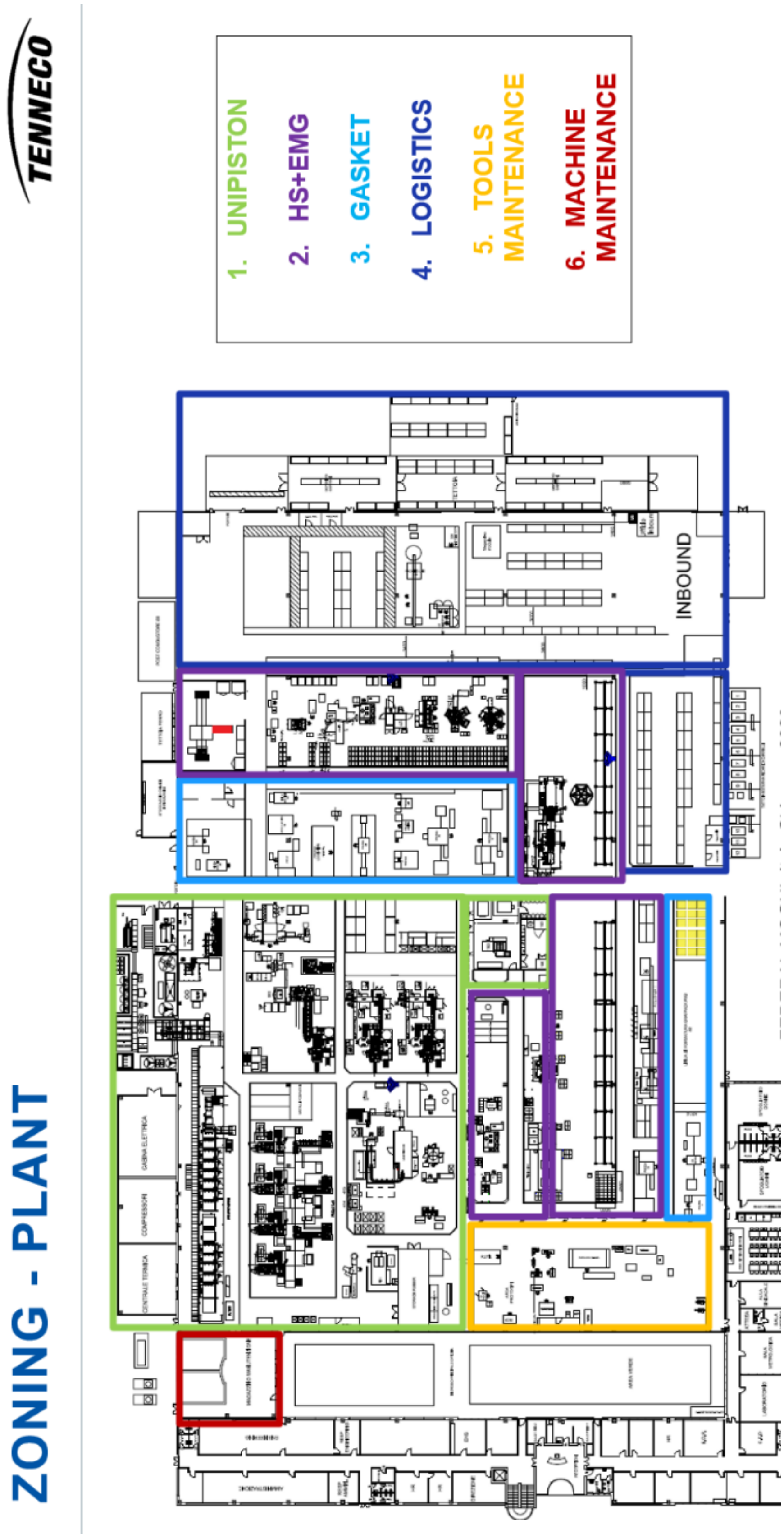

Figure 13: Chivasso plant layout (Tenneco, 2021)

The main customers of the Chivasso company are BMW and DAF, with a products division percentage of 27% and 14% over the total offer respectively (Tenneco, 2021), as it possible to see in figure 14.

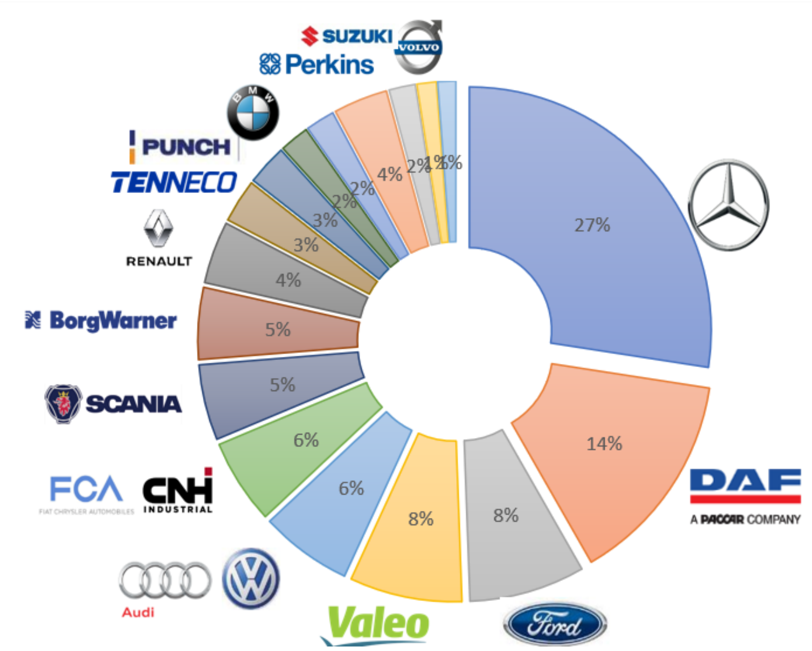

Figure 14: Chivasso plant customers division (Tenneco, 2021)

2.5.1. Product portfolio

Chivasso product portfolio includes gaskets. A gasket is an elastomeric component that covers the intersection between two surfaces. Automotive gaskets are sealing and cushioning material, frequently placed between two surfaces joined by bolts. Mechanics commonly replace a gasket when performing major work on the engine. The production includes stainless steel exhaust gaskets, both single and multi-layer and coated steel with rubber or foam coating. The production of heat shields was introduced in 2018, while the production of exhaust manifold gaskets was transferred to this plant in 2019. Heat shields examples are shown in figure 15. Other products offered are seals, as represented in figure 16. Automotive seals play critical roles in different types of four-wheeler vehicles. They are primarily used with bearings, hubs, and different types of mechanical systems. The seals are designed to prevent leakage of oil, lubricant, and component damage due to heat. Tenneco offers graphite or steel sandwiches, exploitable for high temperature applications. Unipiston is a registered trademark and it consists in a clutch piston with a high modulus of elasticity, which allows flexibility and the possibility to increase the engagement pressures, higher rotational speeds of the clutch and greater clutch diameters. Federal-Mogul Powertrain invented this technology and now Tenneco inherited the capability to manufacture co-molded clutch pistons using a high-modulus, environmentally friendly material, shown in figure 17. Other products in the portfolio are dynamic crankshaft seals, as it possible to see in figure 18. The dynamic seals have the task of ensuring the seal between two moving machine components. Radial shaft seals have the task of hermetically sealing the rotating crankshaft to the outside. Heat shields are products made of steel, aluminum, mica or glass fibers. In figure 19 an aluminum heat shield is represented. Due to the large amounts of heat given off by internal combustion engines, heat shields are used on most engines to protect components and bodywork from heat damage. As well as protection, effective heat shields can give a performance benefit by reducing the under-bonnet temperatures, therefore reducing the intake temperature. Heat shields vary widely in price, but most are easy to fit, usually by stainless steel clips or high temperature tape (Tenneco, 2021).

Figure 15: Heat shields (Tenneco, 2021)

Figure 16: Seals (Tenneco, 2021)

Figure 17: Unipiston (Tenneco, 2021)

Figure 18: Dynamic chankshaft seals (Tenneco, 2021)

Figure 19: Aluminum heat shields (Tenneco, 2021)

3. Losses management and control

In this chapter the first part of the thesis project, which is losses management and control, will be presented. The discussion will explain the steps that led Tenneco to get close to Lean Manufacturing and *kaizen* principles, which consequently help defining the way the company manages the criticalities connected to the production process. The aim of the project was to create a standard to identify the types of losses, to help operators, team leaders, Supervisors and managers start corrective and optimization actions.

3.1. *Kaizen* in Chivasso plant

Many U.S. automakers are running their plants with three shifts of workers and scheduling overtime, particularly factories that make pickup trucks, Sport Utility Vehicles (SUVs), and crossovers. Of course, the automakers' success in extending this upswing depends on the ability of their suppliers to keep up with industry growth. For tier one automotive suppliers, such as Tenneco, the pressure to meet demand must be carefully balanced with the ability to maintain and even improve quality. U.S. companies, as the other ones around the world, are trying to replicate the principles of the Toyota Production System. Since its development inside the automotive industry, Lean Manufacturing has revolutionized the sector in the last years and, in order to be competitive, companies like Tenneco need to apply Lean principles, to cut costs and improve efficiency. It is also a way to enhance the company's image to customers, suppliers, management, and employees [22]. After the acquisition of Federal Mogul, the Chivasso plant was enlarged to contain new processes and products that were moved from a German facility. This expansion and the growing attention to Lean topics in the automotive sector led the company to start focusing on Lean methods to optimize the production plant and be more aligned with the needs and requirements of its customers. Clients like BMW and other key players of the car manufacturing industry are looking for reliable partners who work in an efficient way, requiring the use of the 5S and other tools to optimize the production and assure a high quality standard for their final clients. The Lean Manager professional figure was created after the acquisition of Federal Mogul, to start focusing on these optimization principles and keep up with competitors.

A way to change the company's philosophy is to include all the employees. The first advantage of employee involvement is the increase in productivity, when workers are more involved, they better plan their work and put enthusiasm into it. This leads to an increase in their morale and consequently in their satisfaction. A healthier relationship between employees and the management is crucial also as regards communication between parties and share of knowledge, making the workplace a better place. Employees need to be given the authority to participate in substantive decisions, to have training or experience with decision-making skills and incentives to participate need to be present. Self-discipline is another pillar in *gemba* management. When they self-discipline, employees arrive on time, they keep the work environment safe and clean, they adapt to standards to satisfy the clients in quality, cost, and delivery (QCD) objectives. When workers participate in housekeeping activities, such as inefficiencies elimination, standard revision and similar activities, they are more likely to embrace change and modify their behavior and actions for the greater good. Their participation in a standard revision procedure that is related to their work is positive because they are more likely to respect that, since they joined the project and their opinion was taken into consideration (Freeman & Kleiner, 2000).

3.1.1. Kaizen training

Training was done in the Chivasso plant to ensure the knowledge of Lean principles. For example, a course about the 5S was proposed to all the employees of the plant. During the two hours course, operators and all the other workers of the company were introduced to the 5S principles in an experimental way, to really understand the concepts and put themselves on the game. In particular, they were divided into two small groups and had to construct a specific building using LEGO, either a lighthouse or a windmill. At first, they had many LEGO pieces, even some that were not useful for the construction, so they had to sort the right ones. During the second step of the game, the employees could only use the right pieces to construct the buildings. Another step of the course included the writing of the work instructions, without knowing the LEGO ones, to understand the importance of clear directions. The groups then switched the building to construct and tried to erect it using the instructions written by their co-workers, checking whether they were correct or if they included some mistakes. The groups were timed at each step of the construction and in the end, they understood they took less time when they had clear instructions and no other superfluous materials on their desks or workstations. At the end of the course they were asked to point out the benefits of the experimental game and they started identifying the Lean Principles and the 5S mentioned in the first chapter, without knowing of it. For example, they understood the importance of having a clear standard and of using just the needed pieces, eliminating the superfluous objects. This course made the employees understand how to apply 5S in their everyday life, for example in the way they keep their equipment in the workplace. A card was given to them with the aim of reminding the description of each of the 5S. Benefits to be derived from implementing a Lean 5S program include improved safety, higher equipment availability, lower defect rates, reduced costs, increased production agility and flexibility, improved employee morale and better asset utilization (Masaaki, 2015). The proposal of who organize the course, the Lean Manager and the Quality Manager, was to start thinking about the possible improvements in their specific departments and start applying the 5S to their desk, so a personal approach to the Lean Production techniques. The future steps, after the course, were the implementation of the techniques to the plant, where operators are asked to work together and help each other to reach a common goal. One incentive to apply the 5S and maintain the standards is a kind of competition between the different departments that is going to take place once all the operators will be trained on the Lean principles. The different departments will challenge each other to reach the last "S", *Shitsuke*, ahead of others.

3.1.2. Kaizen projects

Tenneco plant started focusing on continuous improvement in many fields of its production process. Continuous improvement as a discipline aims to share, within an organization, ways to streamline processes and improve internal efficiency through the adoption of structured, repeatable practices [23]. The Lean Manager, who is also focusing on Logistics Department based on the company's organizational chart, takes care of the optimization projects inside the plant. Those projects are developed at the same time of the normal activities and include many people from different departments gathering and discussing about problems and possible solutions. Those people, coming from engineering, tooling, maintenance, quality, production planning, form a cross-functional team and are guided by the Lean Manager to create a Plan-Do-Check-Act (PDCA) plan to support the analysis of the chosen process. They start the analysis from a specific department or machine, and they are trying to check and improve the entire production plant. A PDCA is a model used in product or project development, when it is necessary to improve, upgrade or develop a process, a project or a new service. The first phase (Plan) is planning and consists of establishing a goal and devising operational plans to achieve it. The second phase (Do) is the implementation of the plan. The third phase (Check) is to determine whether the implementation is proceeding according to the proposed objectives and whether it is producing the expected improvement. The last phase (Act) is to execute and standardize the new procedures to avoid a recurrence of the initial problem and continue the improvement (Masaaki, 2015). Figure 20 shows the outline used to create the PDCA plan. First of all, it is important to define the problem. The team assigned to the project usually starts observing the process. As regards a specific machine, the experts study the process by looking at what the operator assigned does, starting from the setup of the machine to the final steps, for example the cleaning operations or the quality check of the components produced by the machine. By studying the actions taken and speaking to the workers, they identify some problems and list them in the left column of the table. After this first step, the team focuses on the causes of the problems, to understand where they originate. The action column is continuously updated, based on the different actions that can be taken to intervene on the problem along the entire PDCA. Every PDCA on a specific machine has got a pilot, who is a person responsible for the creation and update of the PDCA that should guide his or her teammates along the improvement plant. The pilot needs to assign to the other team members the different problems or actions, depending on the field. For example, if the encountered problem is a logistic one, the problem will be assigned to the head of logistics, else if it is related to the production process per se it will be assigned to one member of the engineering team, usually the Supervisor in charge of that specific department analyzed. It is important to establish some dates to the various actions, to keep track of the improvements and better schedule the project. The estimated end date is not always the final one and it can be updated, because of the occurrence of many problems that can arise around the project. The pilot marks the

P,D,C,A columns in green to keep track of the development of the project. The used model has usually got another column called notes, in which the pilot can extend the description of the problem or the action.

PDCA

#	PROBLEM	CAUSE	ACTION	PILOT	START DATE	END DATE	P	D	C	A
1										
2										

Figure 20: PDCA scheme

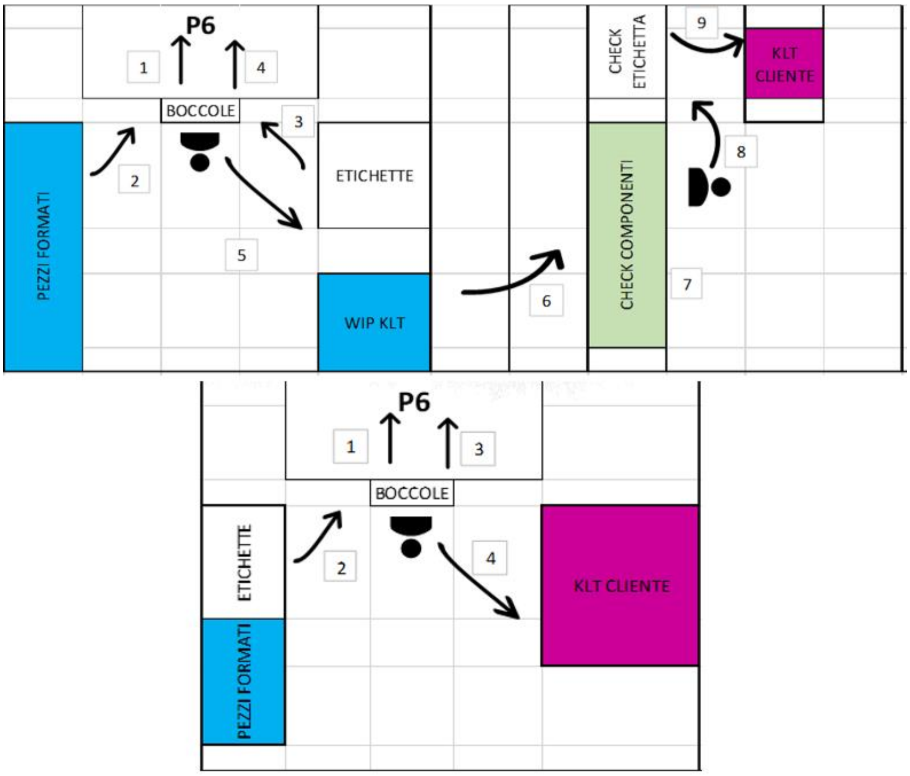

Figure 21: Kaizen project on P6 machine

The company has already closed some projects, while other ones are still under the direct observation of a team. For example, the on-going ones regard the application of the 5S principles to every department. Among the closed ones, it is possible to name the project regarding the Heat Shield department assembly machine, called P6, focused on the optimization of the materials flow. In figure 21 it is possible to see how the team applied Lean principles; the upper part represents the old process while the lower one is the new flow. The activities done to reach the goal were to implement some sensors to streamline the operator actions, which reduced the space needed for the defect's inspections, and to change the layout of the work station, following the ergonomics of the operator. At the end of each *kaizen* project a new standard is created. The implementation of the new standard starts with the application of the 5S and the workers involvement is fundamental to achieve greater results. During the 5S course employees started learning some principles they can apply during the *kaizen* projects. Their involvement enhances the possibility of innovative thinking and ideas to tackle problems. The PDCA team, or part of it, helps the operators usually working on the machine starting from the first S, which is *Seiri*, meaning eliminate whatever is not needed by separating needed tools, parts, and instructions from unneeded materials. In this phase three different colors are used: the green, the yellow and the red. Operators divide everything which is placed in the workstation based on the colors, using some bins to divide the material, marked with colored stickers. In the green bin they move everything which is necessary to the process, in the yellow one they put objects which are useful in the plant or the department but not used in that specific workstation. In the area marked in red, they add objects or materials that are not useful at all and should be thrown away, for example broken ones. Standards occurred in the closed projects were related to the layout of the departments or of the workstation, meaning how each necessary component or tool is positioned near the operator to accomplish the tasks. Other improvements were related to the work instructions. The steps were standardized to help the workers, using a Poka-Yoke method, which means a system developed in order to avoid human errors and understandable by everyone. This can be useful when operators assigned to a specific machine are missing because they can be temporarily substituted by their colleagues, without wasting time. Once the new standard is defined, the checking period allows to prove if the proposed solution work or if they can be enhanced. Despite the benefits brought by employee involvement, some of them are reluctant to change. Many operators have been working in the company for many years now and they are used to certain work practices or communication escalation methods and it is difficult to completely change their habits because it takes time. It is very useful for them to clearly see the results of the ongoing projects and of the closed ones, that is why communication among the entire plant is very important. Furthermore, even if the standard is respected, processes are continuously evolving and need to be checked. There are many variables affecting the correct results that a standard should bring and it is fundamental to continuously observe the production process.

3.2. Project introduction

The discussion presented in Section 3.1. is the starting point for the analysis done during the thesis project. As previously mentioned, Total Productive Maintenance (TPM) is one of the main approaches within the Toyota Production System and therefore the Lean Production model, aiming above all at reducing all possible production losses: due to stops (breakdowns, production changes, retooling, etc.), speed (slowdowns, micro-stops, etc.), and quality losses (rejects, etc.). At the beginning of the thesis project, a study of the present situation was done, to analyze the company and understand the changes needed. During 2021 Tenneco became more technological and started a paper-to-digital transition. The aim of the project regarding the losses analysis was to create a standardized methodology to keep track of the problems and their solutions, creating a database useful to every worker of the company, both at the operator, Team Leader and Supervisor level. A digital system is useful also to the management level, to keep track of the efficiency of the company. Losses were managed thanks to a hands on process. The operators had to fill some tables in which they computed the efficiency of the machine using some indicators, as will be presented in chapter 4. Despite the possible human errors they could incur in, it was hard to check the losses while working. It was a system based on operators' feelings, because they sometimes identified criticalities based on their experience in the work. The same applied to the management, for which people taking care of the efficiency did not have clear data on which to work on and indicators were not computed in a precise way. The need for a standardized and more rigorous way to consider losses, which could benefit the entire plant, was identified by the Head of Production and the Lean Manager, who were in charge of the project. The Heat Shield department will be the pilot area of the chapter 4 regarding the problems' escalation and it was chosen for this reason as an example in this section. Another reason is that it is representative of the company case study, because it is one of the most important departments working all the time.

3.3. A tool for the analysis: Production data

As mentioned in the research article by Jwo and others (Jwo & Lin, 2021) in the era of Industry 4.0 manufacturing sites are becoming more sophisticated and connected with the aid of digitalization. What makes a smart manufacturing enterprise as opposed to a traditional one is the ability to solve existing problems and predict issues to fix them before they occur while creating advantaged value. Benefits associated with digitalized and highly connected production systems and supply chains enabled by Industry 4.0 technologies include revenue gains, increased efficiency and productivity, machine downtime reductions, faster cycle times, improved supply/demand matching, improved product visibility and traceability in supply chains, among many others. Softwares used in companies range from database Graphical User Interface (GUIs) to employee wikis and are highly-tailored to an organization processes. The Chivasso plant's internal tool used in the losses analysis of the present chapter is a production tracking system customized for their specific needs. Tracking technologies used in the Industry 4.0 are strictly connected to Lean philosophy because they can provide real-time, accurate data to help improve workflows and save time. With real-time data, workers can minimize the gap between when errors occur and when issues are addressed, so that time and resources can be allocated for better use, improving the efficiency of the company [24]. This software keeps track of the production data and highlights the different types of losses. It was created in collaboration with a developer at the beginning of 2021. After a trial period, done on some machines, the product was completely adopted by the plant and gradually every department and machine are being connected to it. There are many sections in the menu, some of them are accessible by operators and some just by team leaders, Supervisors or the management team. The advantage with respect to paper is that it is used by the Planning department to upload the orders, so line operators and their bosses do not have to print or ask for them and by the Production department to keep track of the entire plant, users and shifts, including the losses occurred and creating a database, keep track of the work done and it is a starting point for the improvement activities. When the operator starts the work, he or she needs to open a new worksheet in the system, specifying some data such as the name and part number loaded on the machine. The tablets that are being added to the machines show the workers the main indicators and the performance of their work during the shift. In this way it is easier to continuously monitor the production. The tablets are touch screen and the interface is very intuitive so every worker and operator can use it easily. Thanks to the internal tool it is also possible to download Excel format files including production data, their losses and other important information which are used for the analysis.

3.4. Losses categorization

There are many types of criticalities in a system and for the project purposes losses have been divided into different categories. (Nakajima, 1988) identified six big losses in companies, which are shown in figure 22. Starting from this subdivision, the losses categorization for the project was done and enriched. Total available time includes the hours a company can use for its activities, for example if it is open 5 days a week, 24 hours a day, as in Tenneco case, the total available time is 120 hours per week. This time is also called total operations time. The first type of production loss analyzed starting from the total time is planned downtime losses, which includes time when an operation is down due to plant policy, for example for the scheduled breaks, lunches, team meetings, clean-up time and the demand shortage. Breaks are granted to workers by the company and their contracts, while the other type of loss is due to the lack of demand, strictly connect to the activity of production planning and to the customer's demand.

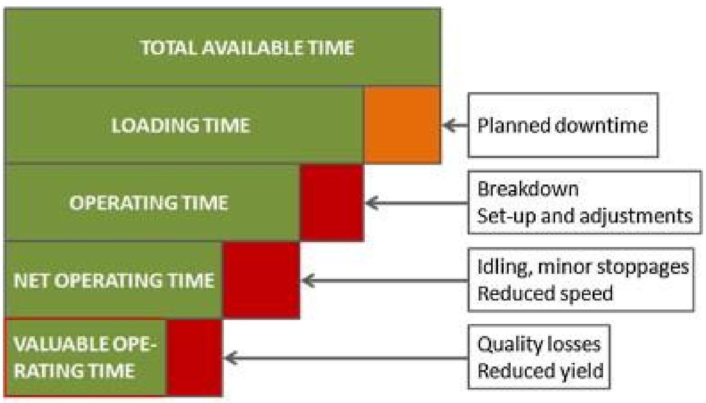

Figure 22: Nakajima losses division (Andersson & Bellgran, 2015)

If there is not enough demand to run a particular process for the total operations time then, by plant policy a decision is made not to run that process during certain hours, and those hours are subtracted from total operations time in order to arrive at the run time number, called loading time by Nakajima. These losses cannot be controlled or optimized much but were included in the analysis for accuracy purposes. Plant management has the discretion to reduce planned downtime in constraint operations by running through breaks, lunches, etc. with substitute operators. Starting from run time, production losses can be taken into consideration, getting to the so-called operating time. According to *kaizen* principles, production losses are commonly divided into 16 categories as regards *gemba*. They are usually grouped into three main categories: equipment, manpower and production subsidiaries resources (Perumal, Yoong, & Tay, 2019). Among the equipment related losses, setup ones are considered. Examples of common reasons for setup and adjustments include setup, changeovers, major adjustments, and tooling adjustments. Setup time is defined as the amount of time taken to change a process over from the last part of a production run to the first good, repeatable part of the next production run. The company Tenneco, differently from other companies, breaks out setup time as a separate category from all other downtime causes. The reason is because those times can vary widely depending on the nature of the operation and it is not useful to judge all setup times to a common standard. This has the advantage of making setup time very clear and identifiable where it is a large contributor to overall downtime, creating an improvement opportunity. Adjustment within the setup time is often hidden and involves tweaking settings until optimal run conditions are achieved. In practical terms, companies try to work to reduce the time needed for a setup than to keep the process running in order to artificially increase the efficiency of the plant, one of the goals of the losses analysis. One way to reduce this type of loss is to create time reduction programs called Single Minute Exchange Die (SMED). Net operative time is computed by subtracting from operative time other minor performance losses. Among the losses causing reduced speed of the production, cycle time loss, which is typically split into slow cycles and small stops, was identified. Slow cycles occur when equipment runs slower than its maximum operating speed. For example, an operator may deliberately run equipment slow to manage material quality issues. Small stops occur when equipment has stopped for a short enough period that the stop is still considered to be part of a cycle (in other words it is not considered to be a downtime event). To reduce minor stoppage, it is important to adequately analyze the phenomena involved and thoroughly eliminate minor defects.

The target number of minor defects is zero. In the company, operators typically address small stops without the involvement of maintenance personnel. For example, an operator may clear repeated equipment jams caused by material feed issues. Furthermore, other losses considered are downtime and maintenance losses. These are originated for mold maintenance and machine maintenance for which it is necessary to call the tooling department of the company or material change that lasts more than five minutes. In general terms, losses to consider can be divided into breakdowns or micro stoppages. The first ones are identified as stops in the system for more than 5 minutes and they are very few. Those losses are recorded on the production tracking sheet and clearly visible by the management. It is possible to fix them and usually they need an expert such as a setter or a maintenance technician. Normally there is high motivation to reduce or eliminate them and they are a priority for improvement. Micro stoppages, on the other hand, last less than 5 minutes and they are not recorded at all in the system, even if there are many. They are almost invisible, except by the operator, by whom they can easily be fixed. In this case there is low motivation to reduce them and they are not a priority for improvement. Dealing with them as they occur may be easier that shutting down the process, diagnosing the problem and permanently fixing it. However, if micro-stoppage problems persist, the team needs to take the time to find a solution to regain needed production time and to keep the team members safe. Sometimes micro stoppages can be tracked down in hard copy thanks to the operators' help, because they are an important source of loss and should be monitored, even if it is only practical to record the number of incidences, rather than the total time of each one. The last type of loss analyzed was due to scraps or re-working and final inspection for quality are also included. Rejects can be made during steady-state production or during warm-up, startup or other early production phases. Sporadic defects are easily fixed, so they are rarely left uncorrected. Chronic defects in contrast, are often left as they are, because their causes are difficult to perceive and measures to correct them are seldom effective to realize zero defects, it is necessary to radically review defective phenomena. It is important to note that setup scrap is not counted as a quality loss. The time used to create setup scrap is already considered as part of lost setup time. However, setup scrap must be also counted as part of the overall scrap cost. By subtracting to net operating time these kind of losses it is possible to obtain valuable operating time, the time actually used to produce one part, net of all kind of criticalities occurred by the system.

3.5. Important indicators used for the analysis

The ideal, fully effective, machine should run all the time, or as long as necessary, at maximum or standard speed, without generating any kind of product quality problem, but most machines do not achieve these ideal conditions. Machines cannot work continuously or at full speed, as they suffer various stoppages and often produce defective parts. By collecting the following indicators on a fixed basis, it is possible to identify processes and interferences that cause problems in production equipment. In addition, the data collected allows to assess whether the actions taken to improve the machine performance have been successful. For the measurement and application process to be effective, operations personnel should be involved, and they should receive feedback on the efficiency results. Monitoring the plant performance is important as regards the improvements done to improve it. Analyzing these indicators, through production data and specific graphs is fundamental to understand which problems provide the biggest opportunities of enhancement (Diaz-Reza, Garcia-Alcatraz, & Martinez-Loya, 2019). A Waterfall Chart is a type of visual analysis that allows your business to understand the cumulative effects of sequential positive and negative values. Waterfall Charts are particularly useful when analyzing a gradual transition in the quantitative value of a variable that is subjected to increase or decrease incrementally [25]. An example is shown in figure 23. In the project the losses are represented as negative values, while the remaining time as a positive one. Other types of visualization tools used in the reports are Pareto charts, as in figure 24, and bar diagrams, as shown in figure 25, in which it is possible to rank related measures of losses in order of occurrence. Pareto analysis is a technique used for business decision-making. It is based largely on the "80-20 rule." The idea is that 80% of a project's benefit can be achieved by doing 20% of the work or, conversely, 80% of problems can be traced to 20% of the causes. As a decision-making technique, Pareto analysis statistically separates a limited number of input factors which have the greatest impact on an outcome. The advantage of Pareto analysis is that it helps to identify and determine the root causes of defects or problems, determining the cumulative impact. Because of this, businesses are able to eliminate or resolve defects or errors with the highest priority first [26]. A Bar Graph is a chart that plots data using rectangular bars or columns that represent the total amount of observations in the data for that category. Bar Charts can be displayed with vertical columns, horizontal bars, comparative bars (multiple bars to show a comparison between values), or stacked bars (bars containing multiple types of information) [27]. In this way it is easy to understand which are the biggest criticalities, the ones on which to focus on. To categorize losses in a visual way, the Excel block chart, also called treemap, was used instead. An example is found in figure 26.

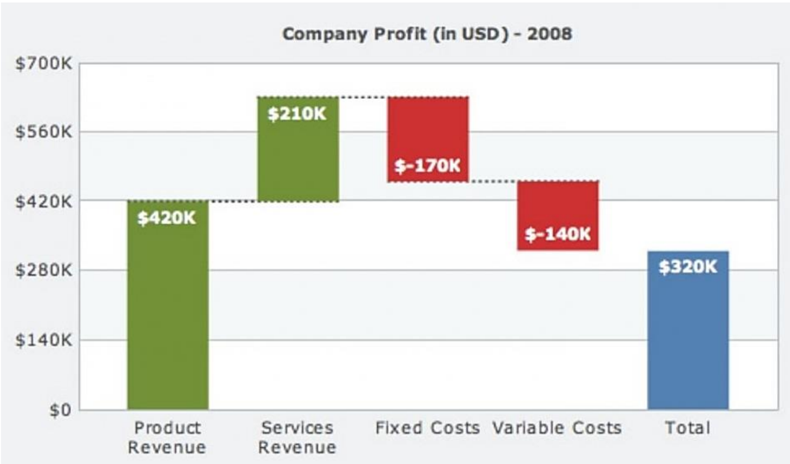

Figure 23: Waterfall diagram example [28]

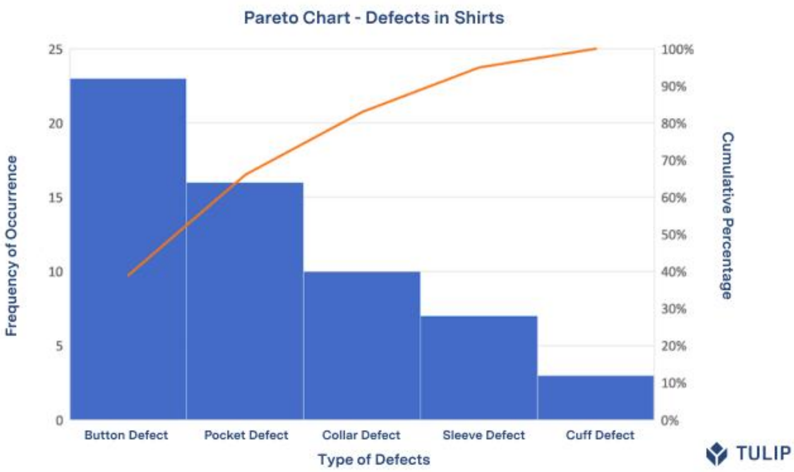

Figure 24: Pareto chart example (Lamarre, 2019)

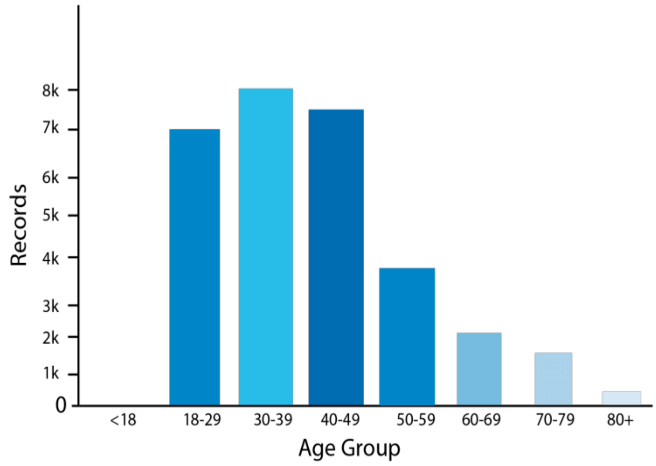

Figure 25: Bar chart example (Bieser, Haas, & Hilty, 2019)

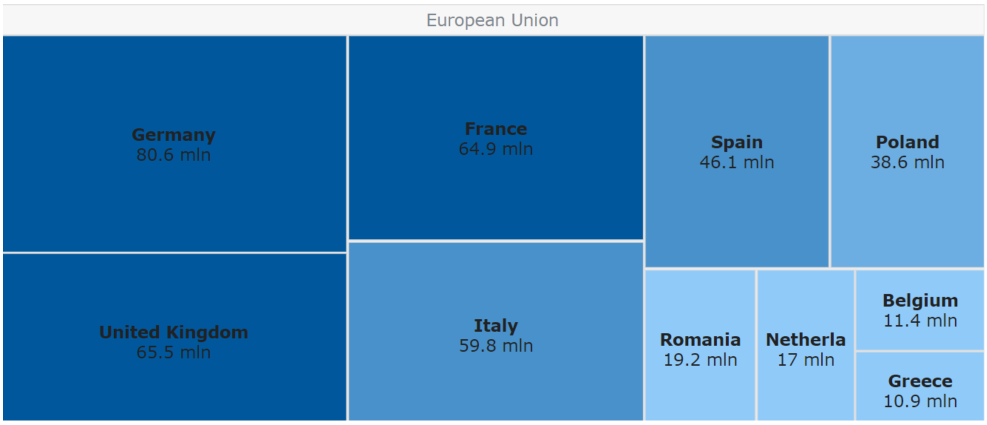

Figure 26: Treemap chart example [29], 2021

3.5.1. Overall Equipment Effectiveness

One of the most important key performance indicators to evaluate the efficiency of production systems is the Overall Equipment Effectiveness (OEE), which is commonly used to evaluate a single machine. The Overall Equipment Effectiveness (OEE) is the traditional evaluation measure of the Total Productive Maintenance (TPM) that must be maximized, and it compares the operating level with the ideal potential of the plant performance, measuring equipment-related losses. The fundamental idea is based on the conception that this ideal operational potential is reduced by various losses. In literature as well as in practice, various terminologies have come up which are either related to single plants or have been extended to a holistic view of a complete factory (Lanza, Stoll, Stricker, Peters, & Lorenz, 2013). As mentioned in section 3.4., (Nakajima, 1988) as well as (Andersson & Bellgran, 2015) introduced OEE in TPM, identifying six big losses in companies, which can be grouped into three categories: availability, performance and quality. The definitions of these three KPIs were taken from (Borris, 2006) The indicator can be computed as the product of these three ratios.

$$OEE = availability * performance * quality$$

Availability measures the impact of downtime losses and it is the amount of time the equipment is capable of running a good product to the total time it could be running. The numerator of the ratio is represented by the so-called run time, while the denominator is the total available time.

$$Availability\ (\%) = \frac{(total\ available\ time - downtime)}{total\ available\ time} * 100$$

In Tenneco, during the thesis project onwards, it was chosen to compute it as the ratio between run time and the difference of total operations time minus the time lost due to demand shortages. The time in which the company does not have demand was excluded from the analysis because it is not related to improvements that can be made to the production system. Performance measures speed related losses and it is computed as the number of units manufactured divided by the possible number of units, which means the amount of product made to the amount of product that could have been made.

$$Performance\ (\%) = \frac{number\ of\ units\ manufactured}{possible\ number\ of\ units} * 100$$

During the thesis project, it was computed in terms of time as net operating time divided by the run time. Net operating time excludes the speed related losses such as cycle time and also the criticalities due to setup, which is necessary to the machines but could be reduced. Net operating time represents the fastest possible time to manufacture the parts. Finally, the quality indicator is a percentage that assesses the amount of scraps found during the final inspections, and it is computed as valuable operating time divided by net operating time.

$$Quality\ (\%) = \frac{(number\ of\ units\ produced - number\ of\ defects)}{number\ of\ units\ produced} * 100$$

In Tenneco this indicator is computed as the percentage of good parts over the total number of parts manufactured, considering the scrap rate computed by the production system of every machine.

3.5.2. Overall Asset Effectiveness

Traditionally, Tenneco and many other industrial companies have used several measurements of asset and process effectiveness, such as OEE. In the last few years, the company is focusing more and more on the Overall Asset Effectiveness (OAE) as its asset productivity measure. For OAE calculations, the baseline is all the hours that the plant is open for business and that the process being measured is available to run. Using the same time division used by Nakajima, OAE can be computed in terms of time as the ratio between valuable operating time and total available time. It can also be described in terms of units, as the ratio between the actually produced parts and the theoretical amount of parts the system could produce. In practical terms, OAE measures the amount of time the production plant is making good parts as a percentage of the total operating time, which is the time the plant was open and the operation was available to run (Pintelon & Muchiri, 2008).

$$OAE = \frac{valuable\ operating\ time}{total\ available\ time} * 100$$

Another way to think of the OAE baseline, is that the measurement is owned at the plant management level. With OEE ownership is at the production team level. Even though the company highlights setup time and performance Losses in a non-traditional way, it is important to note that the final OAE calculation is exactly the same as it is when using the traditional representation.

3.5.3. Other indicators used in literature

Another indicator which can be considered is Total Effective Equipment Productivity (TEEP), which considers maximum time to be all available time, which means it is 24 hours, 365 days a year (Pintelon & Muchiri, 2008). It is computed as the product between the OEE indicator and the utilization. The difference with OEE or OAE lies in the baseline of total hour available for production. With TEEP, ownership lies at the corporate level. The utilization is the ratio between the planned production time and all the time available. TEEP indicates how much capacity is waiting to be unlocked, it shows how much potential there is to increase throughput with the current equipment. In many cases, reclaiming time from the “hidden factory” is a faster and less expensive alternative to purchasing new equipment. TEEP can also be used to get a sense of the potential sales capacity as it considers the full capacity of your manufacturing plant. It is possible to notice tough that even a world-class manufacturing plant operating around the clock typically achieves only 80% to 90% Utilization of total capacity. Another metric that can be considered is Output per Employee (OPE), a measure of labor productivity (Pintelon & Muchiri, 2008). OPE measures the number of good units produced divided by the total number of direct labor hours required to produce them for a given period. The elements needed to compute it are the number of hours in the shift, the average direct headcount and the average production for the shift. At first glance, it may appear that the OAE and OPE calculations are at odds with one another. For example, I can probably improve my machine up time by adding labor to the process, but it is not always the best choice. In processes that are highly equipment-intensive, and use little direct labor, it is better to use OAE. A fully connected piston machining line, similar to the Tenneco one analyzed in the thesis project, is a good example. Another case in which to use OAE is when the process is at or near capacity, when companies are thinking about investing in new equipment to meet customer demand. On the other hand very labor-intensive process which uses little machinery (such as a final inspection line or a manual assembly cell), use OPE. In such cases, optimizing labor is more important. Also, if the process has excess capacity (if you have more time in your work day than is needed to meet customer demand) use the Labor Productivity metric (or OPE).

3.6. Flashcards and legends for operators

Some flashcards were created for employees’ training to help them understand the different type of losses the system can have while they are working. Flashcards and legends are useful to operators to create a Poka-Yoke system in which every worker can understand the criticalities occurred during his or her shift. It is important to train workers to identify the losses they see on the screens, so they know how to explain the possible problems occurred to their team leaders and consequently team leaders should remember the different types to decide possible actions to take and understand who to contact depending on the related department. This can also be useful to read the production files downloads on the system, containing all the production data related to their assigned department, or communicate with their Supervisors, in case major problems occurred. It is important to continue training the employees on the internal tracking system, so that the switch from hard copy communication to the digitalized track of the production data is accomplished in an easier way. The first card, shown in figure 27, represents the losses categorization used for the OAE calculation and it was created to support not only operators but also team leaders and Supervisors. It is composed of a Loss Structure Diagram, which is a graphic tool used to help sort the elements of OAE. It is added in the weekly and monthly reports for the losses, OAE and indicators calculation to guide people to read the graphs and the related calculations. The second card of figure 28 is instead a legend created to identify the different types of losses and explain their significance in the system. It explains each button visible on the internal production system, to standardize the knowledge of the losses categorization and the consequently measures done to optimize the process. The operators have to select some of these buttons inside the system while working, to indicate their actions. DOMA indicates a stop for the lack of demand by the Planning department, due to shortage in the clients' orders. PAUS means the machine stops for operator's breaks such as coffee or lunch. As regards the setup, the symbol is SETP. Cycle time losses are directly identified by the tracking system. Among downtime and maintenance losses MSTA indicates a mold maintenance, which is needing the Tooling department intervention. MMAC is selected for machine maintenance for which the team leaders call the Maintenance department. CMAT specifies a material change that lasts more than five minutes, while MATE a machine stop due to raw materials shortage. Other types such as "non assigned" labeled, or NASS, loss or missing operator, NOPE, for which there are no workers assigned to the machine are also included in the analysis. Finally, in the production system a label "other" is present, called ALTR, to identify other types of losses that are not clearly addressable to the other causes.

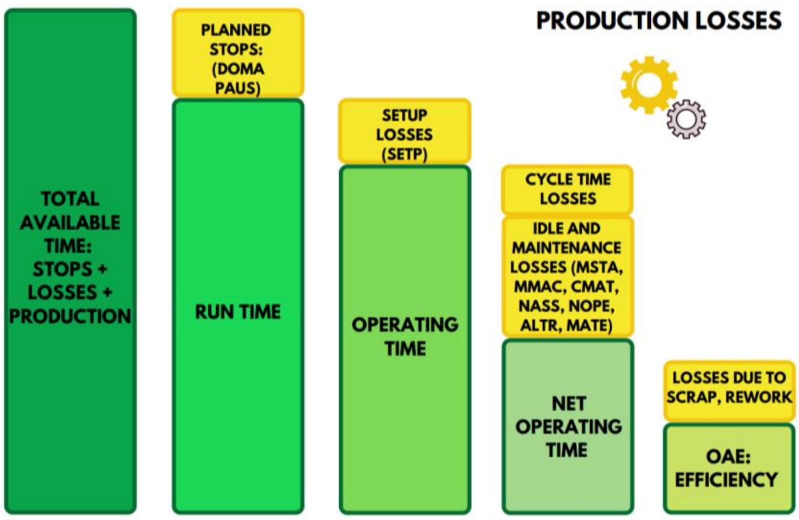

Figure 27: Losses categorization flashcard

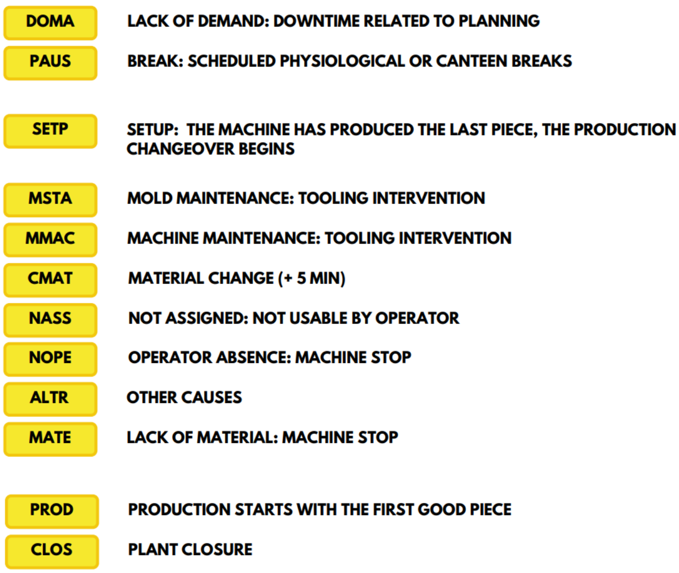

Figure 28: Losses types flashcard

3.7. Losses reports

The Value Stream Manager must ensure the efficiency of the plant, which is strictly connected to the losses analysis mentioned. The value stream is the entire creation process for a product, it starts at concept and ends at delivery to the customer. Every stage the product goes through should add value to the product, but often this is not the case. In order to improve the value adding activities, it is important to reduce waiting time, errors and losses [30]. Reports are tools used in companies to receive feedback on the current state of the production systems or on the progress made during a period of time. The report formats created for the losses analysis in Tenneco were standardized both for weekly and monthly reviews, and the results shown are graphs regarding the losses for every machine and every department, to easily understand on which ones to focus on to identify and possibly solve the problems occurring. As regards the weekly report, production data are extracted at the end of the week from the production tracking system and the graphs presented in the sections from 3.7.2. to 3.7.4.are updated. Knowing these data, Supervisors can check whether the problems occurred are already solved, if the tablets are used in the correct way and they can identify where to direct their effort for improvements. The models of the reports were set on Excel and they are the same for every department of the plant, except from the Maintenance one, which had different analysis needs and will be presented in section 3.7.4.. To clarify the explanation, an example regarding Heat Shield department will be presented. The choice of a specific week or month in the following sections are random and just for explanatory purposes of the reports' items.

3.7.1. Preliminary reports study

The project started in May, 2021 and the first versions of the reports were created based on some KPIs chosen by the Value Stream Manager, who was used to present them at the end of the month. The indicators used were mainly OAE and OEE. The project started focusing on the weekly reports, with the idea of using the same layout for the monthly one. The idea was a PowerPoint presentation including two types of graphs. The following discussion will present the report model using week 20 data as a reference. The first one included a brief overview on the considered department, showing a stacked bar chart in which it is possible to see the relationship of individual items to the whole. This graph is shown in figure 29 and it includes for every machine that has worked during week 20 in the Heat Shield department the specific losses. The types of losses included were just downtime and performance ones, because they are the ones in which the improvement has to focus on. They were divided in categories: MSTA, for mold maintenance, CMAT, for material change, another category for the more undefined ones, including NASS, NOPE, ALTR and MATE, and finally cycle time losses.

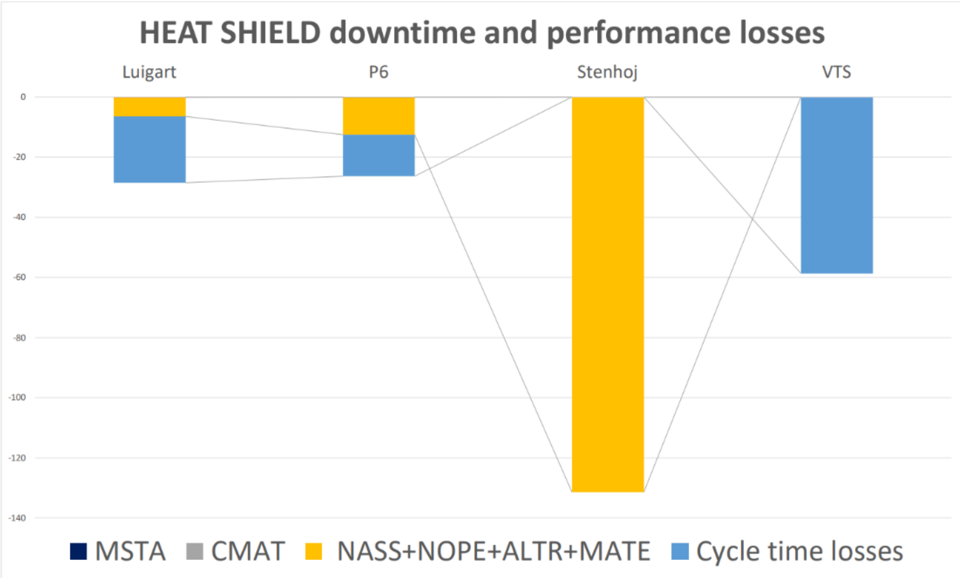

Figure 29: Heat Shield overview, week 20

The second graph of the presentation is shown in figure 30 and it is a waterfall diagram, constructed for every machine, in which losses types are shown. The example shows the graph of Luigart, a forming machine. The chart represents all the reasons for process downtime and other elements with contribute to lost production. The blue bars represent available chunks of time and are the same as the bars on the losses categorization flashcard presented in figure 27.

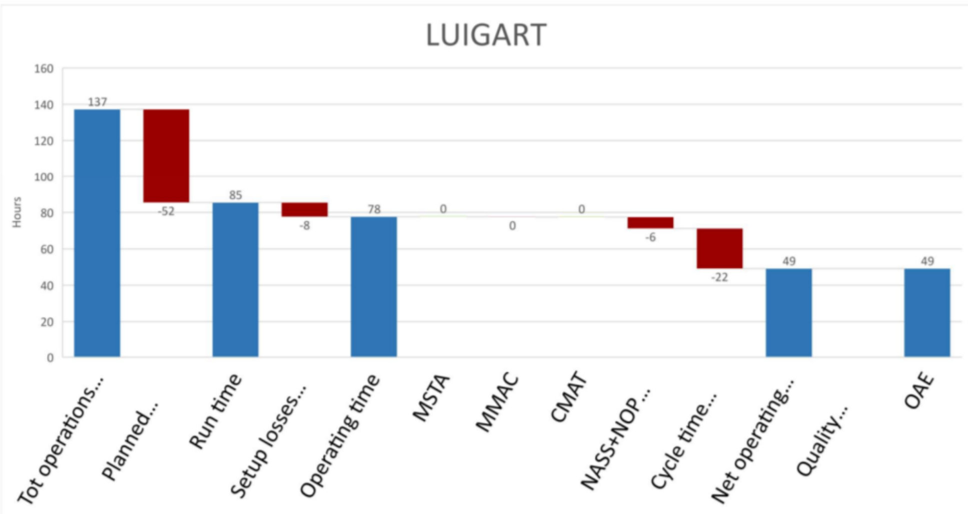

Figure 30: Luigart OAE example, week 20

The red bars represent time lost and include the loss name. Another possibility is a positive loss, occurring when the time spent was less than the standard one and this is represented with a green color. The colors used are intuitive and are based on Tenneco standard ones used in corporate presentations. After a trial period during the month of May, the final types of graphs were chosen and standardized up to September. Starting from the first idea, new types of reports were created. Some drivers taken into consideration of the optimization were the easiness in reading and understanding the reports, including the important information and the right graphs.

3.7.2. Weekly reports

The weekly reports focus on the OAE indicator and they are created for every production department. At the beginning of the report, there is an overview of the specific department, composed of some summary tables. Figure 31 is a pivot table showing, for each machine, the planned stops, which include the lack of demand and the breaks, and the losses, with respect to the total time. In this case the label "losses" indicates the difference between operating time and net operating time, minus cycle time losses. This means the categories found on the system, such as NASS, MMAC, MSTA, NOPE, ALTR, MATE and CMAT, already presented in section 3.6..The data are expressed in terms of hours per week. For example, in this department, the AIDA, a very important press machine used for shearing purposes, lost 11 hours on week 27 due to material change that lasted more than 5 minutes. Furthermore, a table regarding the part numbers produced that had the greatest delta are added for every department and machine. The delta represents the difference between the actual hours spent to produce the part and the standard hours that the machine should have taken. In this way positive values must be checked because they represent a loss. Figure 32 shows the five part numbers with the higher delta in the department, which means the ones for which some problems incurred during production. The number five was chosen to standardize the output for every machine and sometimes it is possible to find some negative deltas, when machines are not losing time. For example, the first component in the example, the one with the highest delta, is 51_FL1, a sheared layer heat shield, and took in total 3.54 hours more than expected. Negative values of delta could be a good sign, meaning the production took lower than expected but if the values are too negative probably there were some mistakes and they need to be double-checked as well.

Machine losses-HEATSHIELD

Department	H

Machine name	Planned stops (h)	Losses (h)	Max loss (h)	Max loss cause
AIDA	58	11	7	CMAT
Luigart	96	0	0	
MA9	0	0	0	
P6	102	0	0	
Rocher	96	9	4	MMAC
Stenhoj	76	0	0	ALTR
VTS	0	0	0	
Totale complessivo	427	20	11	

Figure 31: Heat Shield losses overview, week 32

Deltas (h) per PN, HS department

Department	Heat Shield

Part number code	Delta actual H-standard H
51_FL1	3,54
L 1446	3,51
05_FL2	3,24
113_FL1	2,44
105_FL1	2,24
Total	14,97

Figure 32: Heat Shield delta overview, week 32

After the department overview, two types of graphs are presented for every machine that has worked in the specific week. It was decided to eliminate the first type of graph present in the first version of the report because it did not add any information regarding losses: the team leaders and the Supervisors can clearly see the types of losses in the graph shown in figure 33, which represents time and losses.

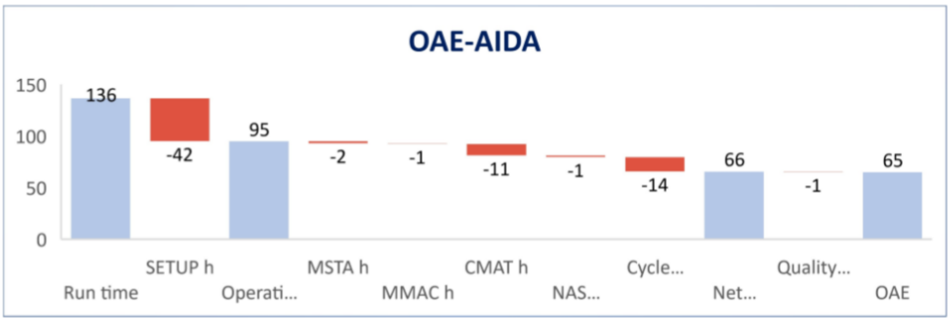

Figure 33: Aida OAE example, week 32

This chart is a graphical representation of the data presented in figure 31, the first one of the department overview. Another difference with the initial idea is that total production time and planned downtime losses, named DOMA and PAUS, were excluded from the analysis for simplification, since the company should focus on the other ones, more easily improvable. In this specific case, it is easy to notice that in week 32, for press AIDA the main cause of loss in production, despite cycle time, was CMAT, material change loss, as previously mentioned. Setup hours were the main loss in terms of hours, but this can be aligned with the tooling complexity of this machine. Furthermore, some graphs regarding the part numbers produced that had the greatest delta are added for every department and machine; this specifies the information in figure 30, with a broader perspective. Figure 34 is a Pareto graph showing the five part numbers with the higher delta, which means the ones for which some problems incurred during production. Differences between the actual and the standard hours to produce a specific product, here identified by its production code, are shown. Data are order in descending order, meaning that the first loss on the left is the greater one and the one that may need more attention. For example, for the PN 05_FL2 production, a sheared layer component which will be coupled with its FL1 version at the assembly, took in total 3.24 hours more than expected.

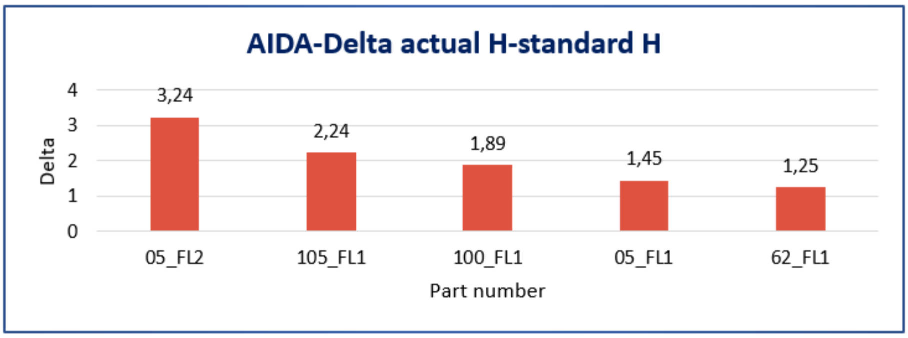

Figure 34: AIDA main standard deviations, week 32

3.7.3. *Monthly reports*

On a monthly base, Supervisors, and people responsible for the production in the plant, as the Value Stream Manager and the Production Planner, receive two types of report. The first one is the same as the weekly type, with data extraction of one-month time. The other report is a more general overview on the department and keeps track of every month, comparing data with the previous months. The first part of the report shows tables for each machine of the department containing different indicators. In figure 35, it is possible to see for explanatory purposes the indicators of machines Aida and Luigart for the month of August. In the report it is possible to check the average value of the indicator on the previous year and the year-to-date (YTD) which includes the average values from the start of the year to the current date. For the analysis, data were used from May 2021 onwards, because previous data were not included in the production tracking system.

HS DEPARTMENT - AUGUST 2021

AIDA		2020	1	2	3	4	5	6	7	8	9	10	11	12	YTD
scrap rate	act						2,5%	1,5%	3,8%	3,5%					2,8%
cycle time eff.	act						60,1%	61,1%	57,3%	65,0%					60,9%
% losses	act						21,5%	16,5%	20,6%	12,3%					17,7%
% set-up	act						30,9%	35,4%	33,6%	37,6%					34,3%
OEE	act						40,2%	38,7%	36,1%	38,4%					38,4%
	target		75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%

LUIGART		2020	1	2	3	4	5	6	7	8	9	10	11	12	YTD
scrap rate	act						3,8%	2,9%	2,9%	3,6%					3,3%
cycle time eff.	act						51,0%	57,5%	67,6%	69,8%					61,5%
% losses	act						21,6%	13,0%	5,8%	16,6%					14,2%
% set-up	act						6,4%	8,0%	11,3%	13,7%					9,8%
OEE	act						41,4%	46,3%	51,1%	51,9%					47,7%
	target		75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%	75%

Figure 35: Heat Shield indicators, August

The first indicator analyzed, the scrap rate, can be found in the internal production system, already computed based on the production data. Cycle time efficiency is computed as the ratio between net operating time and operating time. Another indicator, the percentage of losses, is the amount of time of the losses in the total time of production, including both losses and production time, excluding the times in which the plant was closed or during planned stops. The percentage of set-up is instead computed as its ratio over the run time and it is useful to know this amount in a company like Tenneco, with very specific machines that have long setup times. The last indicator considered is the OEE, computed as explained in section 3.5.1.. The indicator called scrap is actually the percentage of good parts, which is computed subtracting the scrap rate to the 100% probability. A target value was assigned to the OEE, during the analysis it was set to 75%, even if it is a very optimistic number. The other part of the monthly report is a block diagram, as shown in figure 36. The example refers to the month of August for the Heat Shield department. Two categories of data are shown, the first one is related to production and the other one to the losses. The production category includes the number of good parts produced during the month, the cycle losses and the scraps associated. The other category includes the main losses already taken into account, in order to understand which one affected the system more. For example, in this case the contribution of MATE, the lack of material that causes a machine stop, is almost null compared to the other ones. Categories ALTR and NOPE, the more undefined ones, are the highest ones in terms of hours lost.

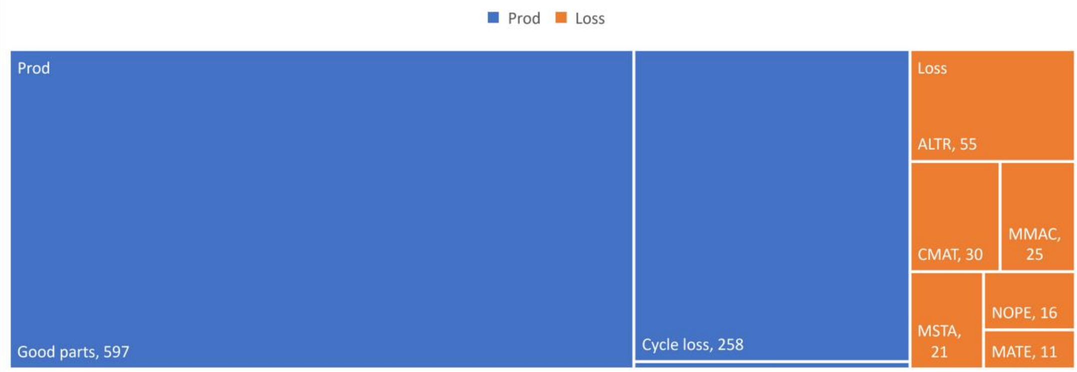

Figure 36: Heat Shield losses and produced parts, August

3.7.4. Maintenance reports

As regards the maintenance reports, only one version was developed, identical for the week and month base. The most important indicators for maintenance are the amount of hours spent in the specific activities and how much they affect the production, so there is no need to differentiate the types of reports depending on the time span. MSTA, mold maintenance, and MMCA, machine maintenance , are the main activities done by the technicians. The aim was to create a description of the maintenance intervention in each department during the selected period because there is just one department which takes care of the various actions for the whole production plant, divided into tools maintenance. The report is divided into three parts, for the departments EMG, Heat Shield and then Injection, Compression and Dynamic together. Figure 37 below describes an overview of the Heat Shield department during week 32, chosen as an example. For each machine there are MSTA, MMAC and losses. The losses column was also added to check the impact of these actions over the total hours lost, due to the categorization already presented. For example, AIDA total idle and maintenance losses were 38.6 hours, of which 9.8 was due to MSTA and 6.6 due to MMAC. Numbers are negative values because they are extracted from the production tracking system and they represent a loss.

Department	H		
Machine name	**Total MSTA (h)**	**Total MMAC (h)**	**Total Losses**
AIDA	-9,8	-6,6	-38,6
Luigart	-0,5	-0,2	-33,8
MA9	0,0	0,0	0,0
P6	-0,2	-12,9	-16,1
Rocher	-11,0	-5,1	-47,9
Stenhoj	0,0	0,0	-22,5
VTS	0,0	0,0	0,0
Total	-21,4	-24,8	-158,8

Figure 37: Heat Shield maintenance overview, week 32

Another part of the report is a graphical one shown in figure 38, in which two pie charts, one for MMAC and one for MSTA, show the effort of the Maintenance Department over the Heat Shield area, specifying the machines that needed more corrective actions during the report period. The last type of graph, in figure 37, added is a combined one composed of a stacked bar chart with machine and mold maintenance times, and a line chart representing the losses for each machine. In such a way the impact of these type of losses over the total hours lost is more clearly visible. Thanks to these graphs, the Maintenance and Tooling Manager can keep track of the interventions done by their technicians, to check if they spent too much time due to potential problems such as availability of tools or other problems that they could manage.

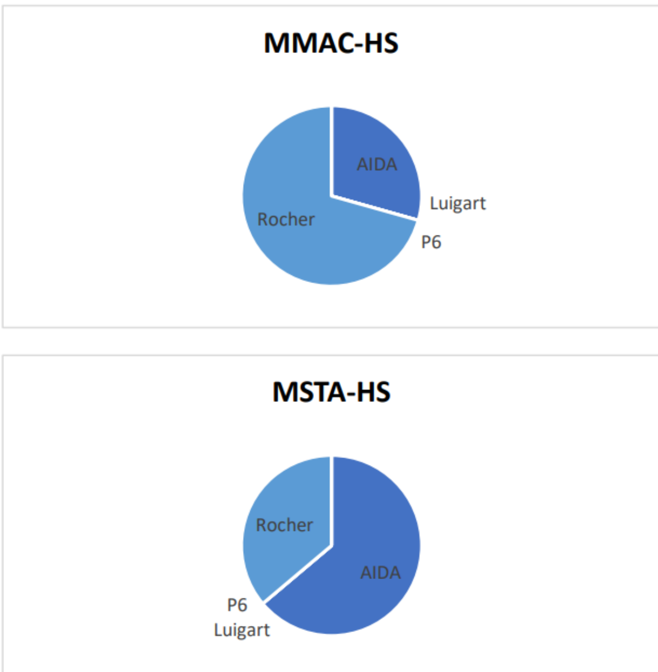

Figure 38: HS MMAC and MSTA losses, week 32

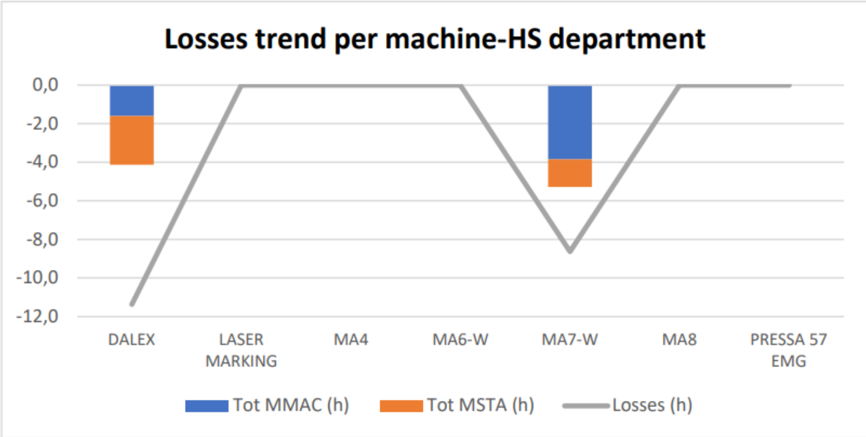

Figure 39: HS maintenance losses trend, week 32

3.7.5. Final optimization

Both the weekly and the monthly report were created in a standardized way and they are very intuitive to read and understand. A written procedure with clear steps was also created to simplify the process of updating the files. Both reports are periodically sent to the Production Planner, the Supervisor of Heat Shield, EMG and Gasket department and the Supervisor of Injection, Compression and Dynamic one, to Tooling and Maintenance managers, one process engineer and finally the Value Stream Manager, who supervised the creation and optimization of the reports. Supervisors were interviewed during the Excel files creation, because they are the people most interested in the losses analysis and the ones who need to propose solutions for their departments. It was asked to them to check the reports structure and the indicators. They confirmed the ratios chosen were the ones they would like to check periodically and they suggested some improvements to the reports layout. As regards the weekly report, it was decided to add as legends for the losses and the time the flashcards of figure 25 and 26. In this way it is easier to follow the calculations of the OAE and the symbols used to describe the types of losses. They proposed to add some legends in the monthly report to read the indicators used, because of the different interpretations of the companies and a key was created, as shown in figure 40. In this way, all the people checking the results of the month can understand the calculations and look for any errors. Another legend, that of figure 41, was added to the monthly report regarding the block diagrams. The key divides between production and losses the data used, recalling the names of the losses in the system.

scrap rate	exported from the production system
cycle time eff.	Net operating time/Operating time
% losses	Losses/(Losses+Production)
% setup	Setup/Run time
OEE	Availability*Efficiency*Scrap

Availability=Run time/(Total operations time-DOMA)
Efficiency=Net operating time/Run time
Scrap=1-scrap rate

Figure 40: Indicators legend

Prod	Good parts
	Cycle loss
	Scraps
Loss	MSTA
	MMAC
	NOPE
	ALTR
	MATE
	CMAT

Figure 41: Losses and production legend

4. Managing and escalating problems in everyday life

Efficiency means satisfying clients' requests with a good quality level, at the right time and the lowest possible cost (Tenneco, 2021). To improve efficiency, it is important to identify the cause of the problems and to reduce wastes, as mentioned in Chapter 3. Keeping track of wastes is not only very important both on a weekly and monthly basis, but also in the daily production activities. As mentioned in chapter 1, the *gemba* is the starting point for all improvements and the source of all relevant information. There are five rules in the management of *gemba*: go to the *gemba* as soon as a problem is identified, check *gembutsu* ("*gemba* things"), take the first temporary measures, find the cause of the issue, set standards that prevent the problem from recurring (Masaaki, 2015). The way the company manages and escalates daily problems started improving after the paper-to-digital transition, previously mentioned in chapter 3. This was also possible thanks to the tracking system which shows real-time results and the use of tablets. This chapter will explain the steps taken to develop and standardize Tenneco procedures, to improve the daily management of problems in the *gemba*.

4.1. Importance of monitoring problems

In process companies, the cost of processing is strongly linked to plant efficiency and manpower. To improve industrial performance, it is necessary to increase the ability of operators to monitor the lines, as well as to carry out focused projects and make investments in technology. There is a need to reach direct operators and create improvements that are sustainable over time. The figure at the center of the entire system is the team leader, who directly monitors the production lines and their functioning [31]. One priority should always be safety: the operators should not be in danger while working on the machines and their actions must not generate danger to others' safety. Team leaders monitor this aspect with specific checks on the machines and procedures at the beginning of every shift, audits, or operators reports. Another priority is represented by the client's needs. The production should be focused on advancing just good parts, avoiding defects. In this way, the client is protected, and the contract is safe. Team leaders control this priority thanks to audits, the 5S respect and continuous training of the workers. Another aspect considered is quality and the key figure checks the percentages of scraps, both hourly and at the end of the shift. The other priority is ensuring efficiency (Masaaki, 2015). To monitor production lines concerning these two last aspects, operators can check on their tablets, when they are incorporated into the machines, two important indicators: percentage of scraps and kosu. The latter is the ratio of the total time worked in each process to the number of units produced. Those indicators were difficult to check when the internal tracking system was not employed yet. The more experienced operators used to keep an eye on the scraps, while kosu indicator was not used or easy to understand. Using a digital system is great support for line operators, it ensures the accuracy of data and the tailoring of corrective actions. When those indicators were first chosen to monitor production, workers had to compute them manually. With the adoption of the tracking system and the tablets, it is easier for them because they just need to check the displays and detect the anomalies. After the line has been monitored, it is important to effectively escalate issues, meaning that problems can be dealt with faster [32]. If the issue is not resolved quickly, it can impact the organization as a whole and productivity can be lost as employees struggle to use the technological tools they have been provided. Over time, improper escalation management will lead to a myriad of issues eventually becoming much larger problems. This, in turn, leads to a team that is constantly putting out fires and playing catch up, because its business processes haven't been properly developed. The first step to ensure good escalation is to have strong internal protocols. Operators should follow clear and written rules, in a standardized way. These rules should be also periodically checked by the organization, with the use of audits or checks that are designed to make sure that a company's processes are still being accurately followed and that they don't need to be changed to account for organizational evolution.

4.2. Percentage of scraps

Scraps are manufactured articles or parts rejected or discarded, output of a production process that is not finished goods or work in progress (WIP) and they cost money and time. A scrap is usually a waste of materials because often it cannot be recycled. It can also be a waste of time because it avoids the machine to produce a higher percentage of good products. The three major scraps are bad products, which represent products that are not in the quality assurance specifics, rework, which are bad products that need adjustments, and first materials scraps, which originate every time the tool starts and consumes materials due to unadjusted parameters [33]. The percentage can be computed as (Chandrasekaran, Campilho, & Silva, 2019):

$$\%\ scraps = \frac{scrap\ parts}{scrap\ parts + good\ parts} * 100$$

The percentage of scraps is the number of defectives found in the total production and it is a measure of the quality of the system. The standard percentage of scraps is a percentage value that has been established by the company as a threshold, considering a "normal" value of scraps. The actual value, instead, is the percentage of scraps found in a cycle time. On the tracking system of the machines, in the worksheet opened by the operator at the start of the production, it is possible to see the percentage of actual scraps. The internal system is programmed to highlight in red the unacceptable percentages of scraps, based on the limit value, to make operators and team leaders aware of the quality inefficiencies. Limit values were decided based on the quality department indications, studied depending on the clients or the production processes.

4.3. Kosu

Despite the quality, another aspect to consider is the productivity of the company. Productivity is a measure of the efficiency of the production process, given by the ratio of output to input. More specifically, labor productivity indicates the unit of product per worker (or hour worked); capital productivity, on the other hand, is measured by calculating the ratio between output and capital employed in production; finally, multifactor productivity is a measure that makes it possible to simultaneously take into consideration all production factors that have contributed to generate the observed output (Grazzi, 2012). The terms "efficiency" and "productivity" are often misunderstood and considered synonymous, but efficiency means how the company is using the resources at its disposal, while productivity refers to the results obtained with the resources employed. Although the two refer to different concepts, they have one thing in common: they aim to produce more with the same amount of resources available. There is no real standard on how to increase productivity, as each company has its distinctive characteristics (in terms of product, constraints, market, resources, and so on) that must be evaluated and analyzed in order to guarantee maximum results. Measuring through specific indicators allows objectivity to guide improvement consciously and helps to establish the correct target to be reached [34]. The terms productivity and efficiency are considered interchangeable in the company, for the sake of simplicity. The main indicator used for efficiency is kosu. The term is used to indicate the number of labor hours per unit of output. Kosu helps companies focus on wasted effort in the process in which the operator works; it helps people to investigate the system of work [35]. The indicator is also related to other aspects of the companies. The time spent to produce one component gives information on the workforce and its relative cost. The goal of companies is to diminish kosu through the elimination of *muda* and of variability. The indicator is also related to continuous improvement in terms of produced parts per hour, which means an optimization of the work rhythm and it also affects the takt time, which is the maximum time one unit takes to go through the entire production process (Federal Mogul, 2016). In the company, kosu is the ratio between total presence time and number of good parts and it computed in seconds as follows:

$$kosu = \frac{operator\ presence\ time\ [h] * operators\ in\ the\ area\ [\#] * 60\ [s]}{good\ parts\ [\#]}$$

The actual values refer to the values of the production, while for the standard values some target values were decided. To decide the reference values the system was investigated and observed for a while, then the standards were set by adding a percentage range of acceptability to the target values. Kosu target, in produced parts per hour, was computed by the company for each machine as the product between cycle time and percentage of losses. By working on the percentage of losses it is possible to improve the efficiency of the machine and consequently of the plant. It is possible to see from the tablets in the machines when kosu is going out of standard. In figure 42 it is illustrated what the operators see while working: one line of the upper table indicates the percentage of scraps, while the last line indicates the kosu indicator, highlighted in red or green in this case. The use of different colors, in a very intuitive way, is strictly connected to the Poka-Yoke concept. The operators can clearly see the comparison between the standard value of kosu coming from their machining steps and the target one, decided by the company.

	1	2	3	4	5	6	7	8	9	10	-	TOT
Buoni	60		125		50	127						362
Scarto			1		2	1						4
Scarto Pressista												0
Scarto %			1%		4%	1%						1%
Info Slot	R23	R23	R29	R3	R17	R53	-	-	-	-	-	148
KOSU	23.0	-	13.9	-	20.4	25.0	-	-	-	-	-	24.5

KOSU Std
18.75
Efficienza
100.0%
KOSU Target
18.75

Figure 42: Production tracking system view

The kosu concept is usually more difficult and relatively new to understand for line operators and the other people working in the company, concerning the scrap components they were used to search for. In order to help them better understand the importance of kosu, the following card of figure 43 was created.

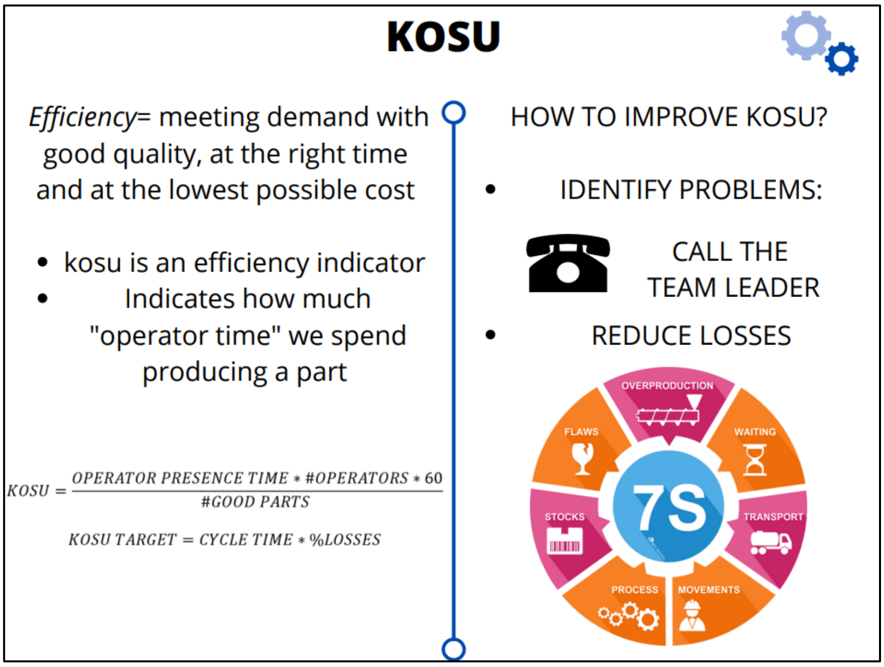

Figure 43: Kosu flashcard

In the left part, there is an explanation of the kosu definition and concept, while on the right one it is underlined how to optimize the kosu value. The main activities dedicated to improve the indicator are identifying problems, thanks to the Andon system and the visual representation of the values, and then reducing wastes and losses. Once operators detect some anomalies in the process, they have to call their team leader, who can help them solve problems.

4.4. Escalation standards: first steps

At the beginning of the thesis project, the company was already trying to apply the Andon methodology, but there was not a clear and standardized way to manage problems. The daily problems response plan thought for the company is based on an Andon system and of few steps that every worker in the company needs to follow. The first step of the process is at the operator level, who can be working with the machines or at the selection departments. The worker identifies the standard deviation by looking at the tablet, compiles the notice report, and calls the team leader. The second step of the escalation is the team leader's work. He needs to manage the problems, by helping the operators working in his department deal with the found problems, proposing some corrective actions, and possibly solving some issues. At this level, unsolved problems are communicated to the upper level, represented by the Supervisor, during the morning meeting. The Supervisor takes charge of these issues and coordinates the creation of some PDCA plans. PDCAs are guided by cross-functional teams: they try to solve the problems, sometimes even changing the standards. The scheme in figure 44 was created to better explain to the workers the flow of information.

Figure 44: Problem escalation flow

Operators with a lot of experience in the tasks were used to recognize some defects or problems and they told them to their team leaders. In order to keep track of the problems, operators had started filling in by hand some notes on the production. The management created some tables to fill to guide the process, by using the 5W method mentioned in chapter 1. The first part of the table shown in figure 45 was the one filled by operators while working on a specific machine. First, they had to indicate whether the problem was an efficiency or a quality one. This was easy to identify in the machines using tablets because indicators are highlighted with different colors depending on their status with respect to the standard: red, yellow or green. They characterized the problem by answering some questions about the issue and then they had to call the team leader. The latter went to the *gemba* and filled the other columns of the table, about causes and actions. The problems with this method were the time lost in filling all the fields and the fact that operators were not used to this process and they forgot to compile it sometimes. The initial escalation from team leaders to Supervisors was also a confusing one because the Supervisors got many different inputs from their team leaders and it was difficult for them to understand which problems to focus on when they did not go into the *gemba*. They spent too much time reading emails or notes about problems but there was not a common way to keep track of the issues. The first activity done to ensure compliance with the standard rules was to create some flashcards to train the operators on the process they should use. Furthermore, some improvements on the tables and the general escalation steps were started. The basic process and the cards, used as a starting point for the thesis project, will be explained in sections 4.4.1., 4.4.2. and 4.4.3.

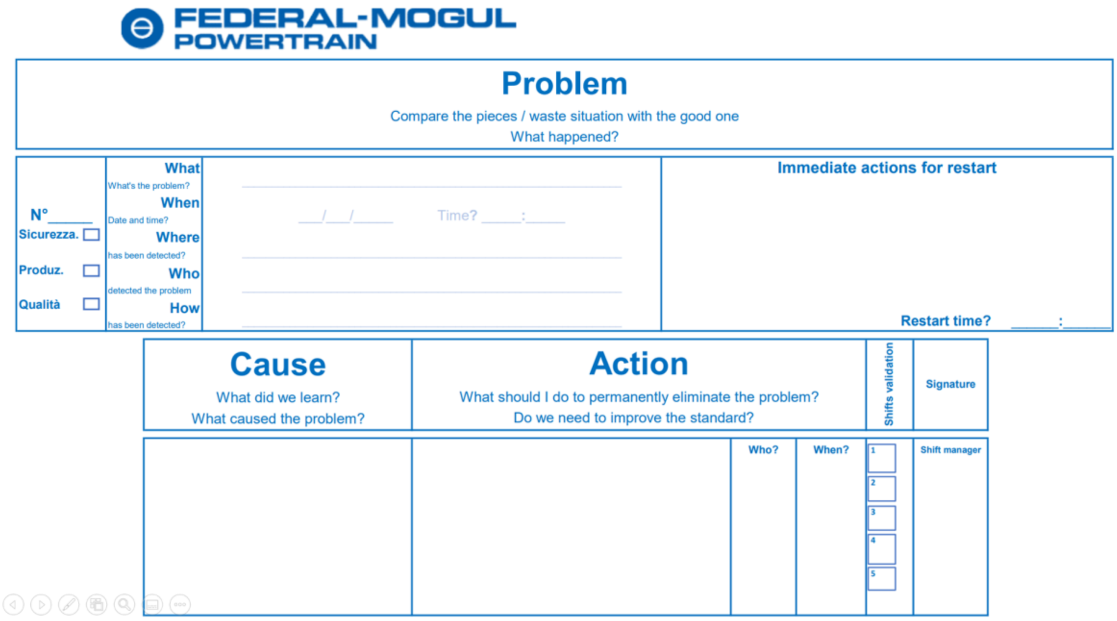

Figure 45: Escalation table, first steps

4.4.1. Operator level

The first improvement done during the project was changing the table to make it simpler to fill and standardize the fields. The table, shown in figure 46, was very intuitive and schematic and the operator had to write some references about the date, time, and shift, followed by some information about the problem. The operator had to select between a kosu or a scrap problem, as in the previous version. The number of questions was reduced and the analysis focused just on the information necessary to team leaders to help to solve the problem. The main section of the table was the description of the problem and the operator had to specify whether the issue was recurring or not. By collecting those production tables, it was easier for operators and team leaders to identify recurring problems and check how they solved them in the past.

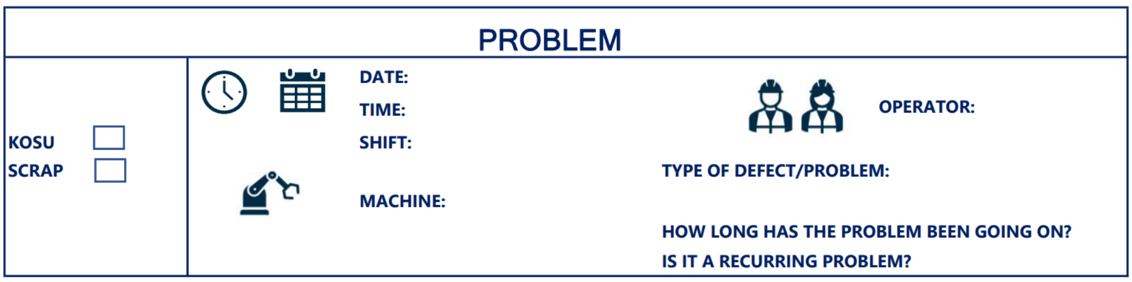

Figure 46: Operator table

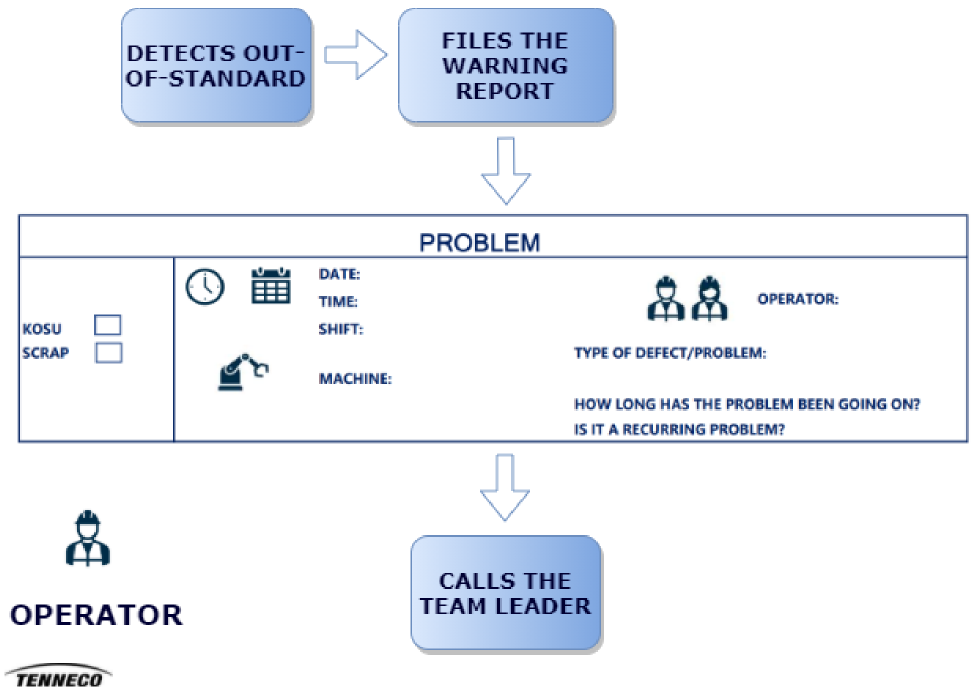

Figure 47: Operator actions flow chart

The Andon system simply consisted of stopping the machines every time a problem was encountered and operators had to notice their team leaders through a phone call. A flashcard was created and hung inside the production line, to better explain what the operator needed to do for the problems' escalation and to standardize the process, shown in the flow chart of figure 47. This one explained the main steps done by the operators and it was given to them so they could check the process if any doubt arose.

4.4.2. Team Leader level

The Team Leader received the call and went to the *gemba* to help the operator. Team leaders helped operators fill the other parts of the table in figure 46, consisting of the two columns called causes and actions.

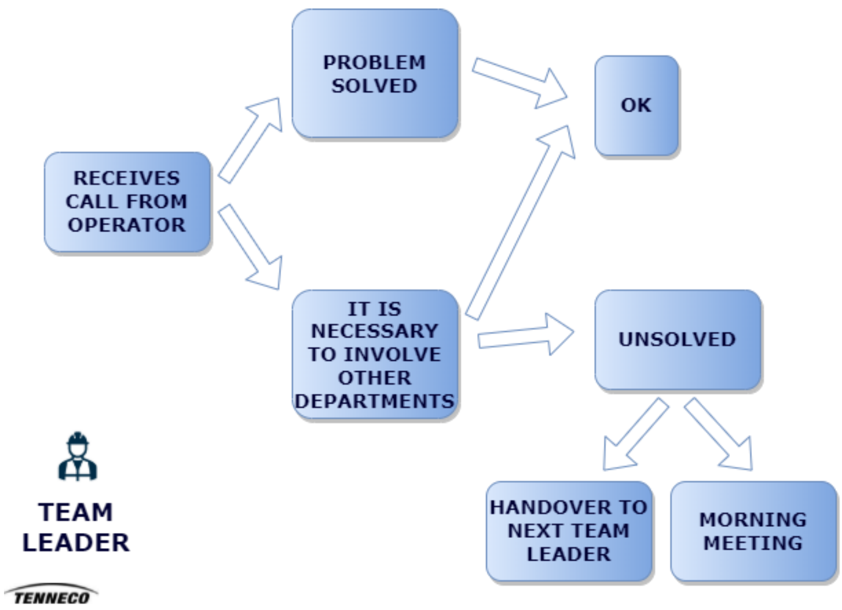

Figure 48: Team leader actions flow chart

They had to analyze the intercepted defect, verifying whether the problem was still existing if it was a problem that cannot be deliberated, what standards did or did not meet, what figures were affected by the problem, whether it had been a change in the process. They then checked whether it was a machine or process anomaly and reported the analysis done to share information with other shifts. After verifying and analyzing the problem, the Team Leader had to record the restored standards or changes made, indicating at what time he restored the process to optimal condition and sharing with the operator the actions are taken. If he could solve the problem, then the issue was just reported to the Supervisor in the email to keep track of what happened and of the solution used in case of another repetition. If the Team Leader and the operator could not solve the defect by themselves, then it was necessary to involve other people, possibly coming from another department, for example, maintenance. When the problem still stayed unsolved, the Team Leader communicated it to the next colleague at the shift change, for warning purposes, and the Team Leader working on the next morning brought the problem to the meeting with the Supervisor. The flow chart, represented in figure 48, was created to help the Team Leader in the action plan and it was hanging to the team leaders' desk inside the department.

4.4.3. Supervisor level

The Supervisor analyzed every problem, communicated to him either by email or during the morning meeting. The process remained confusing in the first part of the thesis project because the first improvements were made at the lower level, to start optimizing the escalation process. Another card was created for the Supervisors and their training and it is represented in figure 49.

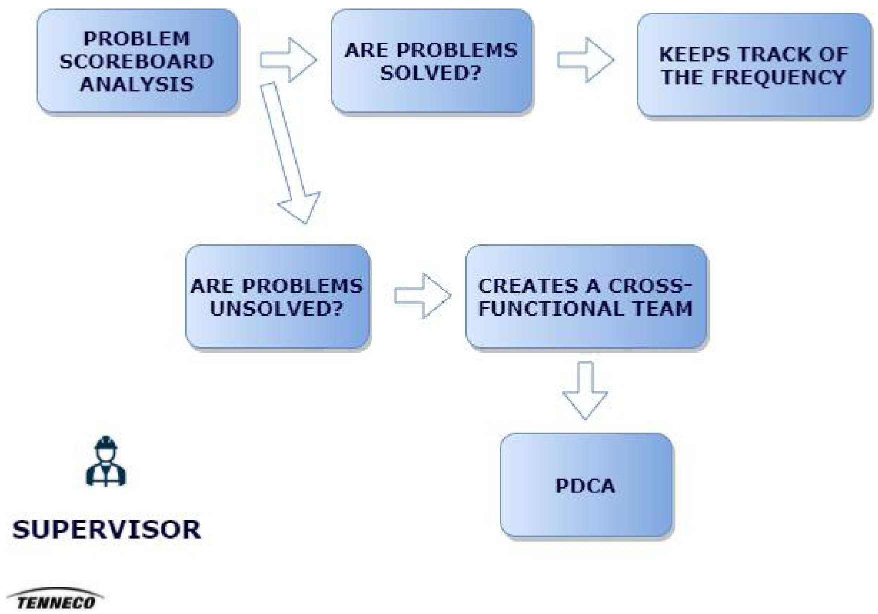

Figure 49: Supervisor actions flow chart

The Supervisor took over the problems identified in the previous step and analyzed the open points differentiating the types of problems. When problems were unsolved, Supervisors tried to help the team leaders by creating a cross-functional working team. This team worked on a PDCA plan to solve the problems. The following rules apply to the different types of problems. A punctual problem is an issue that has been solved after the intervention and needs no more actions, but it is important to collect the information reported by the Team Leader to give evidence and keep track of improvements. If the issue is a recurring problem, which even if currently resolved continues to recur over time, the Supervisor has to report the problem in the PDCA shared with Engineering and Maintenance. In case of an issue of non-compliance with standards, the Supervisor verifies training of operators involved in the problem and he provides new training in case they lack information. He also verifies that the standard was correct or involves other agencies to improve it. When the type of problem is related to raw materials, the Supervisor involves the quality department for analysis and management of non-conforming material and creates a body to solve the problems with the Quality representative, Tooling and Warehouse (depending on the problem), using a PDCA (Federal Mogul, 2017).

4.5. Importance of Daily KAIZEN™ methods

Problems escalation improvements were carried out after a two-day intensive course done by *Kaizen* Institute. *Kaizen* Institute uses a ”learning by doing” approach at all levels of the organization, coaching leaders to develop and deploy effective strategies or training and coaching team leaders to apply Daily *KAIZEN*™ creating daily improvement routines to engage the total workforce [36]. Very often companies committed to continuous improvement stop after an initial "low hanging fruit" phase, where improvement comes from a few focused projects. Usually, the first phase of continuous improvement in a company is realized with specific "spot" projects, with high impact, involving cross-functional teams and external experts on focused problems: these are the *Gemba Kaizen* Yards. They are very useful for breakthrough changes but less so for building daily leadership and developing daily problem-solving skills in teams. This way of doing things does not realize the full potential of continuous improvement: after the worksite, there was often the problem of maintenance. "Every system left to itself begins to degrade", said Masaaki Imai. This causes the need for Daily *KAIZEN*™, which is the tool to access a new level of improvement of the plant, able to contribute to the reduction of transformation costs year after year. The Daily *KAIZEN*™ program addresses the “natural teams”, which are all the people who work together in lines, offices, departments or processes. It is thought that the involvement of these teams weights around 2-5% of the improvement activities, in terms of OEE and efficiency. The result of the program is having teams capable of improving and maintaining standards, managing shift production, highlighting anomalies, solving problems, conducting training, creating effective standards, and monitoring their application and maintenance. The tool is used to manage improvement by engaging a large number of people in an organized and effective way, thereby improving the teamwork and leadership skills of managers. The maintenance and improvement of work standards is a daily activity carried out by teams made up of people naturally more involved in each area, to create and reinforce a culture of excellence. The main activities are maintaining standards, using rapid problem solving to ensure quality and performance, improving standards and monitoring and sharing area performance to initiate effective improvement activities. The teams follow the 70-20-10 rule, already applied in Toyota, which leads to continuous learning during daily activities. 70% of the time is dedicated to working, 20% to managers' feedback and 10% to individual study and training. The main benefits found through years of experience are the alignment of all people with company goals, improved communication; the creation of a mechanism to resolve problems quickly, a sense of responsibility for maintaining standards in every area of the organization, a decrease in unforeseen events and rapid problem resolution and finally a creation of a culture of improvement [37]. Starting from the existing procedures, already going towards Lean principles, the collaboration with *Kaizen* Institute helped Tenneco define and optimize the processes, following the Daily *KAIZEN*™ methodology. The course was attended by team leaders, one for each production department, their Supervisors, the Lean manager and the thesis author. It was also supervised by the Value Stream Manager because the improved results of the program are of his interest.

4.5.1. DK0

The so-called Daily *KAIZEN*™0 (DK0) level of communication is used by team leaders at the shift change, instead of just speaking to each other, and as a report for the end of the shift, to send to the Supervisor. The first step in creating the DK0 file was the analysis of the existing procedure of filling tables, presented in sections 4.4.1. and 4.4.2.. The first file was thought during the two-day course. The first model was an Excel file in which team leaders had to write down some data during their shift or at the end of it.

Fields to add in the table were taken from the tables they used to fill by hand and they proposed some new indicators and fields to express the information they were used to say to each other. In this first version of the DK0, the Team Leader had to add the week number, the date, the shift (numbered from 1 to 3 inside the day) and their name. The first part was about the machines and their relative work priorities, meaning when an operator has to work on different machines, the name of the operator working on the specific machine, the part number code, the machine scheduling, the machine status, for example working or waiting for material and finally a blank column to write some additional notes or comments. This section is shown in an example for week 32 in figure 50.

WEEK	DATE	SHIFT	TEAM LEADER	MACHINE	OPERATOR	OPERATOR PRIORITY	WORKING PN	SCHEDULING	MACHINE STATUS	NOTES
32	10/08/2021	1	TATTI	AIDA	GIACOMAZ	1	GO189FL2	G0106FL1-		
32	10/08/2021	1	TATTI	LUIGART	AMINE	1	HS10037			
32	10/08/2021	1	TATTI	P6						

Figure 50: Shift status

The second part of the file was about the problems encountered during the shift. It was more specific with respect to the previous version and the Team Leader had to distinguish between security issues, operative ones and quality ones, for each machine of the department, as shown in figure 51.

MACHINE	SHIFT SAFETY ISSUES	SHIFT OPERATIONAL ISSUES	QUALITY ISSUES
AIDA			
LUIGART			
P6			
STENHOJ			
ASTALINE			
MA9			
VTS			
GIGANT			
ROCHER			
SELEZIONE			
P35			
ASSENTI			
OMERA			

Figure 51: Shift problems

The last part of the table was about the indicators. The first one reported was the number of security problems encountered during the shift. Then, some data such as the percentage of scrap, the standard and production hours, the losses and the planned stops are copied from the tracking system, for each machine selected. The efficiency values were directly computed on Excel once the other data are added to the file. The formula used was a ratio between standard hours and actual production hours. Target values of percentage of scraps and efficiency were added in order to guide team leaders to identify problems in an easier way. The part of the table related to indicators is shown in figure 52 with an example.

SAFETY (#PROBLEMS)	SCRAP (%)	STD H	PROD H	EFFICIENCY	LOSSES (mmac + msta) [h]	PLANNED STOPS (setp) [h]	SCRAP TARGET	EFFICIENCY TARGET
	0,64%	4,1	5,8	71%	0	3	2%	60%
			3,5	0%	0	1,6	2%	60%

Figure 52: Shift indicators

4.5.2. DK1

Daily *KAIZEN*™1 is the second level of the problems' escalation. It is used during the morning meeting between Supervisors and team leaders. To optimize the process, it was decided to focus only on two indicators: one for efficiency and one for the quality of the product. The model was created during the two-day course with the participation of all the people involved.

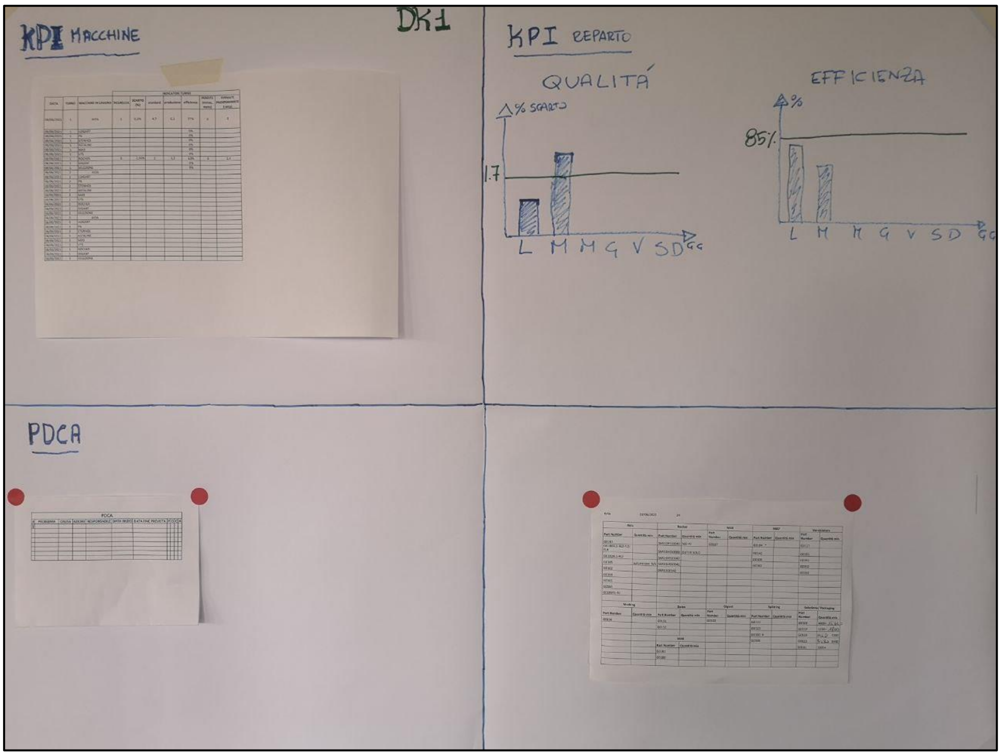

Figure 53: DK1 model

The idea developed during *Kaizen* Institute course is represented in figure 53, it was decided to visualize the different data in four different sections of a whiteboard. The standard process starts during the morning meeting when the first indicators analyzed are the ones about the machines of the specific department filled in by the Team Leader during the DK0, to have an overview of the situation. These data are hung on the board on the upper-left side. After that, a more detailed analysis is done on the quality and efficiency indicators. As regards the quality measure, every morning the Team Leader updates on the DK0 the graphs showing the trend of the week of the percentage of scraps. Efficiency is instead represented by the kosu indicator. Data are compared to the standard values computed by the company. In figure 54 some KPIs computed during week 32 in August are shown as an example. On the left, there is the percentage of scraps, the data are average values of the department for each day of a selected week. The right graph represents the efficiency values. The blue bars of the graphs represent the actual values, while the orange lines show the target values. As for the scrap rate, actual values should be lower or equal than the target ones, while for the efficiency they should at least equal them. These graphs are printed every day and brought to the morning meeting of the next day.

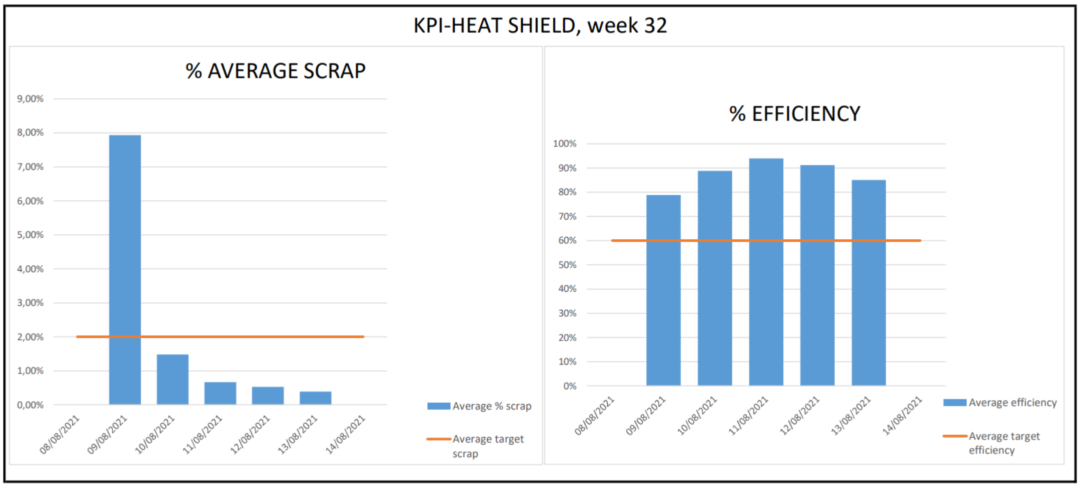

Figure 54: KPI graphs, DK0

The Supervisor then updates the PDCA and at the end, the production schedule is analyzed. People attending the meeting and using the DK1 are the Supervisor, the Team Leader who is working in that morning, one representative of the quality department, of the process engineering and of the planning section. The planning department provides the scheduling for each production department, which is a file containing the minimum amount of a product produced by a specific machine. Thanks to this file, which is usually hung near the team leader's desk, they can fill the DK0 and keep track of the scheduling plan to assign operators to each machine.

4.5.3. Daily KAIZEN™ results

The process of filing tables was tried for a couple of weeks and team leaders were continuously asked their opinion, to check whether it could be considered an improvement or not. The DK0 was developed with their help because they identified the information, they needed the most to keep track of the problems. The pilot department was the Heat Shield one and the files were created with the help of one Team Leader who attended the *kaizen* course. The three team leaders working on the different shifts were trained on how to use the Excel file, which was automatized in order to be as simple as possible to be updated. During some interviews, they confirmed the new process was easy to use and much quicker with respect to the written table. The benefits are that it is possible to keep track of the problems in an easier way, on the same file and without using paper. Another advantage is saving time in writing the email to the Supervisor at the end of the shift because with this file team leaders just needed to take a screenshot and send it, without writing down every problem again. For the morning meeting instead, they just had to print the indicators of figure 54. At the beginning, they had some difficulties in using the tracking system to copy the data for the indicators part of figure 52. They needed to write down in Excel data coming from different sections of the production system and the risk of mistakes was high. The filling of the Excel files was just a temporary action that was needed to detect the right indicators to fill and the information useful to team leaders and Supervisors. Thanks to the software developer, the system was then modified in order to show the indicators selected, similarly with respect to the tables presented in section 4.5.1.. The new tracking system modification screen is excluded because it contains sensitive data. Alongside the advantages brought by the Excel tables, the digital process now takes very little time to team leaders, who can focus on solving problems inside the production department or helping operators. They just need to open the system and take a screenshot in the specific interface, attaching it to the email they send to their bosses daily. As far as the selected indicators of quality and efficiency of figure 54 are concerned, a section was added on the system automatically showing them for each department. As regards DK1, the first idea was adapted to the plant and used during the morning meetings. Supervisors confirm this method is helpful for them, because the meeting is more structured and data are visualized and commented in a specific order. Another advantage is having the problems displayed on the board, which avoids writing everything down and it helps them when they have to think about corrective actions. When Heat Shield Department started the project, other areas of the plant started to think about Daily *KAIZEN*™. Unipiston Department, including injection and compression production, also adapted to follow a standardized approach to escalate problems. Since this department is smaller and produces fewer types of products, it was easier for them to realize a white board in which to add the different parts of the reporting. For these reasons, this version of the Daily *KAIZEN*™ shows both the DK0 and DK1, which were unified choosing just the most important data needed. In the upper part of the whiteboard shown in figure 55, on the left, there is the PDCA spot for machine and tool maintenance with a reference for each machine. The plan consists of the different sections problem, analysis, action, pilot, who is the person in charge of the specific action, date and notes. The structure is the common one used in every PDCA of the company. The right part of the board shows instead the PDCA for dies and blocks. In the lower part on the left there are some graphs showing the department trends, in terms of scrap percentages. The graphs are updated every week and they also show the target value computed for the department. Finally, on the lower right part there are the shipment orders, showing the different part numbers to be produced in the week, with the client reference, the number of parts in the batch and the product.

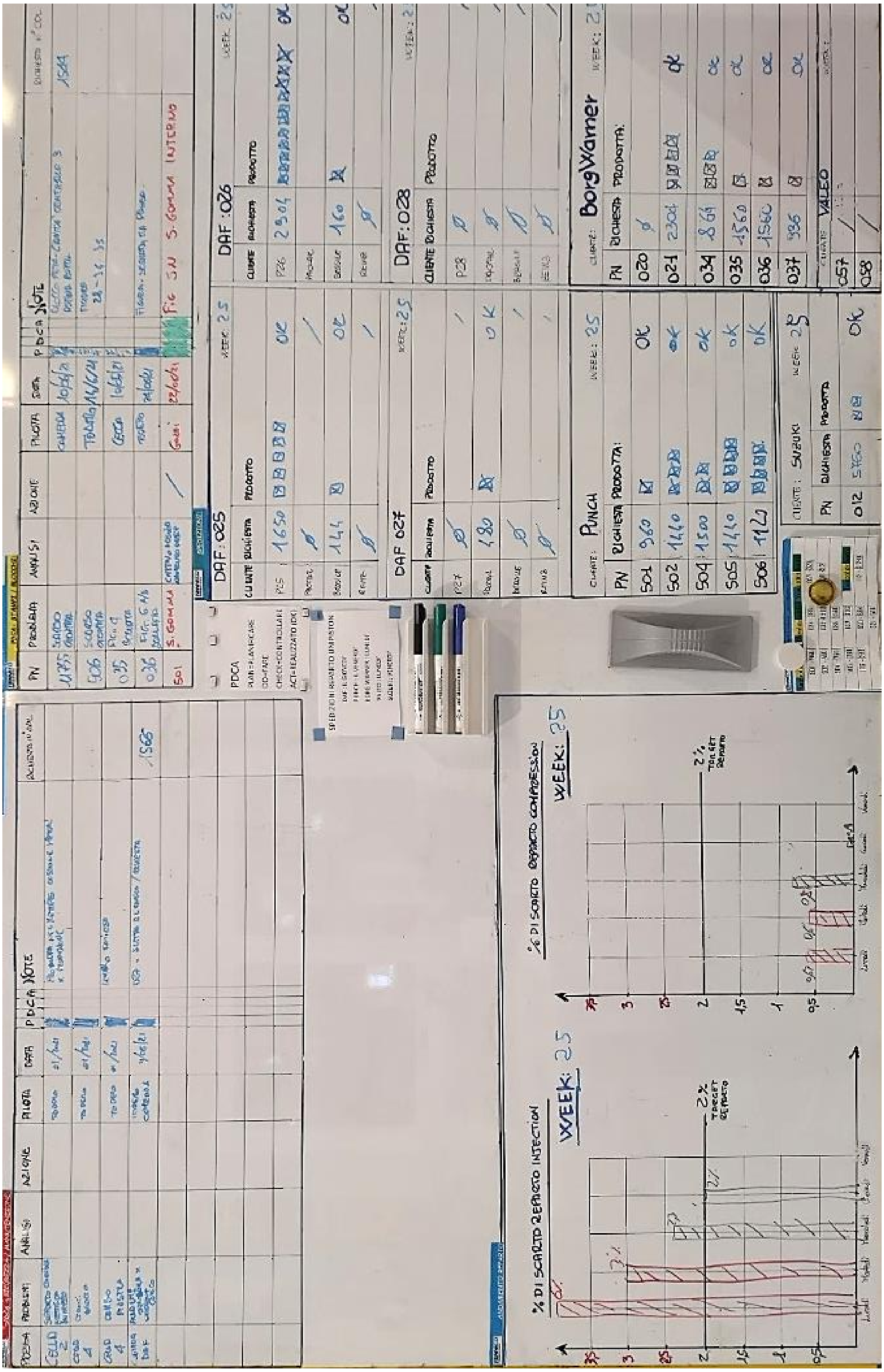

Figure 55: Unipiston board

4.6. Escalation standards: optimized procedures

After the two-day course and the trial period of about a month, the new rules of Daily *KAIZEN*™ were integrated into the Tenneco plant and, along with a more digitalized process and the key importance given to the production tracking system, the new procedures of management and escalation of problems were studied and introduced.

4.6.1. Operator level

As regards the operator, the general process is similar to the one thought at the beginning. The following card of figure 56, created for operators' training purposes, shows the steps the operator needs to follow. Once the issue has been identified, the worker fills a report on the internal system, characterizing the issue directly from the tablet, and then he calls the team leader.

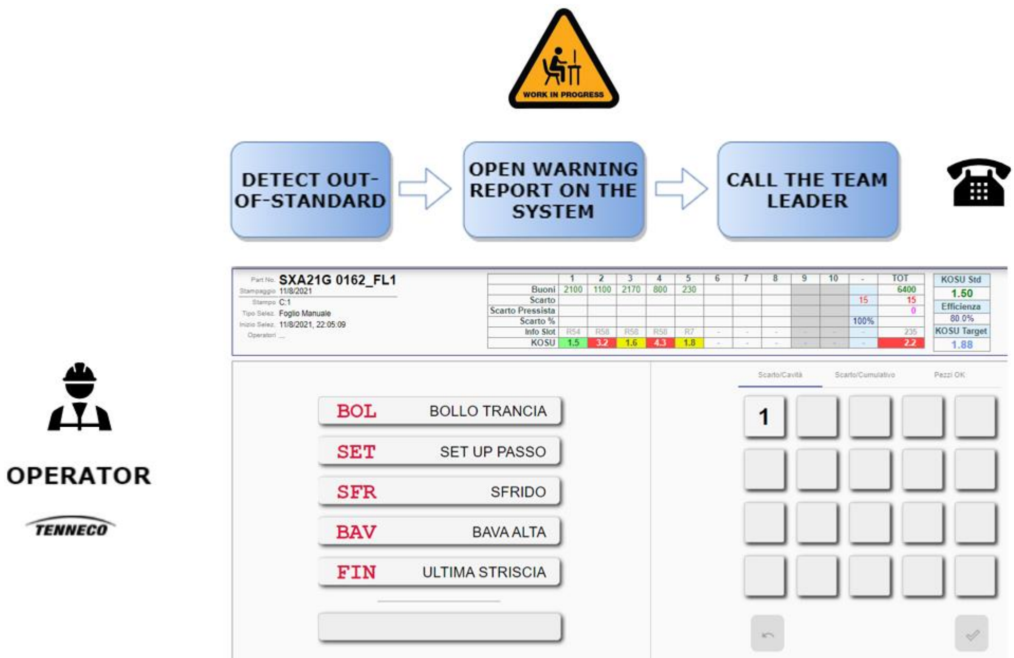

Figure 56: Final operator flow chart

The new reporting method is an improvement with respect to that of figure 46, it was standardized and discussed with team leaders and Supervisors. Their help in deciding the fields the operator needs to fill was fundamental; they were asked which information they needed in order to help workers solve the problem. Instead of wasting time to fill the tables, operators just need to fill out a preset form, accessible from the tablets. This gives the possibility to create a database to keep track of the problems during the duration of the shift and it reduces the filling time and the risk of errors. The first fields of the report are automatically copied from the sheet of the tracking system, already opened by the operator at the beginning of the shift or of the work and consists of the part number worked, the name of the machine, the date and time and the operator name. The worker then has to pick the type of the problem, between efficiency (kosu) and quality (% of scraps). A description of the issue is added, to better explain what happened and what they detected. This is integrated with the quantity, in terms of time lost, the number of scraps identified, time of raw material shortage, with the relative unit of measurement. Finally, the operator can write down on the tablet a potential cause and action he could take to solve the problem. Regarding the causes, the operator selects them from a list; some examples are mold problems, materials shortage, work instructions or machine problems. In figure 57 it is possible to see a scheme of the different fields; it was created during the development process and sent to the software developer to customize the new operator interface.

Problem report-OPERATOR	
ID	xxxx
pn	xxxx
machine	xxxxx
date-time	xxx
operator	xxx
type of problem	
problem description	text
quantity? Time lost-scrap pieces-missing production	15 sec
potential cause	incoming material
potential action	text

Figure 57: Operator report interface

4.6.2. Team Leader level

Some automated features changed the Team Leader escalation process as well. This improvement helped them to better monitor their departments. Once the warning report has been filled by the operator, the Team Leader can see on his computer the entire report lists coming from the machines of his department. The interface on the system shows a list of the issues, which are numbered to count the total problems of the department. The following example of figure 58 was created during the analysis to check the needed fields. For each problem, the main interface shows the reference of the tracking sheet with the most important information regarding the occurrence of the issue. The type of the problem is added as a filter, to more easily identify them. The other columns show the problem description with the quantity. The green columns, as shown in the picture, are filled by the team leaders. Their task is to analyze the problem, trying to understand the causes to avoid it in the future and to identify some corrective actions. It is also possible to see the problem status, decided by the team leader, which can be solved or to be escalated to the superior levels.

TEAM LEADER interface

		Sheet ID	pn:	machine	date-time	operator	type of problem	problem	quantity? time lost-scrap pieces-missing production	problem analysis	action	problem status
PROBLEM ID	1											✓
PROBLEM ID	2											↑
PROBLEM ID	3											
PROBLEM ID	n											

Figure 58: Team Leader interface scheme

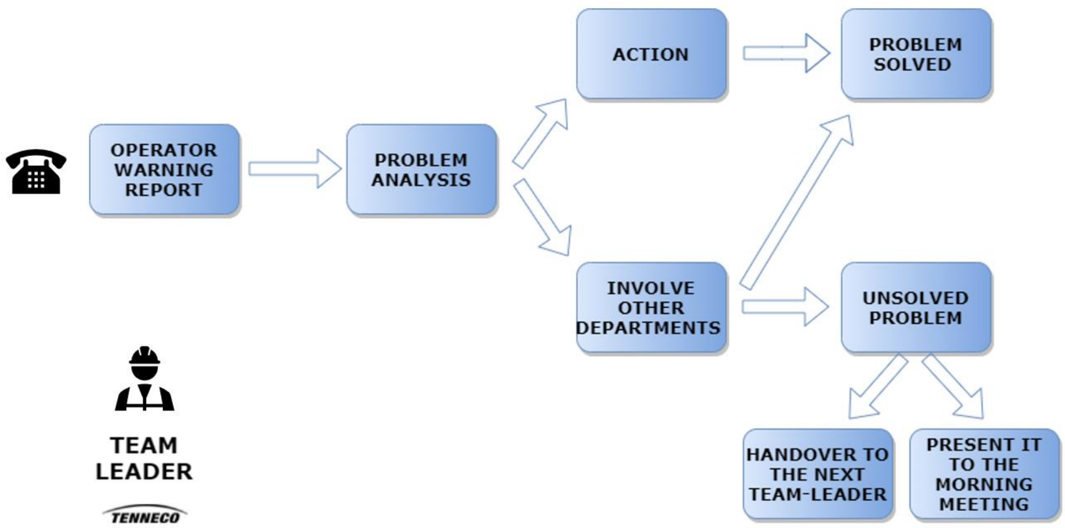

Figure 59: Final Team Leader flow chart

Figure 59 shows the Team Leader flow chart. The first step he needs to take, after the operator's call, is the problem analysis on the internal system, thanks to the new interface. If the problem can directly be solved by the team leader, he simply goes to the *gemba* to help the operator and then he updates the report on the system, adding his considerations. The same applies when he asks for some help from other departments, such as quality or maintenance. When problems are difficult to solve or he runs out of time during his working hours, the Team Leader can communicate them to his colleagues during the shift change and he can discuss them during the morning meeting with the Supervisor, using the DK0 format.

4.6.3. Supervisor level

The Supervisor can access the system from his computer and see another interface. The page is similar to the Team Leader one, with some other columns, as in figure 61. The Supervisor takes charge of the unsolved problems with the help of the reports. The problems labeled with the tick from the team leaders are the ones the Supervisors receive by email. They can see them on their interface to keep track of them or to compare some issues with similar ones. The problems labeled with the arrow to escalate, instead, are the ones the Supervisors need to analyze. Those issues are exposed to them during the morning meeting but having them on the system is easier and it can be useful to create the PDCA. The plan-do-check-act plans are identified on the interface assigning a pilot, who is the person responsible for the problem, start date and potential end date. The Supervisor receives some advantages coming from the new procedures because he can have a broader view of the department he is in charge of, accessing every type of problem from the same web page. Once some actions are taken, he can update the problem status. The flow chart explaining the Supervisor's operations and used for their training is shown in figure 60.

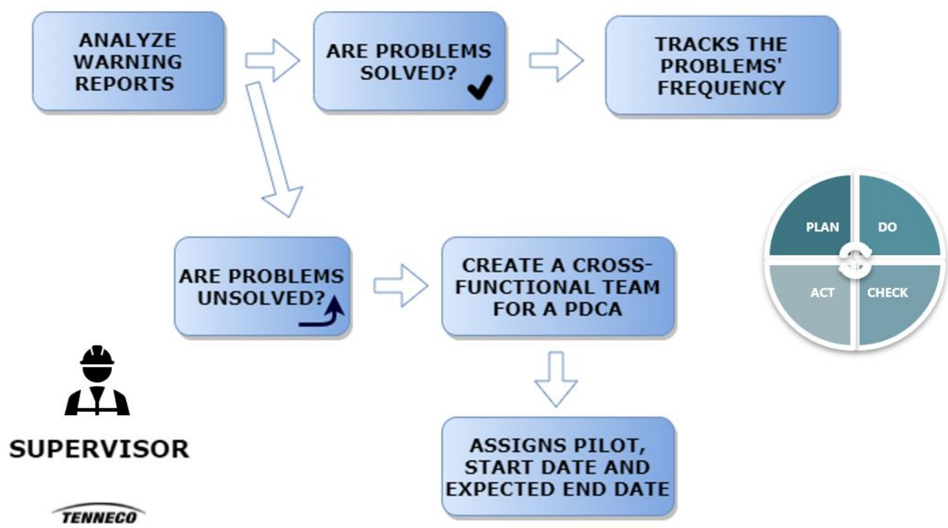

Figure 60: Final supervisor flow chart

SUPERVISOR interface		Operator								Team leader		Supervisor			
		Sheet ID	pn:	machine	date-time	operator	type of problem	problem	quantity? time lost-scrap pieces-missing production	problem analysis	action	PILOT	START DATE	EXPECTED END DATE	problem status
PROBLEM ID	1														✓
PROBLEM ID	2														
PROBLEM ID	3														↰
PROBLEM ID	n														

Figure 61: Supervisor interface scheme

4.6.4. Management level

Managers have an important role in the Andon system and in the management and escalation of problems. A good manager should help his workers in achieving the best results, supporting them in case of any problems. Traditional managerial levels exist to provide the necessary support for directly productive operations. Therefore, management must maintain close contact with the *gemba* figures to be in a position to resolve any issues (Masaaki, 2015). Inside the Tenneco organization, the management team receives the problem reporting from the Supervisors, during the meetings or by email or phone calls, as shown in figure 62. The team members, depending on their field of expertise, go on the *gemba* to help operators and team leaders solve the problems, analyzing the possible causes with them and helping identify the corrective actions. The way these problems are reported to the managerial levels are part of the DK2, which is going to be standardized after the thesis project end.

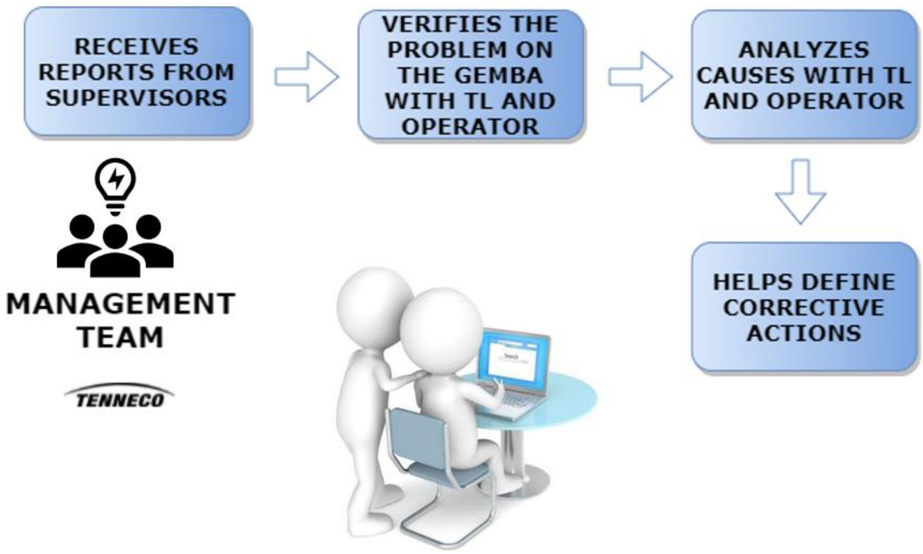

Figure 62: Final management team flow chart

5. Conclusions

This chapter summarizes the work done during the thesis project, focusing on the benefits and limits of both the losses analysis and the problem escalation plan. Furthermore, the possible developments of the two projects have been added.

5.1. Benefits

The two *kaizen* projects aim to bring benefits to the Production. In the long term the use of standards avoids unpleasant surprises. The inputs and outputs of the process become more predictable and easy to plan. Knowledge is a key to success; by standardizing processes it becomes easier to document and then retain knowledge. Standardization involves drafting clear instructions, which means it is far less likely to lose important knowledge when someone leaves the company to find a new job or retire and it also helps onboarding new staff more quickly. When everyone in the organization is performing a task in the same way, it then becomes easier to spot any bottlenecks or sources of waste. Once these issues are resolved, the company will become more economical with its use of energy, raw materials, and human capital [38]. The losses analysis result creates a simpler way to analyse the problems occurring in every machine, to solve them in the long term and optimize the entire process. The new standard is very easy to use and clearly shows to the Supervisors and other people analysing the chosen indicators, such as OEE or OAE, where to focus improvement actions. The analysis, using the tracking system's help, is now easier and quicker to do with respect to the past, when the indicators were directly computed by Operators and Managers did not have a broad perspective on the production activities. The other project, concerning the Andon system and the problems' escalation, has brought advantages in terms of time to solve the issues. The Daily *KAIZEN*™ steps created with the help of the *Kaizen* Institute are very helpful and guide employees during the process, reducing the time needed to fill the tables or report issues, especially after the tracking software modification. This new standard helps every professional production figure identify real-time losses, in order to try to solve them and to avoid their recurrence. The optimization actions due to the thesis experience are now fully implemented in the company and everyday Operators, Team Leaders, Supervisors and Managers are using the new standards. Another reason the projects are successful is the employees' involvement in every improvement step. Their opinion is fundamental to reach a better result in every step and since they feel more involved in the process they are more satisfied with their work.

5.2. Limits

The main limit of the improvement actions taken in consideration has been the workers' mindset. Although Lean principles has been diffused for many years, the greatest challenge is to convince long-time workers of the possible optimization results. The employees of the company have already attended some Lean courses in the past, at Federal-Mogul, not very successfully and they were disillusioned. Since the plant has been part of Tenneco corporation, there has been a huge shift going towards Lean, to keep up with the automotive industry's results and to be competitive with the competitors. The workers are continuously attending training on how to apply this philosophy in the everyday activities, thanks to the Managers or the *Kaizen* Institute. As mentioned in chapter 1, one limit to the correct Lean implementation is a cultural difference, since Lean is founded on Japanese culture and Western organizations do not fully adapt to it. Workers are used to the mass production principles and have difficulties in changing their mindset, because they have spent their entire professional life repeating a certain action or setting other priorities. Another limit of the project is represented by the time. The thesis experience has lasted about 6 months and the results are just a starting point to start optimization in these fields. One limit regarding Daily *KAIZEN*™ reports is the Team Leaders' ability to use computers. They have experienced some difficulties in the Excel files filling and they have been helped by other employees of the company, such as the Lean Manager. The process is quite easy to use now but they need to be trained at every software modification. As regards the losses analysis, the company has to assign the task of updating the weekly and monthly reports to one employee of the company, even if the task is simple and easy to accomplish. The worker should revise the Excel files and check the data integrity, sending the reports to the people involved in the project, such as the Value Stream Manager, the Supervisors of each department and the Planning department.

5.3. Future steps of the project

The two projects can be further expanded, based on the continuous improvement principle. As regards the losses analysis, a future step can be to include the different types of report in the production tracking system. This could avoid the time lost in extracting the production data and filling the reports, even if they are created on Excel to be easy to manage. In this version, every worker could access the internal system to check on the indicators, not only on a weekly and monthly basis but after each shift. To do so, a software modification on the system would be necessary. The tool is customized so the programmer can improve and modify the tool as requested. By adding this feature in the tracking system, workers can have every graph and indicator in the same interface, an easier way to guide corrective actions and keep track of the problems, to avoid their repetition. As regards the escalation of problems, a further expansion of the work could be the standardization of the other levels of Daily *KAIZEN*™ not considered during the thesis project. For example DK2 and DK3 level, concerning Supervisors and Managers. Those roles are very busy ones inside the company and a standard way to communicate and coordinate in the problem solving could help them to better manage their working activity. Another idea for the future development is the use of a new Andon system. Operators use the phone in the production line to call Team Leaders on their mobiles, while Team Leaders usually communicate with Supervisors by sending the shift report email or by phone as well. Other Andon methods already used by companies, such as digital systems with notifications or light or sound sensors, could improve the process. The tracking system could automatically set the alarm, without the Operators’ manual help. Another development step could be represented by the creation of a new interface for the system, in which Team Leaders and Supervisors, and consequently their bosses, could see the real-time problems, using different colours. This could be included in the interfaces presented in sections 4.6.2. and 4.6.3..

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