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Class LM-33 (DM270)

Composites: technology & maintenance. Evolution and optimization of plant equipment at Automobili Lamborghini's CFK centre.

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Attenzione… macchina veloce!

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0. Introduction

The purpose of this master's degree Thesis is to provide a technical and managerial tasks overview about my nine-month traneeship period at Automobili Lamborghini CFK centre as a maintenance engineer. The traineeship period took place from November 2022 to August 2023.

I have joined the company in the Technology department inside, the composite production centre where, from the others, the Lamboghini Revuelto monocoque is made up. My tasks were multiples but all of them related in the boost of machine efficiency acting on the reduction of the stop time.

Three main area of improvement can be highlighted and have been exploited by me in carrying out my job:

- Creation and organization of maintenance KPIs in the new maintenance organization CFK (MTTR-MTTF-MTBF-OEE-OA);
- Creation and organization of the Kaizen Team linked to plant equipment maintenance;
- Creation and integration of MAO, MPI (TPM) on production plants and their digitization on MES.

This Thesis will begin with an introduction highlighting the properties and use of carbon fiber in Automobili Lamborghini. Concerning this fact, a detailed description of the production flow process inside the CFK centre will be provided. Then, an introduction to the purpose of my job as a maintenance engineer will be presented, as well as all the set-up of the new technology and maintenance department organization system. Highlights of the main activities carried on will be described following Figure 1.

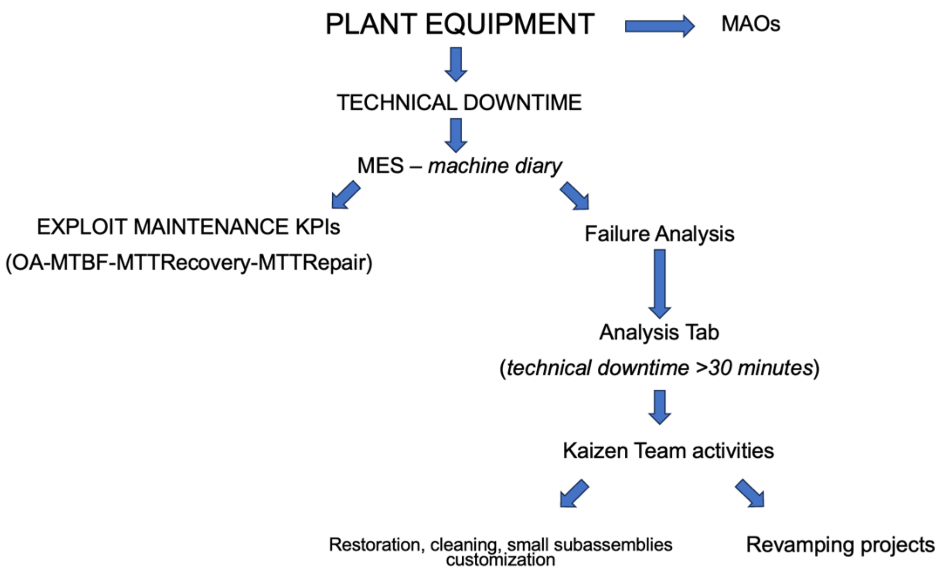


Figure 1 Conceptual maintenance flow operation

After an introduction and preliminary project on the new maintenance KPIs previously mentioned, I will describe the concept of bathtub curve: this will be necessary to understand why some solutions have been adopted despite others and abstract them from the plant equipment to give a much more general value.
Concerning technical stops, example of analysis tab and when to be used will be shown. Instead, for analysis which reported the need of customization or complex recovery processes, I will bring example of machine revamping for an old plant that needed drastically changes as well as for a new one that needs to be adapted to permit autonomous maintenance into the company. I will then conclude by describing maintainers training and definitions of procedures but also a new concept of autonomous maintenance and its relation external supplier service in terms of costs.

1. Innovation and excellence: carbon fiber

Carbon fiber is known worldwide for its incredible strength-to-weight ratio. Concerning this fact, Automobili Lamborghini has taken a big step in research and development on this material, developing dedicated technologies from time to time, according to the different specifications of the Project.

The history of composite materials in Lamborghini began in September 1982 when the engineer Giulio Alfieri, General Manager of Nuova Automobili Lamborghini, taking advantage of European funding, decided to start the design and construction of an experimental car in composite materials. For the occasion he decided to hire Ing. Rosario Vizzini, an Alenia aeronautical engineer who had worked as a consultant at Boeing in Seattle WA for the construction of the drift of the B-767 aircraft in carbon fiber. At the beginning of 1983 engineer Vizzini decided to start the preliminary design of a Carbon Fiber Reinforced Plastic (CFRP) chassis for a brand-new Lamborghini Countach, which however was never officially presented.

Figure 2 Lamborghini Countach Evoluzione, 1983

The Countach Evoluzione boasted a 100% carbon fiber composite body and had a weight reduction of about 500 kg compared to the reference Countach models. Performance also benefited: despite being equipped with a standard engine only slightly retouched by 490 hp, on the speed ring of Nardò the Countach Evoluzione exceeded 330 km/h.

Throughout its history, Automobili Lamborghini has been increasingly committed to research on composite materials, until in 2007 it founded its own internal research division, the Advanced Composite Research Center (ACRC), dedicated to the research of innovative materials and the development of new concepts and technologies applied to carbon fiber able to maximize the performance/weight ratio of the parts and the car. The department consists of two divisions, Engineering and Manufacturing, which simultaneously follow all phases of product development. The Concurrent Engineering approach allows the multifunctional team to design by integrating rapidly evolving technological processes to achieve increasingly extreme technical requirements. The

group is also responsible to produce spare parts and the repair of the Aventador's monocoque.
Lamborghini with its dedicated team is the only manufacturer in the world to have "in-house" the complete know-how of the entire composite cycle: from the birth of an idea to the concept, to the creation of the product, up to the repair. With a view to continuously improving car performance, lightweight design and safety, the Engineering division develops and selects materials, technologies and innovative solutions aimed at using carbon fiber for components unthinkable until now for the extreme automotive world.
In 2007, the collaboration between Lamborghini and Boeing was also established, which made it possible to transfer the technology used in the Aerospace sector to the Automotive sector, with particular attention to Crashworthiness, the modular BBA (Building Block Approach) approach in vehicle engineering and repair techniques for composite materials. Also, in Seattle (WA), the ACSL NPO was established in 2014 and officially inaugurated in June 2016, a technological laboratory led by prof. Paolo Feraboli, which has the task of working in complementarity with what is done by ACRC in Sant'Agata Bolognese. This is how Lamborghini's leadership in the world of composites continues, towards which the company always stands as a "precursor" of new challenges that arise, in a constantly changing sector, from external collaborations with Boeing, the Advanced Composite Structures Laboratory in Seattle, prestigious Research Institutes and renowned Italian and foreign universities.
For over 30 years, Lamborghini has been applying and developing carbon fiber technology to the automotive world, through international research that also includes the Advanced Composite Structures Laboratory (ACSL) in Seattle.
Thanks to the partnership with Boeing, Lamborghini has opened new scenarios for composite materials, confirming itself as the leading car manufacturer in terms of carbon fiber research.
The collaborations established with partners from the aeronautical world have led to the Sesto Elemento, a highly technological project in which the design partnership with Aerospace has been put into practice, achieving results never obtained before in the use of carbon fiber.

With a structure made extremely light using advanced carbon fiber technology, the Lamborghini Sesto Elemento can offer extraordinary performance, going from 0 to 100 km/h in just 2.5 seconds. This car is a true masterpiece of lightweight engineering and demonstrates all of Lamborghini's expertise in carbon fiber technology and choice of materials. The name Sesto Elemento comes from the periodic table of the elements, in which Carbon is ranked sixth.

Figure 3 Lamborghini Sesto Elemento

At the base of the car there is the monocoque in Forged Composite®, an extremely solid, rigid, safe and light structure. The monocoque, the front, the exterior bodywork, the shock absorbers, the main components of the suspension, the rims and the transmission shaft are made of carbon fiber, because they are able to guarantee for a high-performance super sports car like the Sesto Elemento better acceleration behavior, exceptional handling and reduced braking distances. Dynamic style from the first glance: the design of the Lamborghini Sesto Elemento showcases the sensuality of high performance and conveys the elegance of pure and uncontaminated power. The Sesto Elemento elevates the design of the Lamborghini brand to a new level and integrates it with the Forged Composite®, an innovative material of the latest generation developed for the future technological challenges of Automobili Lamborghini.

1.1 Research for the excellence: the use of Carbonskin®

In the history of Lamborghini, carbon fiber with thermosetting matrix, so called because it hardens with increasing temperature, has been used since the eighties for the development of rigid structural and aesthetic components.

To be able to express itself once again with innovation, taking inspiration from the Aerospace world, Automobili Lamborghini for the first time extends its thinking in the field of flexible materials, and after years of research and development conceives a new carbon fiber material with flexible matrix, suitable for the application for car interiors. The Carbonskin® has been developed entirely by Automobili Lamborghini's Research and Development team, the ACRC, and complies with all the homologation and validation requirements required in the Automotive world. This product is patented worldwide under the name "Carbonskin®" and is the only product in the world able to meet the quality and homologation requirements of the VW group. This innovative material offers in addition to weight savings (- 28%, - 65% respectively for Alcantara and Leather), unique aesthetic

Figure 4 Lamborghini Aventador monocoque

characteristics such as the naturalness of carbon fiber, the three-dimensional effect, its softness immediately perceptible to the touch when compared to any other material.
The intensive use of carbon fiber at a structural level in the passenger compartment area and the constant development of technological processes allowed Lamborghini, in 2011, to win a new challenge with an innovative carbon fiber monocoque for the Aventador super sports car.
Conceived and designed from the beginning as a single structure in carbon fiber, it is produced entirely by the house of Sant'Agata Bolognese.
The Lamborghini monocoque is of the "Modular" type as it integrates in a single structure all the parts that make up the passenger compartment, the floor and the roof of the car. The monocoque module weighs only 147.5 kg and looks like a single, monolithic shell, thanks to the integration developed during the project, taking full advantage of the extreme rigidity of the composite materials and their design flexibility. Also important was the achievement of the modularity of the project, which allows to obtain most of the components of the different model versions using the same production equipment. Every single part that makes up the monocoque has been designed by the ACRC team with a specific function and produced with three dedicated technologies. With the Aventador, the series production of the monocoque made its debut in the Sant'Agata Bolognese house with an industrial process of the highest quality in which various carbon fiber technologies are used, of which the most important is called "RTM Lambo®", patented by Automobili Lamborghini, which has highlighted important economic advantages of the project compared to traditional autoclave technologies. The decision to produce the monocoque in-house gave Lamborghini a very important cost advantage over its competitors who had similar structures, and which stood at values 3 to 5 times higher.[1]
The front and rear of the central monocoque are connected to aluminum subframes, which have been designed to combine in coherence with the monocoque to absorb the energy generated in the event of a front or rear impact, and on which the engine, transmissions and suspension are assembled. The entire frame weighs only 229.5 kg and offers unprecedented torsional rigidity with an excellent result of 35,000 Nm per degree of torsion. This engineering solution is able to guarantee and meet the performance

demands required for a super sports car like the Aventador, which led to the extraordinary lap time at the Nürburgring.

Figure 5 Lamborghini Aventador time attack at Nürburgring in 2018

In 2013, the European Patent Office (EPO) in Munich, Germany, asked Lamborghini to exhibit the Aventador's Rolling Chassis, as an example of an innovative project that has led to numerous patents. The collaboration with the EPO has lasted for many years and has led Lamborghini to file numerous patents on innovative Aventador technologies and processes based on carbon fiber, such as the Forged Composite®, the CarbonSkin® and the CarbonFlex® and others under development.
Undergoing development since 2008, Forged Composites® is an advanced composite material. After more than thirty years of research carried out around the world, Lamborghini is introducing Forged Composites® with a single goal: to give major impetus

to technological innovation in composite materials and raise them to a level that had never been reached until now. Record performance and an original appearance are revolutionizing everything that came before: the era of Forged Composites® has begun.
With Forged Composites®, Lamborghini takes the lead in technological innovation in the automotive world. Technical properties unthinkable up to now and a completely new molding process are the elements that make Forged Composites® the cutting edge of composite materials.
The application of Forged Composites® to Lamborghini supercars has opened up the potential for exploring new scenarios in the automotive world: integrated geometries, maximum flexibility and molding cycles that are just 3 minutes long. But that's not all: the avant-garde beauty of Forged Composites® shows how this material has huge benefits to offer in terms of aesthetics and not just for its technology and performance.

2. Inside the factory: welcome to CFK centre

Since 2010, with the creation from scratch of the CFK plant (Carbon Faserverstärkte Kunststoffe, equivalent of English CFRP), all the knowledge acquired in the field of composites has been implemented in a production center capable of performing the "mass" production. *"The CFK plant represents: the future of supercars, the present for Lamborghini"*. Above the last decade, CFK underwent significant transformation, some of which are still under planning and yet to be realized.

Figure 6 Automobili Lamborghini CFK centre in 2010

Year 2010 marked, therefore, an epochal turning point, a step forward for Lamborghini, because with the opening of the new centre it was decided to start producing cars in which carbon fiber is the master and the focus has been on the development and production of the product par excellence available to each customer. Instead, in 2011 the world assisted to the take life of the Aventador, whose special details have been highlighted in the previous chapters.
In other words, this Lamborghini flagship consists of a unique shell in which the roof and floor (tank) behave like a single body capable of transmitting a feeling of solidity out of the ordinary, but also a control, reactivity, and steering precision unique compared to competitors as well as a very high degree of passive safety.
In summary, the advantages deriving from the wide use of carbon ensure that you can achieve unique weight/power ratios resulting in enhancement of performance (both in acceleration and braking) in addition helping the drivability. Also, the "side effect" of reduced consumption and pollutant emissions, allows you to devote the right attention to a theme that over the years has become increasingly of primary importance.[2]

Carbon fiber has a specific resistance up to 6 times greater than metal alloys (e.g. aluminum alloys), it is almost completely recyclable, has great corrosion and fatigue resistance, as well as high flexibility in the realization of complex forms starting from a few subassemblies (think that the before F1 in carbon consisted of only 5 blocks against 50 of one in metal alloys).
On the other hand, CFRP materials have very high production costs, due to especially to the fact that the production processes are strongly manual. Here's the reason for to which research in recent years is aimed above all at reducing the costs of production such as to allow the manufacture of composite products on a large scale.
Therefore, CFK is not a department that deals only with production, but based on the perspective of continuous improvement realizes process engineering, optimizing day by day the technologies, materials and plant equipment used. This is also made possible thanks to continuous contact with suppliers, who are involved from the early stages of design and development of equipment and materials.
The creation of new types of fibers has allowed the production of components with low-cost technologies, it is a a clear example is the production of visible carbon pieces with RTM technology in replacement for the more expensive manual lamination. Concerning this fact, with the CFK, the costs of production of monocoques have been made competitive with other conventional technologies. Lamborghini can boast thirty years of experience in the world of composites and especially in carbon fiber, for this reason the Bolognese company is the only one manufacturer in the world able to guarantee the entire process of the fiber of carbon, from simulation, to design, production, testing, quality control and repair.
So, after the extraordinary success achieved by the life cycle of the Lamborghini Aventador, the tests that present themselves at the CFK become increasingly challenging and the new Lamborghini Revuelto, with its carbon components, new weight target and hybrid engine is nothing more than a new incentive to overstep those limits that from time to time seem more and more impossible to overcome.

2.1 Lamborghini's CFK centre today

With the latest Lamborghini Revuelto LB74x project, the need arose to expand and strengthen the current CFK, new work areas and above all new systems were needed for the construction of the new supercar. This CFK ADAPTATION has also had a great influence on the startup plan. In fact, the installations and expansion works have suffered strong delays that if not kept under control could have compromised the pre-established ramps upstream of the project.

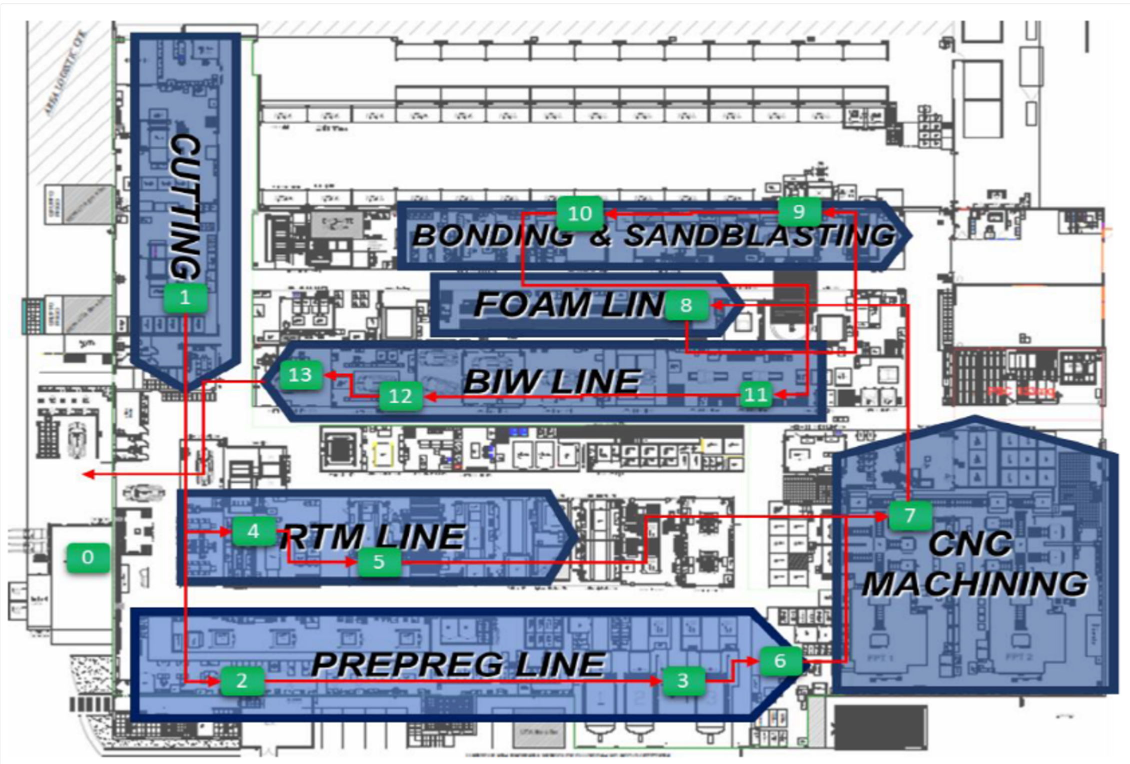


Figure 7 CFK production flow plant

The main change of the new layout was that the Body in White Line had a dedicated plant, built in front of the current CFK to allow the exchange of Assemblies that are

automatically and efficiently pasted. The Foam line has disappeared, the warehouse has been reduced in order to allow the installation of new CNC machining centres, press systems and the new Climatic Room dedicated to carbon preforming.
The bonding area has been expanded to allow accommodation of the new Robots as it has become a fully automated process, a completely new aspect since for the Aventador this process was carried out manually.
Finally, new overhead cranes and flags have been installed to help operators handle components and molds during their work.

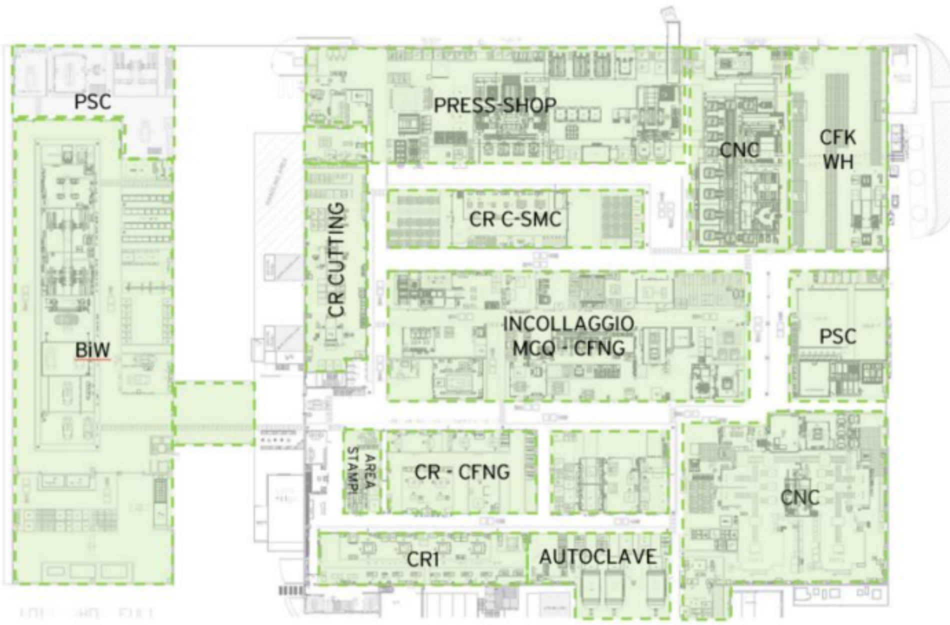


Figure 8 CFK production plant evolution

Obviously, the Adaptation process has been carried out in such a way as not to block the current production, taking advantage of holiday periods for the most demanding changes and carrying out work in parallel with production whenever possible.

In the next chapters there will be a brief description of the processes that will be carried out in the new CFK and of those that characterize the production process of the roof of the new Lamborghini Revuelto, in order to allow the reader to understand the work behind only one of the 11 components made in the headquarters of Sant'Agata Bolognese.

Figure 9 The latest Lamborghini Revuelto

3. CFK's Production process & plant equipment

As already discussed above, Revuelto has implied innovative new production processes that have never been used in the history of automotive to produce structural parts for serial cars. The following will be described and listed to understand how some of the components of the latest Lamborghini project. *Process information subject to patent resolution will be omitted.*

3.1 Cutting line

The materials used in the processes arrive at the company in the form of rolls. Afterwards, they are stored in a cold room located outside the CFK. At the time of need are brought inside the Climatic Room which, for reasons of technological constraints of the materials, must guarantee a controlled temperature of about 20 ± 2 °C and systems of adequate suction.

The Climatic room contains three cutting machines that work independently of each other, their operation is ultrasonic and completely automatic once the component cutting program is loaded into the management of each machine. The phase that precedes the cutting process is the "Nesting" process, from which we try to optimize the number of templates that can be extrapolated from each roll of material. The templates are nothing but the projection in two dimensions of the parts of the mold, which in turn copies the shapes of the final piece. The number and size of the templates depend on both the dimensions reported on the project both by the shape and complexity of the mold.

In principle the number of templates increases as the complexity of the piece increases, and therefore the mold itself, since it is necessary to release the material at complex shape changes such as very narrow radii of curvature, edges, etc. In such a way, problems of stretching of material are avoided, as well as accumulations of resin and areas with absence of resin.

Obvious is the consideration that as the number of templates increases, their dime decreases dimension. The templates obtained are grouped into "kits" that contain all the materials that are used to make a certain component. Once the kits are ready are distributed by logistics workers to the process line in which the same component will be realized.

Figure 10 Cutting machine

3.2 Pre-preg line

The Pre-preg line, also called "Autoclave Line" begins inside the Climatic Room 01 where the process of Roof lamination takes place.

The Prepreg process line comprises three main stages:

- ➢ Lamination
- ➢ Autoclave care
- ➢ Extraction and Recovery

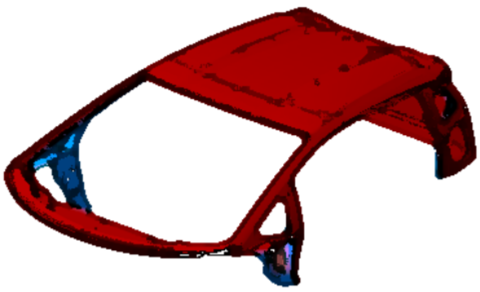


Figure 11 Lamborghini Aventador's roof

The first phase takes place inside a Climatic Room as during the process requires a controlled temperature that is as constant as possible, as the Material templates are pre-impregnated with resin and the latter is very sensitive to temperature variations; in fact, above 22 °C it may be too sticky and at temperatures below 18 °C too little malleable to allow the operator a good arrangement of the material on the mold.

At each mold, the operator has an arrangement of a material mix kit, intermediate empty kits, compaction kits and the necessary PPE which he will use during this phase of the process. The lamination phase consists in stratifying the carbon layers, previously cut, wrapped and inserted inside the "Roof templates kit".
This operation is carried out manually by trained operators who, with the help of special cutters and spatulas, distribute the ply trying to get a good adherence on the mold reaching even the most difficult points near corners or edges. To make a correct positioning of the materials, the operators have available Ply Books, *i.e.* a list of instructions supported by descriptive images.
These processes, being manual, represent an added value for these supercars. The templates are "off set" with respect to the size of the mold to avoid uncovered areas of material due to a succession of errors in positioning them on the mold. The stratification of the ply is designed with the aim of obtaining pieces that from a structural point of view meet target requirements and that are free from defects, such as porosity and air bubbles.
Precisely to avoid the onset of these defects, "intermediate voids" are carried out during the lamination that exert a uniform pressure allowing the compaction of the layers in order to guarantee a good adhesion between the templates and the mold and therefore a hardening of the homogeneous resin during the autoclave treatment. Once the last layer of the "Lay-up" of the component has been arranged, we proceed with the last compaction vacuum accompanied by a longer stop under vacuum. Following that, there is the autoclave treatment phase that allows the polymerization of the resin and then the solidification of the component through cycles specifically designed in relation to the result to be obtained. Normally a cycle is composed of an ascent ramp in which there is an increase in both temperature and pressure, followed by a treatment phase, where the compaction of the resin takes place and the attenuation of tensions residue, and one of post care. The post care consists in further heating the material and then cool it to room temperature in order to maximize the elimination of residual tensions.
In the Autoclave the material, which is already vacuum-packed, is exposed to a pressure greater than the atmospheric one, this in order to obtain a high degree of vacuum that guarantees a perfect mold-material adhesion. Thanks to the use of Nitrogen is possible

to obtain an inert atmosphere inside the Autoclave that reduces the occurrence of dangerous situations such as fires, which on the contrary would be much more common with the presence of Oxygen.

In the CFK centre of Automobili Lamborghini, three autoclaves are available.

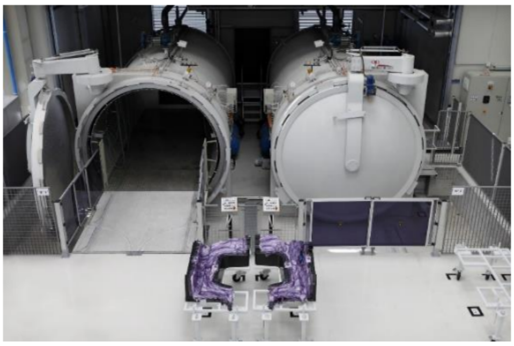


Figure 12 CFK's autoclaves

At the end of the treatment cycle, the mold from the Autoclave is collected and expected to be completely at room temperature to proceed to the next step of extracting the component. The mold is separated from the solidified piece, and the latter will then be taken to another area of the CFK waiting for is finished and machined with machine tools.

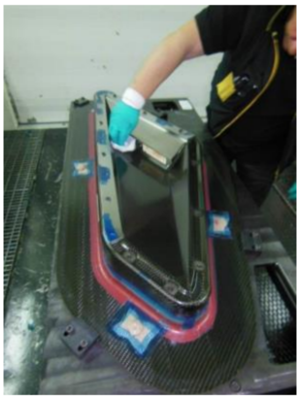


Figure 13 Mold restoration

While the Mold undergoes the "restoration" within a fan cabin as it will be necessary to use chemicals that, although essential for cleaning, emit vapors and fumes that need to be knocked down. The residues of polymerized resin are removed from the molds by utilization of compressed air and teflon spatulas. If present, also any dowels are restored with the same tools and finally, a layer of release agent (also on containment stops, bushings and screws).

At the end of the restoration phase, the molds are again made available to the lamination process in special dedicated spaces both inside and outside the Climatic Room.

3.3 Press moulding line

This production process is certainly a novelty in the automotive world. Figure 3.3.1 illustrates the material creation process short fiber used in this process.

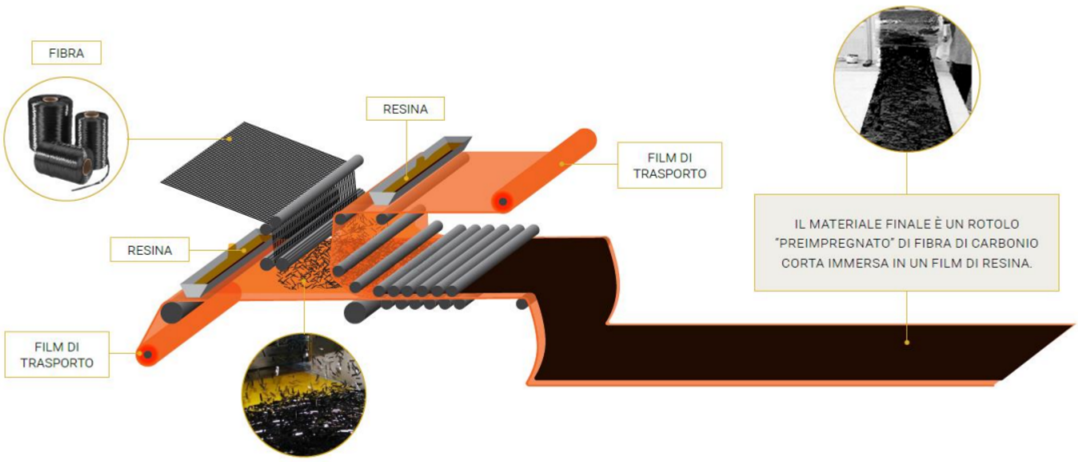


Figure 14 Pre-preg short fiber material creation

It begins from a pre-impregnated UD carbon fiber which is chopped into tiny pieces and placed in the middle of two layers of a particular type of thermosetting epoxy resin. The layer thus obtained is pressed by a series of rollers that release as the final material a roll of pre-impregnated short carbon fiber, immersed in a resin film that acts as a matrix.
This characterizes the raw material that arrives in CFK and that must undergo the cutting operations described above. Lamborghini has focused a lot on this material starting from the "Sesto Elemento" and since then has patented an advanced form of this material called "Forged Composite" with extreme resistance and workability properties, with the possibility of being able to be processed even for high volumes and even with properties not only structural but also aesthetic.
Let's now define the fundamental steps of this process.
At first, the carbon sheet cut into templates must be preformed on molds that allow the distribution as precisely as possible of all the layers necessary to create the desired "lay-up". This takes place inside a climatic room with controlled environment and temperature. In Figure 15, the introduced steps have been highlighted.

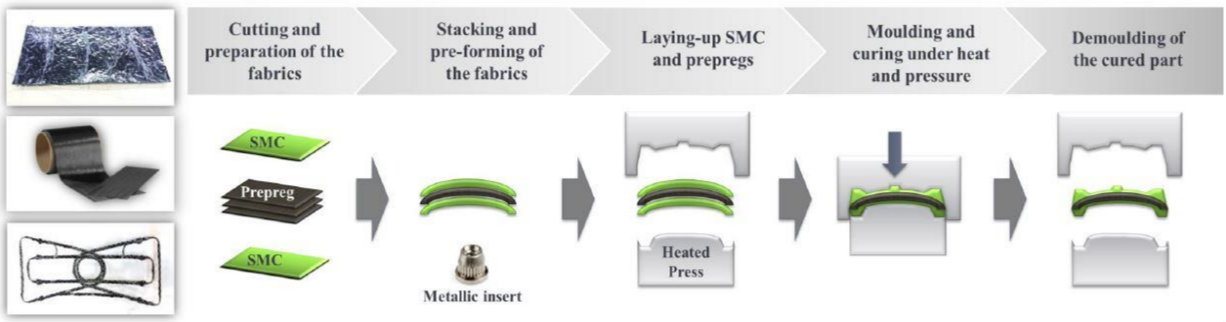


Figure 15 Press moulding process steps

Once assembled is finished, through specifically built trolleys, the preforms end up inside the press which, depending on the mold that will mount, will release a different component after a cycle time of about 30-40 minutes for all its phases: opening, workpiece loading, press closing, reaching care temperature and care time, opening robotic extraction press through a robot with gripper at the ends and positioning on the conformer, which will allow the extracted piece to cool down maintaining the correct shape, without giving in to shrinkage tensions.
Three presses will be installed, each of which will produce in batches until a period of mold change that will take place at the end of the working turn shift and needs little more than an hour to be completed. In Figure an example of a simplified layout of one of the presses that is actually installed inside the CFK Press Shop.

3.4 CNC, grinding and sandblasting lines

Once the piece has been removed from the mold, it requires trimming and elimination of burrs, but also of drilling and cutting. The machine tool department in the Old layout was characterized by 2 5-axis machining centers; with the advent of the new Revuelto and with the increase of components to be processed Lamborghini has strengthened the department inserting a new robotic machining center. It is important to minimize the exposure of operators to composite powders, and the use of CNCs as well as avoiding this exposure makes these phases of the production process faster and above all repeatable. Both before and after the machining phase there are areas of buffers that allow you to decouple material flows. In the machine tool the Elements perform one or two steps.

In the case of the roof after the first step to carry out the trimming, it is not necessary to return to processing, while the tank undergoes two processing rounds, first alone loose piece just produced and then after becoming "red tank" with all the parts that compose it (for example the spars) and the inserts glued after the bonding process. Grinding is a surface treatment dedicated to the removal of possible defects both in terms of aesthetics and tolerance while sandblasting (which it can be either manual or robotic), prepares the surfaces for the next phases of gluing and installation of small parts.

3.5 Bonding line

The last operation that leads to the creation of the monocoque is the bonding phase. The first gluing concerns the red parts on the green tank, and these give rise to the "tub red" or "Assy Tub". At this point the Assy Tub will be brought back to the ward machine tools to carry out a machining again.

The bonding lines occupy a certain amount of surface that must be previously finished and degreased. Obviously previously the components that must be glued undergo a sandblasting process, which allows the resin to have an optimal surface for the purpose of gluing. The new car has introduced the concept of robotic bonding; in fact, two new plants have been installed inside the CFK plant, one dedicated to MCQ and one to Cofango. In Figure 16 we can see the three robotic gluing stations MCQ.

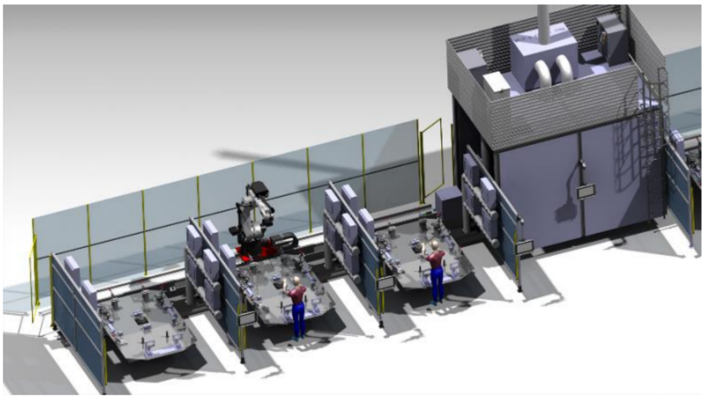


Figure 16 Bonding plant equipment layout

The reason why you want to adopt such an entirely automated bonding process concerns the fact that it will allow us to obtain repeatable and optimized processes from the point of view of glue consumption and time through the entire phase. It is important to underline how essential and relevant this phase is, as it is precisely on this that the structural solidity of the entire cell depends.

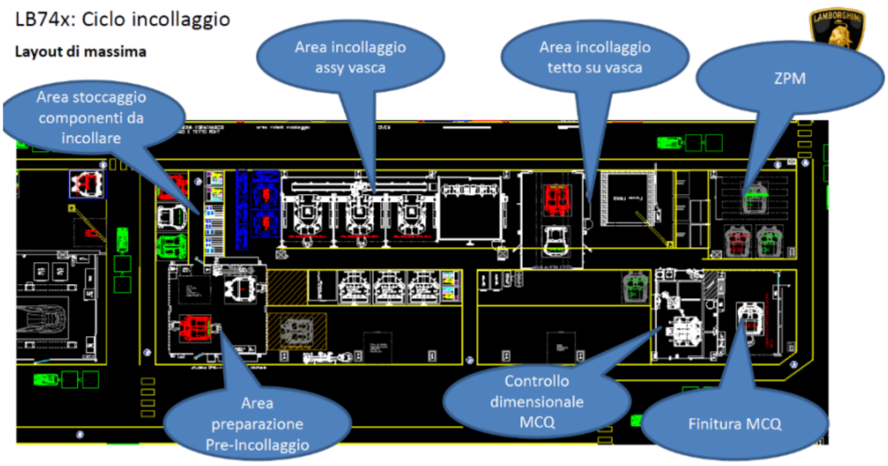


Figure 17 CFK's bonding MCQ layout

All these maneuvers take place through the help of bonding masks that allow not only to have a stable and repeatable process, but also to be able to adjust and adjustments before the monocoque finishes its care phase after passing through the oven. In order to verify the correct positioning of the elements, checks are carried out through a 3D measurement. This process has limitations related to the technological constraints of resins and other substances used. In the figure on the side, the layout of the MCQ gluing area of the LB 74x.

3.6 Quality inspection

When making cars like a Lamborghini, prestigious and of interest to a small range of people, attention to small details is indispensable.
Especially in the Start-up phases, it is important to carry out checks with a frequency of 100% on each component, in order to be able to refine and optimize the processes arriving at the SOP with components that respect the dimensional and aesthetic targets. Initially, the dimensional control is carried out only by the CFK Quality Department but, once we start with mass production, we sensitize and train the production operators so that Quality controls are carried out less and less.
During the checks, checks are carried out to ensure:

- ➢ Suitability of WAGENPRÜFKARTE (WPK) and its correct compilation; Yes it is a documentation that certifies that all phases of the production process, including the personal details of the employee who carried them out. It also contains any anomalies found during the process or rework that a component has suffered, as well as the outcome of the final resolution;
- ➢ The integrity of the laminate: characterized by a visual inspection that prevents the presence of porosity, swelling, breakage or scratching;
- ➢ Aesthetics of the piece: it is also a visual inspection, with the aim of certifying the goodness of the piece from an aesthetic point of view.

Quality control takes place at certain "check points" and at defined times of the process: ZPE, ZPM and ZP5.

In ZPE the control of the parts in carbon look, mainly aesthetic, takes place. Defects such as inclusions, fiber distortion, fiber defect, visible markings (due to bonding or carbon layers), excessive accumulations of resin, incorrect lamination of materials.

In ZPM 100% of the monocoque produced arriving from the upstream gluing process. As a first step, the suitability of the WPK is verified then any problems had during the process and any rework. The integrity of the laminate and aesthetics of the components are also evaluated.

In ZP5 the completed Body in White is placed under the light tunnel and a last check is aesthetics that games and profiles are carried out. If everything is *OK* the last one is released deliberates and the Body can move on to the next steps outside the CFK.

For dimensional checks are used the GOM and the DEA, where the first represents an optical instrument that uses a scanner to carry out dimensional control of smaller components;

while the DEA is the instrument used for dimensional control of Green Bath, Assy tub, Roof and MCQ, it is a tactile coordinate machine that performs checks on RPS (Reference Point System), i.e. systems of reference points established together with the Prè-series in the conceptual design phases.

In figure, the Quality Check Point on the Body in White assembly.

Figure 18 Quality control checkpoint

4. ***MAINTENANCE 2023***: my training on plant equipment management

From now on, the focus will be on the specific role played by me in the Technology & maintenance department inside Automobili Lamborghini's CFK centre. The entire evolution of this work was based on organizing not only maintenance activities in terms of proper proactive operations on plant equipment subassemblies, but also on coordination and problem-solving activities which will lead to better reliability of the entire production process for future perspectives.
At this purpose, it is crucial to introduce the "core concept" of the new maintenance organization inside the CFK department during my stageur period: the definition of TPM.
TPM (Total Productive Maintenance) represents a maintenance strategy based on the idea that everyone operating within a facility should participate in the maintenance of machinery and production plants, helping the maintenance team to do their job in the best possible way.
In this sense, more than a maintenance strategy, Total Productive Maintenance (TPM) represents a real philosophy, a global approach adopted by a company with the

common goal of continuous improvement, thus creating the conditions for optimization of work, the reduction of waste and the achievement of the highest levels of efficiency.
The term TPM, Total Productive Maintenance, refers to a set of activities aimed at the prevention and continuous improvement of business processes, especially through the involvement of operators who run machinery and plants in simpler maintenance processes that require fewer skills compared to those required of a real maintainer.
The TPM, like all active maintenance policies, tries to solve the problems related to the decrease in the performance of machines and plants. The objective of Total Productive Maintenance - TPM is therefore to increase general productivity by optimizing the availability of equipment and processes involved in production.
The particularity of the TPM compared to other maintenance and analysis policies, such as Root Cause Analysis, lies in the fact that total productive maintenance involves the entire company, at every level. This is a fundamental fact to understand the importance of TPM and how it can reduce waste, avoid failures, productivity losses, reduce environmental impact and much more, in what is defined as a continuous improvement process.
However, we often run into a very common misunderstanding: that of considering TPM as a methodology linked solely to the maintenance of machines and systems. It is not so. Total Productive Maintenance is a process capable of involving all aspects and roles related to company management.
The main objectives of TPM Total Productive Maintenance are:

1. Reduction of unplanned maintenance interventions: Through careful planning of scheduled maintenance, it is possible to significantly increase the life cycle of our assets and avoid - in addition to unexpected stops - even small losses in productivity due to micro stops not attributable to real machine downtimes and which is not always easy to keep track of except with CMMS or EAM maintenance software.

2. Reduction of machine stops: Increasing the number of planned interventions, scheduled maintenance and preventive maintenance leads to a decrease in the

number of actual machine stops. By implementing proactive maintenance strategies, breakdowns and downtime are minimized.

3. Reduction of production costs: By improving the OEE (Overall Equipment Effectiveness) production costs are reduced. An increase in production leads to higher profits and reduces expenses due to equipment failures and repair times, as well as those of rework of products that do not conform to the standards established by the company.

4. Improvement of occupational safety: Since TPM is based on the 5S method, the workplace must be systematically organized and clean (Straight and Shine are the two Ss involved, but we will see better in a moment). This is important to improve the efficiency of the maintenance team, discover new issues and ensure a suitable working environment.

5. Optimization of resources: Starting from the maintenance team, the TPM makes it possible to involve the whole company within the maintenance processes, freeing up resources so that the technicians can concentrate on maintenance interventions for which greater skills are required.
As already mentioned at the beginning of this article, in the TPM philosophy, anyone within a company can participate in the maintenance processes, starting from the top management up to the workers who work on a given plant. In fact, everyone is called to make his own contribution.

• Top management: in the very concept of TPM, management should be involved by promoting, in addition to a cultural change (absolutely necessary for a correct approach to Total Productive Maintenance), also all those preparatory activities for continuous improvement, through the imposition of an actual corporate policy that takes this into account. Furthermore, through the analysis of the data recorded and organized through a CMMS software, it is possible to generate important metrics and establish KPIs whose monitoring can provide valuable insights into our production and maintenance processes.

• Operators: Technicians and operators are those who work most assiduously on a machine or plant. For this reason, they should be responsible for the daily operations carried out on the machinery, such as cleaning or lubrication necessary to ensure the health of the plant. Furthermore, it is reasonable to expect that they are the first to detect signs of malfunction or deterioration and report them to the maintenance department.[2]

• Maintenance managers, supervisors and technicians: These figures are responsible for the maintenance of company assets. It is therefore necessary to continuously monitor metrics and indicators (such as MTBF – Mean Time Beteween Failure, or MTTR – Mean Time To Repair). The monitoring of these metrics represents a fundamental aspect for continuous improvement, since it makes it possible to develop, choose and perfect the most effective maintenance strategies for each asset, increasing their availability and efficiency (and therefore also production levels) in full compliance with the principles from which the TPM philosophy moves.**[3]**

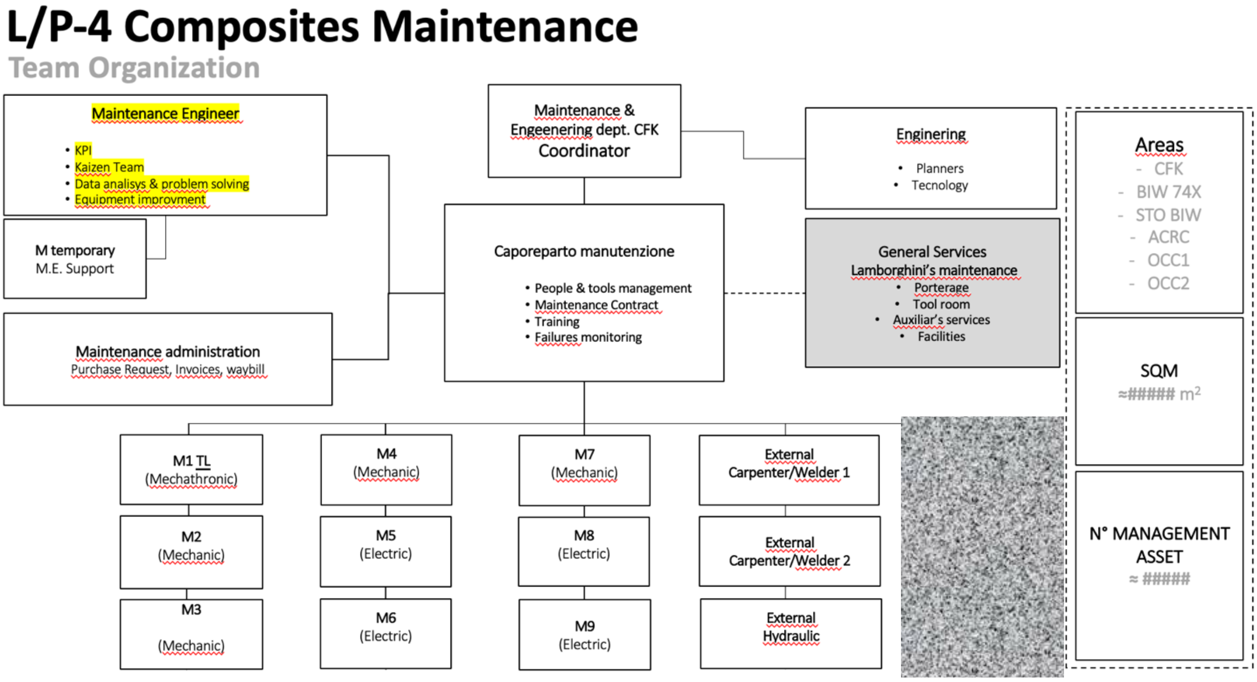


Figure 19 Composites maintenance team organization scheme, highlighting my working area

4.1 Our concept of "maintainability"

To start in a useful and clear way I want immediately to point out what a failure is considered when dealing with production process:

Failure: events that stop the attitude of an entity to perform a specific requested function

The failure condition is generally determined on the basis of two main aspects:

Who or what has caused the failure?

- Design (lack of consideration of some effects)
- Production (lack in respecting design specifications)

- Usage (inappropriate usage)
- Ageing or wear out

How did the failure occur?

- Instant break
- Accumulation of deployed services (wear out)
- Relaxing (increasing of failure probability due to the failure of other components)
- Combination of causes

Of course, it is worth pointing out that failure event can be considered as an intrinsic property of every machine. However, what really matters is to be ready for this to happen repairing in the fastest and in the best possible way (we will often refer to this specific topic under the name of “proactive maintenance”).
For these reasons some approaches must be done to ensure to easily detect and fix any problem that may occur during the normal use of the machine.
This is not only related about the usage and maintenance after installation, in fact, to be effective, we must think about it since the first design of the machine itself that must be done in according in a proper way letting it to be maintainable.

The design aspects are obviously demanded to the supplier in according with the technical specifications provided by the various planners before the order.
Then, after the installation, the maintenance, together with the supplier service will be in charge to keep it able to work.

Here comes the core of this thesis, and so the investigation and implementation of solutions to improve the maintenance efficiency in CFK, shortening as much as possible the Mean Time to Repair (MTTR) and so the Total Time of Stop of a machinery.

To decrease the amount of total stop time that I've in a certain period, and so improve the Machinery efficiency, I can work on three different cluster of actions:

- **Restoration / Fixing:** this include all the actions that are settled down to reduce the stop time once a breakdown failure occurs improving the maintenance team skills to let the machine quickly come back in normal operation status. Here we find actions focused on the improvement of the maintainers skills as trainings as definitions of procedures but also management actions as setting up well stored set of spare parts and tools for every operation (SMED) that becomes crucial to minimize the time wasted in looking for what is needed to repair a certain failure. A real example of how I improved it can be found in *Chapter 4.3* where I will describe the benefit of a training that I organized to bring inside the company some restoration activities usually demanded by the external supplier, and in *Chapter 5* where you will find a new solution based on augmented reality that let the maintainer to have the machine's supplier support without need for him to come in the company.

- **Machinery improving:** That include small action on specific components that are directly or indirectly involved on failures and so machine stop, as well as machine's revamping.

They are usually exploited together with the machine supplier since will include new design and, depending on the type of action, also a new ISO and a CE certification.
Also, they are generated by luck of design or wrong utilization of the machine, and it is common in the first year of utilization since most of the machines in CFK are custom made machine.

- **Preventive:** this last action is related to the analysis of past failures to identify and plan, scheduling with a defined periodicity, preventive actions that can be done to avoid them to show up again.

4.2 Maintenance management in Lamborghini

As in every company, also in Automobili Lamborghini the maintenance is well organized with a clear procedure that defines responsibilities and operating methods. This is necessary to quickly react when a failure occurs and provide a complete documentation about what has been done and who did it that will become very useful for further analysis.
Starting from the internal division, we can see the maintenance divided in three branches:

- Maintenance on production plants (MIP):
  This branch manages all failure maintenance, preventive and predictive activities on production process plants inside the Lamborghini site.

- Maintenance on Utilities (MEP):
  This branch manages all failure maintenance, preventive and predictive on Utilities systems as hot & cold water, compressed air, electricity, air conditioning, water treatment, air handling units and vacuum systems.

- Infrastructure Maintenance:

  This branch oversees maintenance management of the plant infrastructure as fixtures, walls, plasterboard, false ceilings, furniture, green areas, painting, roads, parking area, roof and infiltrations, bathroom accessories and internal and external flooring.

The maintenance on production plants, the one of interest in this thesis project, can be described by analyzing the four milestones on which it is based and how they are managed. We refer to the Breakdown Intervention, Preventive maintenance, the Autonomous Operator Maintenance and the machine diary, the instrument used to report machines failures and resolutions.

4.2.1 Breakdown intervention management

A soon as a blocking failure occurs, the RR (*Responsabile Reparto / Department Manager*), must promptly report to maintenance, by telephone call to the internal emergency number and subsequently fill in the machine's diary.

In case of a non-blocking fault, the RR must open a ticket from maintenance on the Lamborghini Portal.

At this point, the RMI (*Responsabile Manutenzione impianti / Plant Maintenance Manager*) or the TLM (*Team Leader manutenzione / Maintenance Team Leader),* after receiving the report, goes, if necessary, to the indicated area. A diagnosis is performed by evaluating the priority and impact of the machine stop with respect to the needs of the production process.

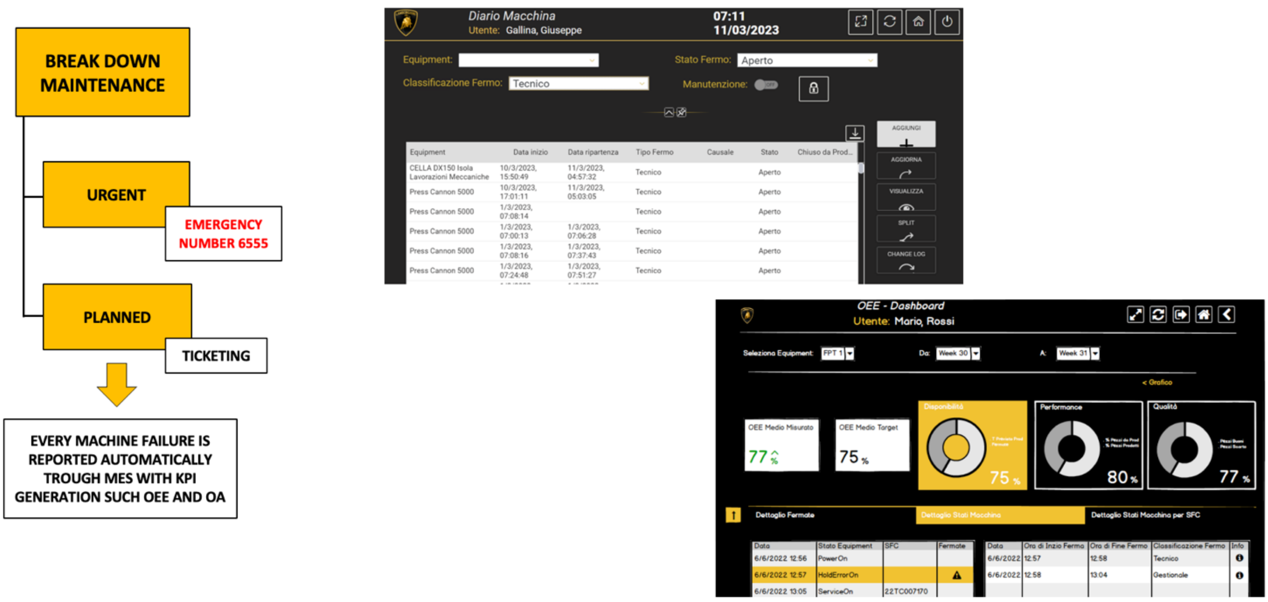


Figure 20 Breakdown maintenance intervention schematic representation

The intervention planning evaluates various strategy, availability of internal or external resources and of spare parts, for a short time resolution.
Completed the blocking intervention, the RMI or TML compiles the machine diary while in case of a non-blocking intervention, RMI and TLM closes the ticket indicating internal or external resource, time spent on the activities and any notes. This will generate a mail to the one that opened the ticket to notify the resolution, while other details can be seen on the SAP portal (the Lamborghini ERP).

4.2.2 Preventive maintenance management

Breakdown interventions are often needed but, especially in case of blocking ones they are very expensive for the company since turns into production (and so economic) losses.
To avoid as much as possible those interventions many preventive actions are carried out on process plants, utilities and equipment.

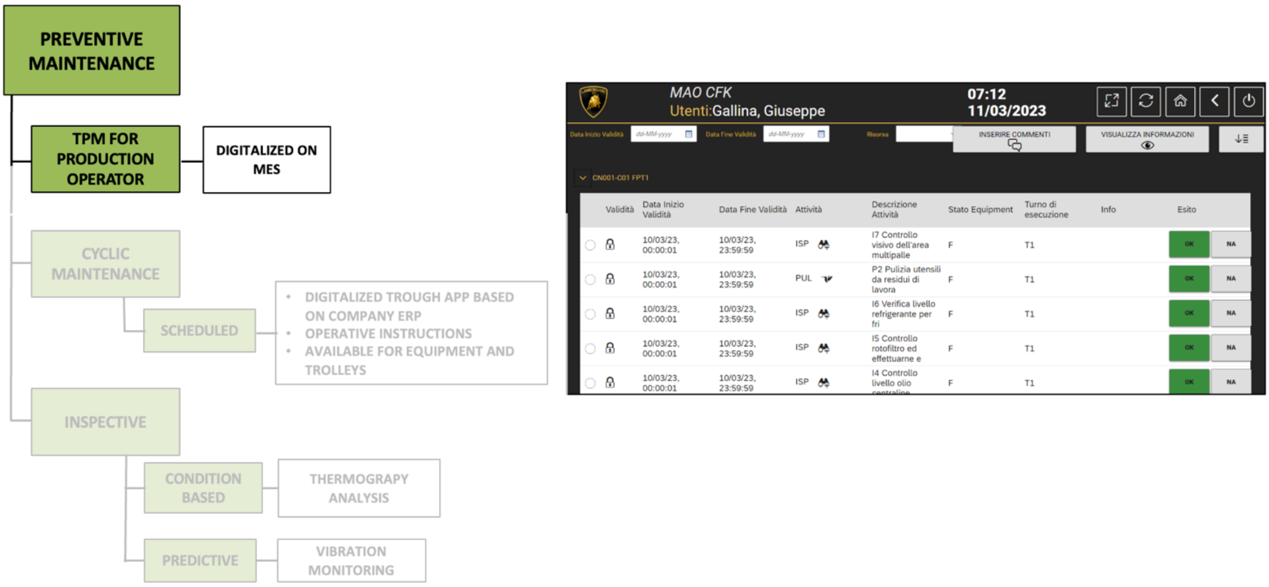


Figure 21 Preventive maintenance intervention MES digitalization

On process plants and utilities, preventive maintenance involves planned interventions, defined either through the consultation of the user maintenance manuals through the detection of failures. The list of activity to be done and their frequency are defined by the Manufacturing engineering department and provided to the technical services one.
This list takes in consideration also the machine ageing, introducing extra and new preventive checks and countermeasures with the time passing.

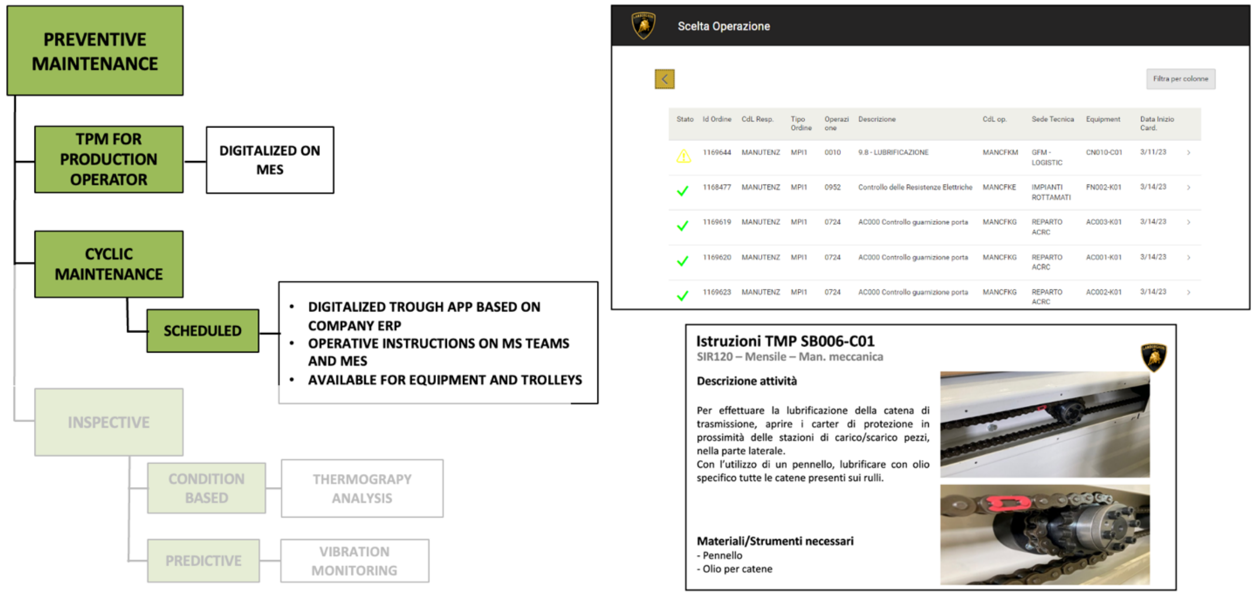


Figure 22 Preventive maintenance intervention MES digitalization

Once those activities have been defined, the maintenance engineering creates work cycles assigning the activities to internal or external personnel, defining execution times, attaching specific documentation where necessary, and spare parts needed to then schedule a work plan with a specific frequency.
Even if are supposed to be done punctual, for plant or utility availability needs, the planned activities can be anticipated or postponed but not as wish. In fact, for the effectiveness of the intervention, it's important that the closing date falls within a predefined tolerance.
All those activities once carried out are then commented and grouped on a shared register with noted associated to describe better what has been found while performing the activity.

4.2.3 Autonomous Operator Maintenance (MAO)

Another important type of maintenance that I want to point out is the so-called MAO (*Manutenzione Autonoma Operatore /Autonomous Operator Maintenance*).
Autonomous maintenance is defined as a maintenance strategy in which machine operators continuously monitor their equipment, adjust and perform minor maintenance on their machines. This is done instead of assigning a maintenance engineer to implement it at regular intervals.
Autonomous maintenance is the first pillar in the total productive maintenance (TPM) strategy. An operator trained in self-service has a thorough understanding of routine actions such as cleaning, lubricating, and inspecting. This strategy requires operators to take responsibility for their equipment and the surrounding area. This is done by bringing the equipment to 'as new' cleanliness and maintaining this standard, by ensuring that operators are trained in the appropriate technical skills to conduct routine inspections, and by establishing a standardized self-inspection programme.
Autonomous maintenance follows two fundamental principles:

- Prevent the deterioration of the equipment through specific operations.
  Carry the equipment and maintain it to a state of "like new", through proper maintenance and management;
- MAOs are generally specific visual control activities that are performed by the operator/conductor of the plant. On site we can see the list of activities in paper format and must be acknowledged by the operator before the start of the shift putting its identifier stamps on each task after having performed it.

The MIP is responsible for entering the operations and frequencies indicating by the manufacturing engineering and printing the MAOs monthly.
The new cards are then deposited by the maintainers on the plant on the last working day of the current month and collected on the first working day of the following month.
The line operator must carry out the checks within the times and frequencies indicated on the MAO, confirming the activity with its individual stamp.

If during the schedule, anomalies occur, the line operator must inform the RR who then will open a ticket for the maintenance indicating the department, plant, and anomaly.
In the next figures, some examples of MAOs developed during this working period have been highlighted. Particular attention must be given to the fact that, for the new MAOs schedule, activities were divided into two main subgroups:

- Inspection: activities indicated with capital letter *I* and highlighted in red;
- Cleaning: activities indicated with capital letter *P* (i.e. *"pulizia"*) and highlighted in green.

Figure 23 Inspection (left) and cleaning (right) indicators for MAO activity number

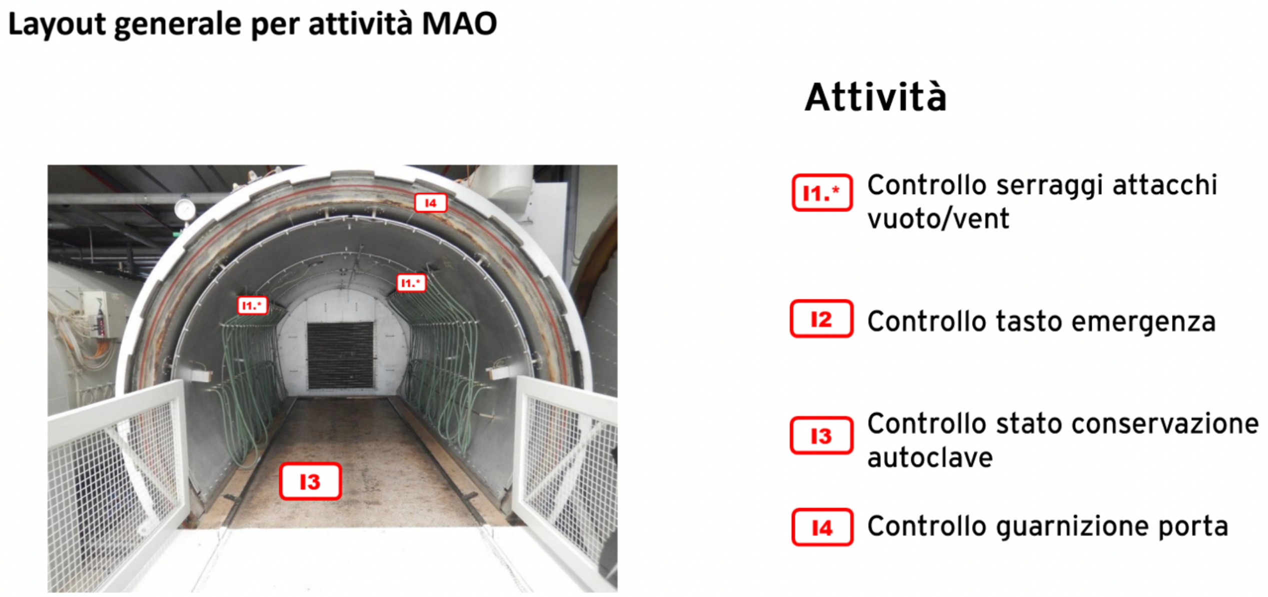


Figure 24 Example of general layout for MAO activity on autoclave line

Figure 25 Example of inspection activity guideline and defined periodicity on CNC plant

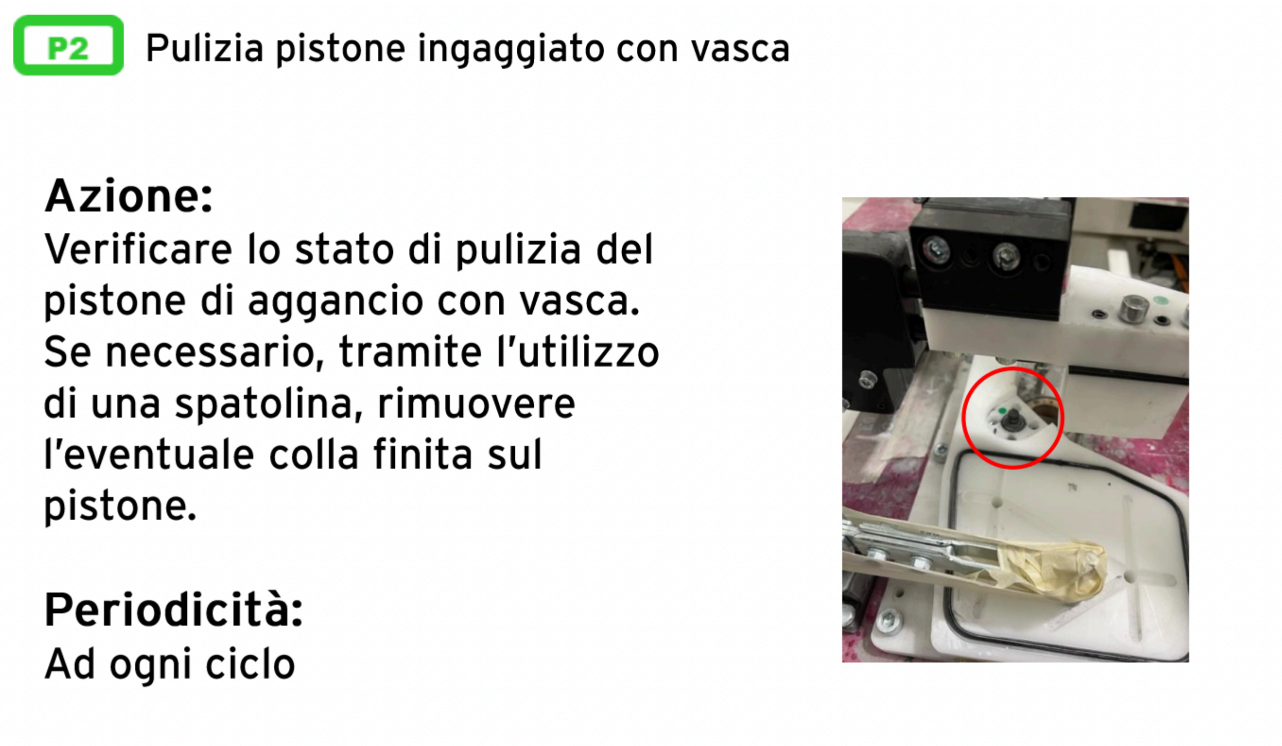


Figure 26 Example of cleaning activity guideline and defined periodicity on bonding plant

4.2.4 Scratch: The machine diary

Another crucial aspect which has contributed to the development, efficiency and reliable organization of Lamborghini's CFK maintenance is related to machine diaries, their function, and their organization. The Machine Diary is a powerful tool used to indicate all the stops to breakdowns, management stops or anomalies on critical plants. It can be in paper format, as the ones that we can find today in CFK, in electronic format.
Once the plants have stopped, the RR or TL check the type of severity, fill the following fields in the machine diary dedicated to the critical system indicating Date and stop start time, fault description and time of maintenance call, if its intervention is needed.
At this point, after a call for maintenance by RR or TL, the plant will be taken over by maintenance which will carry out, analyzes and actions to resolve the fault. After

resolution of the fault, maintenance will complete the compilation of the machine diary with stamping or with a signature of the open machine diary and adding some notes regarding the procedures done for the resolution.
In case of resolution by the production itself and so without the need to a call for maintenance, the completion of the open machine diary with stamp/signature will oversee the RR or TL.

The Plant maintenance manager will then collect the machines diaries the first day of the working week to be transcribed on a database and then processes to extract various reports and OA (Overall Availability) and OEE (Overall Equipment Effectiveness) to be sent to production and maintenance managers.
The right and clear completion of this diary is essential to have the maintainability history of the machine taking trace of all the past failures and implement proper preventive operations that will allows to save time and money.

4.3 The Bathub curve

Now that the maintenance management in Automobili Lamborghini has been described, we can move to the so called *Bathtub Curve*.
This curve is often used by reliability specialists to describe the lifetime of a population of products related to the hypothetical failure rate.

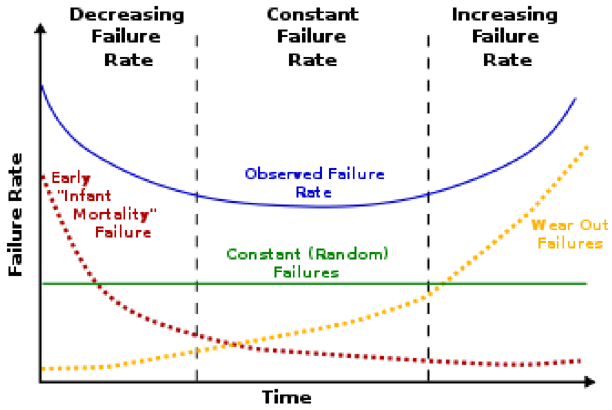


Figure 27 The Bathub curve

It divides the product's population lifetime in three different periods. The first one that we found is the *infant mortality* period with a decreasing failure rate, then a *normal life* period where the failure rate is relative low and almost constant, going then to the *wear out* at the end of the life where we have an increment of the failure rate.
Failures during infant mortality are *highly undesirable* and are always caused by defects and blunders: material defects, design blunders, errors in assembly, underestimation of the machine signals or wrong utilization by the production operators and so on. Normal life failures are normally considered to be random cases of "stress exceeding strength", while for the wear-out, it is a fact of life due to fatigue or depletion of materials.
The graph in the picture above is generated by mapping together those three different behaviors. This is a general model and not every product strictly follow it, especially cause some intervention can be done to attenuate, for example, the wear out time or increase the speed for which the infant mortality time reach its minimum, together with a reduction of the entity of the constant rate that we have in normal life period.

4.4 Maintenance "definition of service metrics" 2022/2023

During my traineeship period, maintenance organization has been rescheduled and subjected to specific guidelines to better cooperate with other divisions, such as Preseries and Production.

All the activities, duties, specifications, and service metrics have been defined on a new Service-Level Agreement (SLA) stipulation. A service-level agreement (SLA) is a contract between a service provider and its customers that documents what services the provider will furnish and defines the service standards the provider is obligated to meet. Service providers need SLAs to help them manage customer expectations and define the severity levels and circumstances under which they are not liable for outages or performance issues. As an introduction, the purpose of the document in question is to identify and share the rationale and guidelines that will regulate the maintenance service within the CFK by explaining the KPIs adopted as well as their calculation. Within this document, a description of all the management of activities with their modality can be found (autonomous, breakdown, preventive, predictive and proactive maintenance) both for the systems than for equipment.

Also, three further documents have been attached to the SLA, respectively concerning CFK's general plant equipment, a preventive maintenance plan and a plan of porterage and technical cleaning assets, in which the detail of the single activity is presented.

MAINTENANCE GOALS

Within the SLA, it is then defined the purpose of our 2023 maintenance team:

Optimize plant production capacity by minimizing unplanned downtime impact production

PERIMETER

The general perimeter of analysis in this preliminary project definition is that of all the systems and equipment present within the CFK and BIW and will be divided into 5 macro-classes subsequently analyzed:

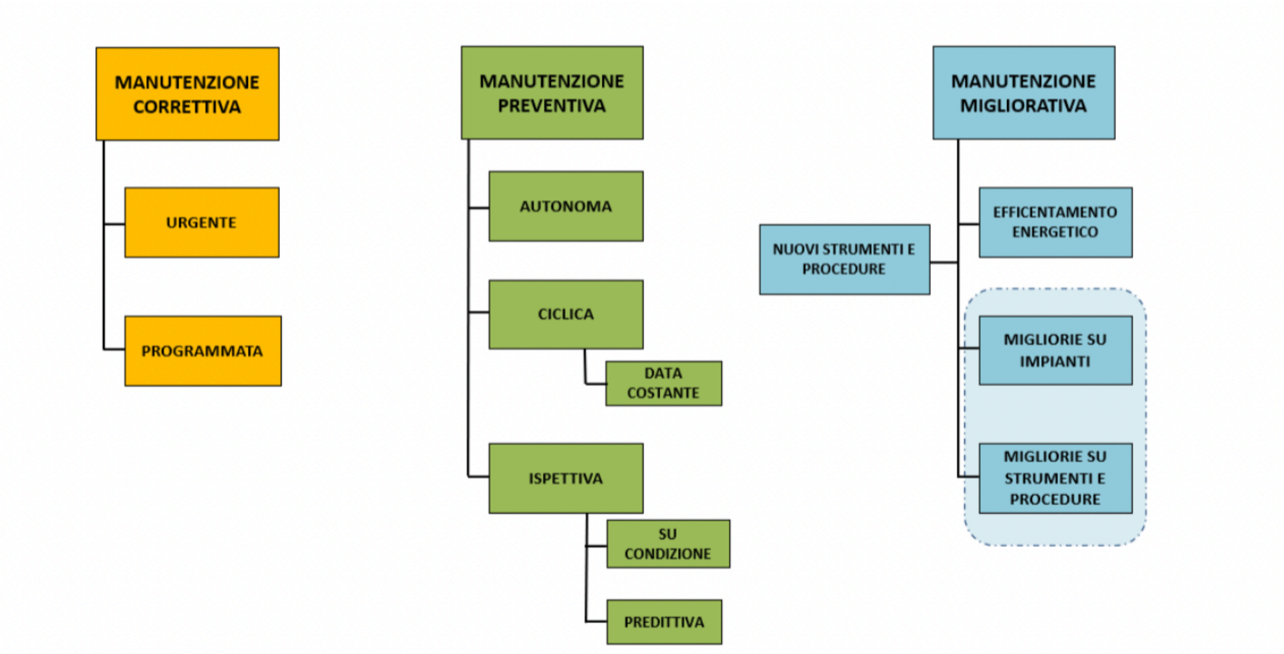
- Complex systems connected to MES;
- Plants not connected to the MES;
- Generic equipment;
- Specific equipment subject to calibration/dimensional checks;
- Measurement tools.

PROPOSED KPIs

The KPIs that our department undertakes to monitor and share on a monthly basis are the following:

- OA;
- MTTRestore;
- MTTRepair;
- MTBF.

MAINTENANCE MANAGEMENT ON PLANTS



CORRECTIVE MAINTENANCE

Corrective maintenance is divided into two subcategories:

- **Urgent**

  For corrective maintenance on process plants and equipment, refer to the unique number ####.

  The call will follow a system based on three levels:

  - Level 1 (first x seconds): Simultaneous call to maintenance TLs;
  - Level 2 (subsequent x seconds): Simultaneous call to all maintenance technicians;
  - Level 3: Department Manager and Maintenance Engineer.

- **Scheduled**

  Use of the Composite Maintenance ticketing system of type K1 (Intervention on plants and K3 (Generic Services)

  Following a call to maintenance to manage a repair, the support of the production operator at least for the initial phases of the intervention (Diagnosis) in order to speed up the understanding of what happened and the consequent resolution.

PREVENTIVE MAINTENANCE

It is divided into three macro-categories described below:

- **Autonomous estimate**

  They include the MAO activities shared with production department and included in the MES system.

- **Cyclic estimate**

The marked activities are divided by type of plant and dedicated resource (electrical maintenance technician/mechanical maintenance technician/generic maintenance technician) and represent the maintenance plan for the periodic activities on a constant date.

In order to guarantee the application of the maintenance plan and consequently compliance with the standards of plant availability, an adequate number of plant hours available to perform the activities described.

Below is a summary of the times required to perform the activities divided by resource and system updated on 01.06.2023.

The times present in the files and tables below are expressed in minutes and represent the necessary time of ACTIVE work without finding anomalies that lead the intervention to transform in off-standard / repair. Outline activities such as the preparation of the material and the. necessary equipment will have to be considered separately according to the type of intervention.

T_{fermo} means that the activity must be carried out with an emergency and/or dedicated system only for maintenance activities.

On the other hand, with T_{attivo} we mean both activities that can also be carried out with the plant in operation and those that need the plant in operation.

Preventive activities also include those assigned by external and non-external personnel explained in the attachment and in the summary tables below. These activities including maintenance and calibrations/calibrations will be organized as much as possible within company closures. In case of impossibility to take advantage of the planned closures, the activities will be agreed with Production department with at least two weeks' notice or in any case with the greatest notice possible.

MACCHINE UTENSILI PRESSHOP

FPT PRESS.	Generico		Elettrico		Meccanico		Pulizie/Facc	
	T_{attivo}	T_{fermo}	T_{attivo}	T_{fermo}	T_{attivo}	T_{fermo}	T_{attivo}	T_{fermo}
Setimanali	0	120	0	0	0	0	0	190
Mensili	20	75	5	0	10	0	0	60
Trimestrali	0	30	0	0	0	30	0	0
Semestrali	0	60	180	300	10	420	0	0
Annuali	0	270	0	0	0	960	0	120
Totali	200	6060	410	600	120	1920	0	8320

Figure 28 Preventive maintenance downtime total estimation for FPT presshop plant equipment

CONDITION INSPECTIVE MAINTENANCE

All the activities that are carried out remain outside the cyclical preventives described above necessary following a signal from the system (e.g. signaling of agreed filters).

Maintenance control cycles are envisaged for the verification of these signals but it is in any case, the production operator is required to signal any alarms on the panel, even if non-blocking, which can lead to maintenance activities on the system.

INSPECTION WITH THERMOGRAPHIC CAMERA

All the activities that are found to be necessary as a result are present in maintenance on condition of a thermographic analysis with NOK ("not okay") result. The planning of the activities that emerge as a result of these checks will be agreed with the department heads.

PREDICTIVE MAINTENANCE

The objective of predictive maintenance is to warn in advance of the occurrence of a fault that can become blocking allowing the planning of its return action.

At the moment this system is present on the fans of the autoclaves and the Fan Cabins inside the CFK plant.

Upon notification of possible damage resulting in maintenance action extraordinary necessary, Maintenance will contact the department head of the affected area to organize the intervention.

EQUIPMENT MAINTENANCE

Breakdown maintenance on technical trolleys:

Breakdown maintenance is applied to all technical trolleys present in CFK and BIW and managed in the manner under following procedures:

- Opening ticket K1 indicating the type of problem encountered
- Signaling of the trolley through colored tags indicating the severity:
  - Red: blocking fault, the trolley cannot be used → structural damage
  - Yellow: non-blocking fault → e.g. damage to non-structural surfaces

The tags must be positioned at the rudder to facilitate its detection by maintenance.

TYPES OF RETAINERS

TECHNICAL STOPS

All cases in which the plant is unable to fulfill its requirements fall within the technical stops works because an alarm or maintenance status persists

Planned technical shutdowns:

Planned technical shutdowns include all those plant shutdowns resulting from a construction activity preventive/scheduled maintenance within the plant opening times and which are not "CYCLIC type" with duration of less than 30 minutes. Therefore, these are internal and/or supplier interventions of the system that cannot be programmed outside the system opening hours occur without a predefined periodicity. All scheduled activities whose duration is greater than 2 hours will be excluded from the system opening time. If a planned activity of this type exceeds the downtime declared and subtracted from the opening of the system, the remaining time will be attributed to a technical stop. In order to consider a stop outside the system opening time, it must be communicated at least 1 week in advance by maintenance department indicating the date and time of intervention as well as the description of the same. For each outage exceeding one day of work (3 shifts) the notice must be at least 1 month or in any case as much as possible based on the criticality/need for intervention.

Unplanned technical shutdowns:

Unplanned technical shutdowns include all those plant shutdowns originating from a changeover of status from machine available/at work to machine in alarm, and therefore all those cases in which it comes to minus one or more basic functions of the system.

MANAGEMENT STOPS

All the slowdowns and losses of production capacity that can be improved are included in the operational shutdowns through a better organization of people and resources that take place while the plant is not located in alarm state

Planned management shutdowns:

All those times which, although necessary in order to produce a given component but are not expressed within the theoretical and non-theoretical cycle time are performed in parallel while the plant is working.

These include set-up and format change times as well as cyclical maintenance activities scheduled (MAO and MPI) with weekly, biweekly cycles.

Unplanned management shutdowns:

All those times in which, despite the plant being
available is not fed (No operator, waiting for preforms)

EXAMPLES OF CLASSIFICATION BY TYPE OF INSTALLATIONS

PRESS

Technical stops

- Breakdown maintenance (Internal or external)
- Urgent improvement/***revamping*** activities (If not exceeding x hours and therefore removed from
  PPT)
- Faults on system interlocks (power supply, vacuum, compressed air, etc.)

- Low periodic preventive maintenance
- Mold cleaning
- Unavailability of bridge crane due to breakdown

Management stops

- Planned preventive maintenance (MPI and MAO)
    - in the event of an anomaly found following a MAO or MPI, a technical shutdown will be opened
- Set-up / mold change times
- Awaiting press and/or oven operating temperature
- Lack of preforms and/or technical trolleys for piece loading/unloading
- Absence of operator
- Lack of release agent
- Press stopped for Gripper/Conformator/Frame maintenance
- Unavailability of the bridge crane due to interference

MEETINGS AND ALIGNMENTS

In order to allow the monitoring of the activities performed by the *Composite Maintenance* body they will be set up the following periodic meetings:

Kaizen team

Periodicity: Weekly

Entities involved: Maintenance

On call Technologies, Pre-series, Production

Objective: Technical discussion on downtimes and maintenance activities with a particular focus on those occurred the previous week in order to identify improvement activities through analysis sheets and removal of the root cause

Weekly maintenance meeting

Periodicity: Weekly

Entities involved: Technologies, Production, Head Of

Objective: Sharing of weekly indicators and updating on the progress of work

Monthly technical report on maintenance status

Periodicity: Monthly

Entities involved: Technologies, Production, Head Of

Objective: Sharing of the maintenance activities carried out and in particular:

- Data collection and stop analysis
- Analysis tabs
- Kaizen and improvement projects
- New operating procedures and training

Quarterly plant efficiency report

Periodicity: Quarterly

Entities involved: Maintenance, L/P-4 Technologies, Suppliers of critical plants

Objective: Sharing of the stops encountered in the quarter and of the efficiency (OA) measured in agreements with the maintenance contract and analysis of improvement activities

5. Proposed maintenance KPIs: scratch and MES

In manufacturing companies such as Automobili Lamborghini, machines and work equipment are often exploited and used at the highest levels. If we consider this continuous use over time and at high speeds, we immediately realize that maintenance management is a process of the utmost importance and, as such, must be tackled with the right tools to obtain the best results.

There are different methods to manage maintenance, some more effective than others or simply more suitable in certain situations. Today the most modern way, and the one

that can lead you to the best result, is the use of specialized software instead of the classic machine notebooks (therefore a digital method and, above all, automated rather than manual).
So far, we have seen the theoretical aspect of maintenance management, but... how is it put into practice? Basically, each machine has its own manual which provides all the information necessary to carry out preventive maintenance. Therefore, as a rule, this is what we rely on to draw up a calendar of interventions to be carried out.
Interventions which will then be recorded and dated in the maintenance log.
It's a very basic process, don't you think?
Yet it can become increasingly complex as the number of machines and, for each machine, the number of usable tools increases. Think, for example, of how many molds can work on an injection molding machine, or how many heads on a machine tool!
For each of these things it is necessary to keep wear and tear under control, remember the deadlines for interventions, make maintenance needs coincide with those of production... This is why paper management, which in itself is entirely manual and therefore more subject to errors and oversight, it soon becomes obsolete.
The 4.0 solution to this problem is to use a MES (Manufacturing Execution System) system that can support you, or your managers, in the optimized management of maintenance.
How?
Actually, Through the MES (Manufacturing Execution System) it is possible to collect production data in real time and always keep plant performance under control. The historical data then provides important information to management for calculating production efficiency and evaluating any areas for improvement.
Throughout MES, it is possible to interconnect both recent machines, already set up for Industry 4.0, and older machines, in order to have them all under control.

The MES system project provides for the connection of the machines with the ERP management system that the company adopts without distorting it, rather enhancing it.
MES can in fact be easily integrated with any corporate ERP system.

The experience gained in our projects has led us to develop a WEB portal to allow any person within the company to view the data of the MES system in real time and in a simplified way.
Thus, was born a portal accessible from a web browser and therefore consultable from smartphones, tablets and PCs.
With MES it is possible to view the progress of a plant equipment status, see the work sequence or access attachments (such as drawings, instructions).
Anyone within the company who has access to the portal will be able to enter and view the status of:

- plants, machines, departments, work islands
- Work In Progress (WIP)

With MES you can benefit from an immediate improvement in production efficiency, and you can get the following results:

- Reduction of production throughput time and WIP
- Elimination or reduction of insertion times and **circulating paper**
- Reduction of lead times
- Increased productivity and efficiency
- Better organization of processes

5.1 MTTR

The MTTR (Mean Time to Repair), i.e. the average repair time of a fault, is one of the main maintenance metrics, used to measure the average time needed to repair a plant or a machine.
The MTTR is a fundamental indicator to assess the quality of maintenance operations within a facility. It can also be used to investigate the value and performance of an asset in greater depth to help the maintenance manager make smarter asset management decisions.

Together with other maintenance metrics and KPIs, such as MTBF (mean time between failure), MTTF (mean time to failure) or OEE (Overall Equipment Effectiveness), MTTR is a great starting point to assess asset efficiency and eliminate redundancies and bottlenecks, so that the company can avoid unexpected downtime as much as possible. The MTTR provides a snapshot of what, on average, the intervention times of the maintenance team in response to an unexpected downtime are.

To provide a precise definition of MTTR, we can say that it represents the expected value to the recovery time of a plant or an asset, in which the time represents the interval – usually calculated in hours or minutes – during which the resource remains in a state of unavailability due to a failure.

The MTTR, calculates the time that elapses between the occurrence of a machine downtime and the moment in which the plant / machine returns to be available for production.

This maintenance metric therefore does not take into account the time of procurement of materials necessary to repair the fault, as well as the time of notification of the fault by the operator and the time of diagnosis of the problem.

The MTTR does not include:

- The time to notify a fault/downtime
- The time it takes to diagnose the fault
- The time of procurement of materials

The MTTR includes:

- Repair time
- The set-up time of the plant/machine
- The time of reassembly/alignment.calibration of the asset
- Testing and start-up time

This means that the mean time to repair clock begins to tick when the maintenance technician intervenes and continues until the activity ends and the system resumes working properly.

5.1.1 Three Important Aspects of Mean Time To Repair

To better understand what MTTR represents, it is necessary to always keep in mind 3 fundamental aspects that characterize this indicator:

1. The MTTR is an indicator that measures the times related to corrective maintenance (or in any case reactive to a failure).
2. Since it is the average repair time, it is obvious that the MTTR must be applied to those assets that can be repaired or that we want to repair. In the event that we are faced with assets that are not repairable or that we are not interested in repairing, the indicator we want to calculate will be the Mean Time To Failure (MTTF) or the average time of availability of an asset (we will talk more about it later in this article).
3. Although it may seem a bit surprising at first glance, the MTTR does not take into account the entire time of unavailability of an asset. For example, it does not take into account the time of procurement of the materials necessary to carry out the repair or those of signaling. Otherwise we talk about Mean Time To Recovery (we see it later in the article).

5.1.2 Mean time to repair and mean time to recovery

Although the abbreviation of these two metrics is basically the same, it is important to understand that they are two different indicators.
The Mean time to Repair indicates only and exclusively the time that the maintainer actively spends at work, thus excluding the times of supply, diagnosis, signaling etc.
The Mean time to Recovery indicates the total time of a machine downtime, from the moment of identification of the fault until the system returns to normal operation.

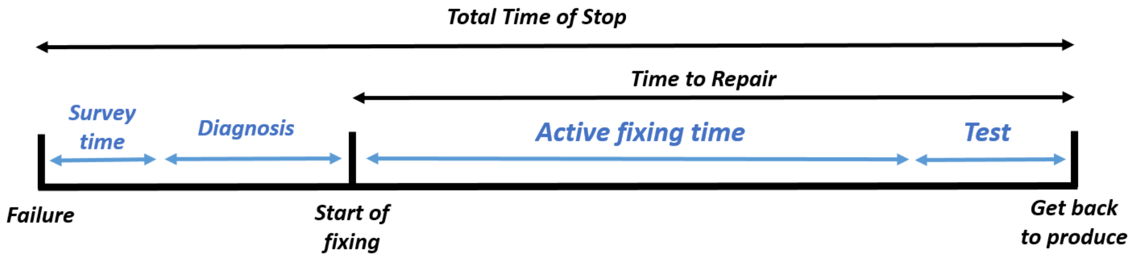


Figure 29 Mean time to repair

5.1.3 The power of data and KPIs' monitoring

Real-time data, its correct storage so that it is easily accessible and the ability to be processed, are vital information for anyone wishing to improve and optimize maintenance operations.

In addition, the opportunity to document work orders, add photos, checklists, interactive lists of necessary materials, combined with the opportunity for technicians to consult this information at any time through their mobile phones, contributes decisively to the optimization of interventions.

The best CMMS also provide the opportunity to historicize interventions, study the causes of failure by performing a Root Cause Analysis in the simplest way, and monitor in real time many of the most important indicators such as mean time between failure (MTBF) and mean time to repair (MTTR), giving a simple and concrete answer to the needs of every supervisor and manager who wants to fully understand the problems and bottlenecks of their maintenance processes.

5.1.4 MTTR formula

The formula for calculating the MTTR is composed of the total time spent on (corrective) maintenance interventions, divided by the total number of downtimes that occurred in a given period.
MTTR is usually calculated in hours.

$$MTTR\ [h] = \frac{Total\ maintenace\ time}{\#\ of\ interventions\ carried\ out}$$

5.1.5 Measures adopted to improve MTTR

Standardization of procedures

Standard and detailed procedures should underpin every effort to improve the average time to repair a fault. It is essential that the maintainer has established checklists and procedures available. Standard procedures provide technicians with a series of actions to be performed sequentially, thus helping them to reduce intervention times.

Canteen & spare parts

Although the MTTR calculation does not take into account the time of procurement of the materials necessary to carry out the maintenance intervention, the availability of spare parts still has an effect on the average repair time.
Adding the necessary materials to the work order helps maintenance technicians to arrive prepared on site, minimizing time and avoiding unexpected events.

Providing adequate training

I will never tire of repeating how important adequate training can be to keep your technicians ready to intervene and reduce the time of the most complex operations.

5.1.6 MTTR calculation example

Some very simple examples of calculating the mean time to repair (MTTR) can be:

1. Let's say that in one month 7 corrective maintenance interventions were carried out caused by unexpected downtime.The total repair time (the actual processing time) is 30 hours. The MTTR will therefore be 4.28 hours.
2. Let's say a pump that stops 3 times within 7 days. The time spent to repair the system (including all three faults) is 2 hours. The MTTR will be approximately 30 minutes.

5.1.7 MTTR vs MTTF

When it comes to maintenance metrics and KPIs, it can be easy to feel overwhelmed by the amount of acronyms.
Although MTTR and MTTF sound very similar to each other, they are not the same thing at all.
We will talk more about this at the end of this article, but for the moment it is sufficient to remember that, while the MTTR is applied to assets/components that can undergo a repair process, the MTTF is applied to components that are not repairable or that we do not want to repair!

But how much should the MTTR be? What, in short, is an acceptable value?
Obviously there is no right answer to this question. Much depends on the type of asset and its age, the criticality it assumes within the production processes, the impact and cost of a downtime.
In any case, as a reference we can take the one indicated by the World Class Standard, which identifies around 5 hours a good MTTR value.
The MTTR indicator is very often used as a basic data for improving the efficiency of operations and maintenance processes (often also associated with the calculation of OEE – Overall Equipment Effectiveness), but also to find new solutions to reduce the number of unexpected downtimes.
Since long repair times, especially on critical assets, translate into loss of productivity, increased costs and production times, MTTR monitoring proves to be an important source especially for finding new opportunities for efficiency and optimization, especially in relation to maintenance plans and asset management choices.

5.1.8 Maintenance MTTR: what does it mean?

Conducting an average repair time analysis (MTTR) can bring various benefits and shed light on maintenance processes.
By relating it to other metrics and KPIs, it can, for example, highlight inefficiencies in material sourcing or in the maintenance schedule.
Ultimately, MTTR is able to highlight inefficiencies that lead to production losses.
But the Mean Time To Repair is also important for making informed decisions, for example when we have to choose whether to repair an asset or replace it (especially in the case of old assets, which often lead to excessively long repair times).
Tracking the MTTR also helps make sure your preventive maintenance plan is as efficient as possible.

Although MTTR is a metric closely linked to corrective (or reactive) maintenance, for assets that have longer repair times they could be associated with scheduled maintenance interventions to optimize production losses.
It is also an important indicator for performing a Root Cause Analysis, helping maintenance managers to trace the causes of failures.
For example, if the average repair time is getting longer, it could be due to a lack of scheduled maintenance or preventive maintenance, or a lack of standardization of these processes.
A technician may receive a work order asking to lubricate an asset, but does not indicate which lubricant to use or in what quantity, leading to further failures.t
But it is by associating this metric with other maintenance indicators that we can reap the greatest benefits. For example, analyzing the relationship between mean time to recovery and mean time to repair we will have an even more in-depth view of maintenance processes.

5.1.9 MTTR and other crucial maintenance KPIs for the study: MTTF, MTBF

We defined MTTR as the mean time to repair of an asset.
Let's now see in more detail how the mean time to repair is associated with other maintenance metrics and KPIs.
If the Mean Time To Repair (MTTR), represents the average time it takes a maintenance technician or maintenance team to repair an asset after a failure occurs, it means that the indicator is applicable only to those assets that are repairable (or that should be repaired rather than replaced).
For plant and machinery that cannot be repaired, calculating the MTTR would be useless and, indeed, impossible).

In the latter case, we therefore speak of MTTF (Mean Time To Failure), a metric in some respects similar to the MTTR, with the difference, however, that, instead of calculating the average repair time of an asset, the MTTF takes into account the average time of availability of an asset.
In simpler words, the MTTF serves to monitor the life cycle of an asset that we cannot or do not want to repair, but simply replace once a failure occurs.

5.2 MTBF

The MTBF (acronym for Mean Time Between Failures) is a very common indicator and reliability parameter in maintenance management and asset management. Describes the mean time between failures, which is the average time expected between the beginning of one failure and the start of the next failure.
Generally measured in hours, MTBF is a statistical indicator that helps plant managers understand what to expect from a machine and better understand the operation of the entire plant. In other words, it is a fundamental value for any reliability analysis.

The MTBF (Mean Time Between Failures) indicator expresses a statistical measurement of the average expected time between two malfunctions.

It therefore represents the average time between the occurrence of one fault and the beginning of the next.

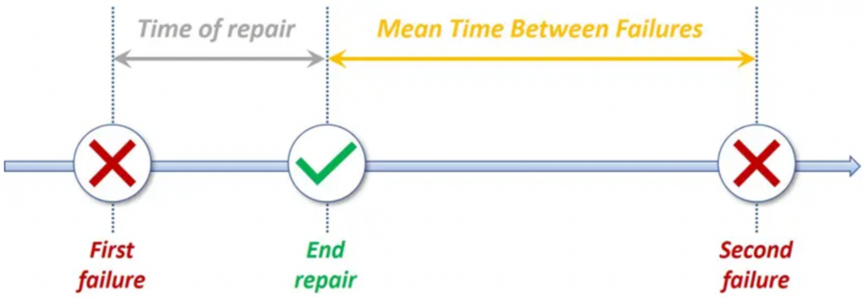


Figure 30 MTBF

As we have said, the mean time between failure represents a time value, usually expressed in hours.

Since the MTBF (Mean Time Between Failure) indicates the operational life of a plant or asset, it is a metric closely related to the calculation of the reliability of plants and equipment, as well as to the metrics used to calculate the operational availability of the machines themselves (OEE, Overall equipment effectiveness).

These characteristics make MTBF one of the fundamental KPIs whose monitoring is one of the key factors to increase the productivity of a plant.

Most often, the mean time between failures (MTBF) is associated with two other important metrics which are the MTTR (Mean Time To Repair) and the MTTF (Mean Time To Failure) respectively the average expected time for the repair of a fault and the average time expected for the occurrence of a failure.

It is important to note that the monitoring and calculation of MTBF is applicable only in cases where repairable assets and equipment are taken into account. If not, the correct metric to use is the MTTF.

5.2.1 How to improve MTBF

Improving the time between two failures therefore means improving the productivity of a plant in terms of operation.

Keeping track of MTBF for the most important equipment or that requires continuous action by the maintainer, allow the manager to efficiently organize and better plan maintenance activities.

The monitoring of the Mean Time between failure indicator is a fundamental element for the correct conduct of a serious plant maintenance strategy, providing us with a statistical measure of how long the asset or machinery can work without suffering unexpected stops. By considering this KPI when drawing up a machine maintenance plan, we can determine more precisely how much to intervene with preventive maintenance measures.
In particular, it can be useful for maintenance operations on condition, through the monitoring of weak signals.

We can summarize the basic steps to follow in this way:

- The first is to make sure that data is collected accurately. For this reason it is important to use specific tools such as CMMS maintenance software, able to store data and organize it automatically within dashboards dedicated to individual assets.
- The second step is to use this data proactively, planning a preventive maintenance strategy based on data-driven choices. Investing time and resources in inspections and scheduled maintenance activities can reduce the number of downtimes significantly, and the average time between two downtimes indicator offers us a fundamental metric to organize work and intervene at the right time to limit slowdowns as much as possible, breakdowns and production losses.[4]

5.3 Overall Availability (OA)

Plant Overall Availability is a key figure that provides information on what percentage of the planned production time an industrial plant has actually produced. It compares whether the actual condition corresponds to the target condition and whether, for example, there have been any unplanned shutdowns. Plant availability is equivalent to machine availability.

The availability of a plant is calculated by determining the actual running time of the plant. To do this, the unplanned downtimes are subtracted from the planned runtime. The actual runtime is then compared with the planned operating time.

$$OA\ [\%] = \frac{Planned\ production\ time - Technical\ downtime}{Planned\ production\ time} * 100$$

Following the KPI analysis introduced below, here is shown a report from cw05 until cw21 highlighting a first aspect of plant equipment in 2023 Automobili Lamborghini's CFK centre. Since this was initially intended to be an "experimental idea", the entire study based on OA, technical downtime and MTBF does not related to the entire centre due to the large amount of data to handle but focuses on the most critical plants as well as the most expensive in terms of maintenance operations. The plant equipment involved in this first analysis are, respectively, the FPT CNC adaption and presshop, a press and finally the bonding plant.[4]

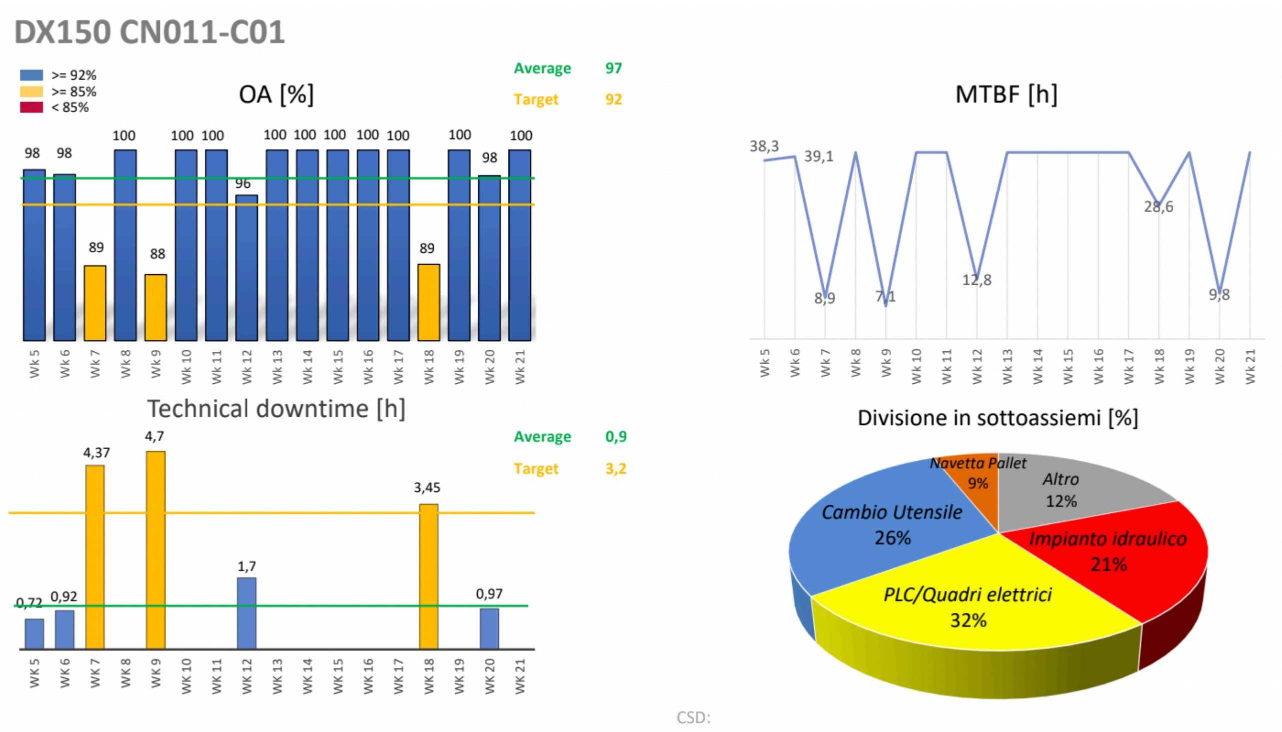


Figure 31 KPI analysis and subassembly percentages concerning total downtime for the FPT DinoX plant equipment

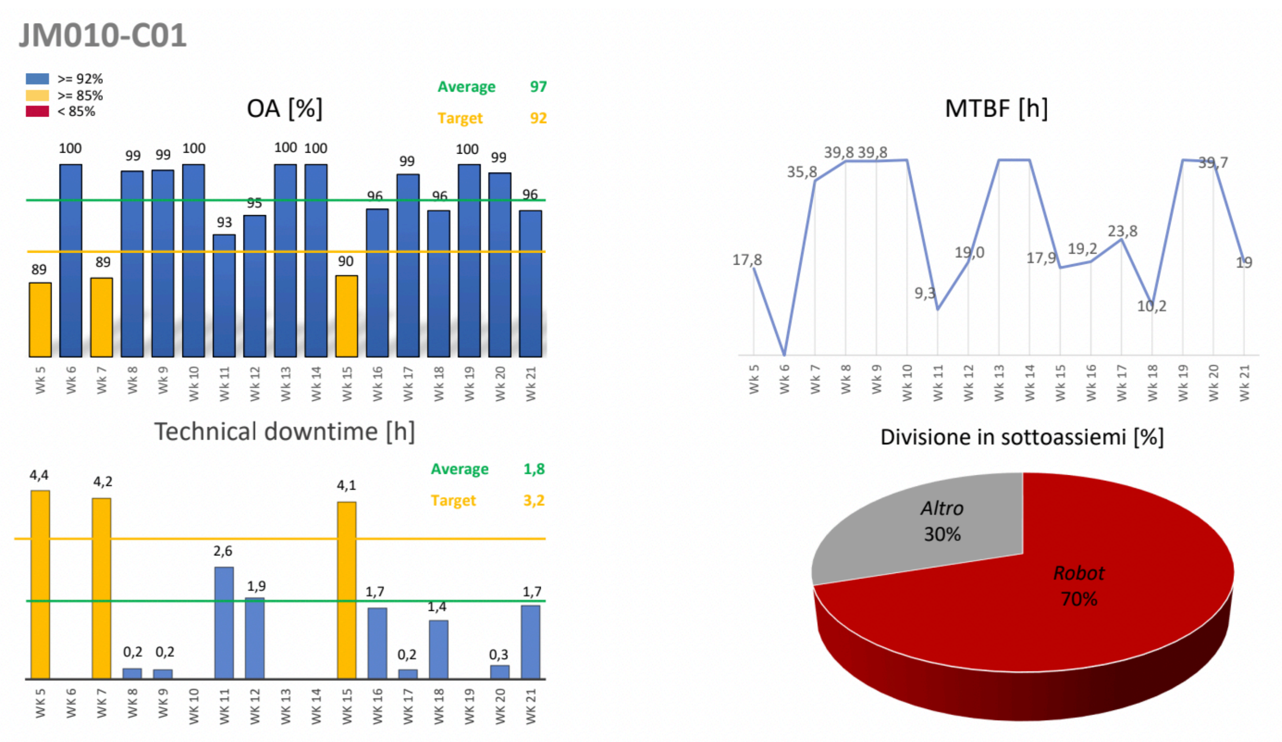


Figure 32 KPI analysis and subassembly percentages concerning total downtime for the SIR bonding plant equipment

6. Analysis tab: management and impact on plant efficiency above the nine-month traineeship period

First of all, it is worth pointing out that keeping maintenance activities documented helps the entire organization to always be updated on the status of the assets.
In particular, managing and organizing preventive maintenance interventions through a maintenance log allows companies to ensure that all machinery is inspected at regular intervals and that it is operating properly, avoiding the risk of sudden breakdowns.
Concerning this fact, an analysis tab contains different information in relation to the asset to which it refers, but generally it is configured as a document that can be divided into two different sections: the first section identifies the general information used to identify the asset as:

- serial number;
- model;
- producer;
- position.

In the second section instead it is possible to find a list of maintenance actions performed on the asset, such as:

- date on which maintenance is performed;
- description of the intervention carried out;
- technician who performed the operation.

For the new 2023 Automobili Lamborghini's CFK maintenance organization, our team has decided that for each plant technical downtime exceeding 0.5 hours (i.e. 30 minutes), an analysis tab must be required.
Following these specifications, in the following figures three cases of maintenance operation registered through the use of analysis tab are shown. Each figure will be

described in terms of root cause analysis and proactive maintenance operation (if possible!).

6.1 CFK's 3D department: issues on part washer "ADA" and 3D printer "POLLY"

My first operating case concerning technical stop and consequent analysis tab was related to the part washer "ADA", present in our CFK's 3D printing department. 3D printing, Rapid Prototyping and Additive Manufacturing are all terms used to broadly describe the same processes, which involve the creation of complex structures and components by the layering of materials which are gradually built up. When parts are produced the resins and contaminants must be removed or they can become permanently attached during the post curing operation. Therefore, the Smart Part Washer – *SPW* "ADA" has the function of cleaning resin and contaminants. Let's now focus on the procedure adopted by the maintenance team considering the described issue. First of all, following the operator's emergency call, the first step was to fill the working order area, in particular:

- Time of the emergency call;
- Time of maintenance team arrival;
- Time for diagnosis;
- Time to eventually look for spare parts;
- Restoration and fixing time;
- Restart and testing trial time;
- End of the intervention process.

Following this first process, the second step focuses on the description of the issue regarding the system. Related to this fact, the washer's display kept showing an emergency banner "hardware problem". At this point, especially through continuous communication and information exchange with the supplier's telemetry, the root cause was attributed to the open rail circuit *24 volts*: more in deep, the current supplied to the

washer showed some peaks which gradually led to the washer's assembly power distribution fail and consequent replacement.
A further inspection, through the use of an analysis tab, is generally made by adopting the "5W+1H" method: what, when, where, who, why and how was the issue caused? Also, in the section dedicated to definition of the problem and root cause analysis, a "5why" method is adopted.
To ensure a better reliability for future perspectives, a solution has been proposed, based on the installation of an UPS unit, in order to avoid further current peaks. What are UPSs? A UPS (acronym for Uninterruptible Power Supply) is an electrical device that compensates for the lack of current, used precisely to put an end to sudden anomalies in the supply of electricity normally used, such as blackouts.

Figure 33 Carbon part washer inside the CFK 3D department

Scheda analisi guasto - Manutenzione Compositi L/P-4

Ordine di lavoro	INTERNAL Data intervento: 29-nov2022	Manutentore: CARBON3D / NOTO / SARDO / DE CAMILLIS	Ora chiamata	Ora arrivo manut.	Diagnosi (min)	Ricerca ricambio (min)	Riparazion e/ sostituz. (min)	Riavvio + test (min)	Ora fine interv.
	Equipment: **PART WASHER "ADA" 5D006P**		28-nov	9.00	/	/	60 min	30 min	10.30

Intervento

Descrizione anomalia

DISPLAY EVIDENZIA BANNER PROBLEMA DI HARDWARE RIFERITO AL CIRCUITO APERTO SULLA RAIL 24V. IL FORNITORE SOSTIENE SIA UN PROBLEMA LEGATO ALLA RETE DI ALIMENTAZIONE

Descrizione intervento

SOSTITUZIONE ASSIEME ALIMENTAZIONE

Ricambi utilizzati

ASSEMBLY POWER DISTRIBUTION 102749-02

Definizione del problema e analisi della causa radice

Analisi 5W + 1H

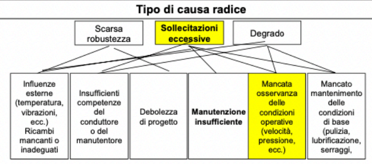
Che cosa (what)	DISPLAY CON SEGNALE DI AVVERTIMENTO
Quando (when)	INIZIO TURNO DI LAVORO
Dove (where)	ASSIEME ALIMENTAZIONE
Chi (who)	ANOMALIA INDIVIDUATA DA OPERATORI SUL POSTO
Perchè (why)	NON CI SONO STATI SINTOMI PREMONITORI
Come (how)	FERMO MACCHINA PER CONSENTIRE SOSTITUZIONE GRUPPO ALIMENTAZIONE

Lista delle possibili cause

1	PICCHI DI CORRENTE INDOTTI AL CIRCUITO ALIMENTATORE
2	
3	
4	
5	

	Verifica delle possibili cause	OK / NOK
1	PRESA IN POSIZIONE CORRETTA	OK
2		
3		
4		
5		

Tipo di causa radice



Analisi dei 5 Perché (5 Whys)-individuazione causa radice

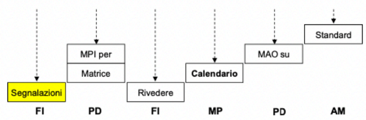
1° Perché	DISPLAY CON SEGNALE DI AVVERTIMENTO
2° Perché	PROBLEMA DI CORRENTE
3° Perché	PICCHI NELLA CORRENTE DI ALIMENTAZIONE
4° Perché	PROBLEMA RETE PRIVILEGIATA
5° Perché	

	Azioni contro la causa radice	Resp.	Quando
1	MONTARE UNITA' UPS		
2	MONTARE FILTRO ARMONICO		
3			

Schizzo (se occorre, usare/allegare altri fogli)

	Azioni per il mantenimento	Resp.	Quando
1			
2			

	Azioni per miglioramento dell'efficienza di intervento	Resp.	Quando
1			



Validazione	Analisi eseguita da (Firma) Verificato da:	**Verifica efficacia**	Verificato da Capo reparto: Firma Ing. Manutenzione:	Data chiusura scheda

Figure 34 Analysis tab compiled for part washer "ADA"

The second issues which will be described in this section concerns a 3D resin printer "POLLY" present in the department.

It is worth highlighting that this issue occurred in the same week of the previous one, and this was another element which helped us to reach the root cause of the problem. In fact, the same emergency banner was shown on the printer's display, but this time the consequent failure was riskier and more unpredictable compared to the previous case. Following a meeting with the supplier, it was recommended to turn of the 3D printer from the general interrupter before proceeding with any inspection. Instead, as soon as the printer was turned off, a 6A fuse placed in the power system suddenly exploded. Fortunately, the subassembly did not seem to be damaged, so a simple fuse replacement appeared to be an effective solution. However, as soon as the printer was turned on again, also the replaced fuse exploded. At this point, again, the implementation of a UPS system was needed, as well as the substitution of the entire assembly power distributor.

However, since we are dealing with different systems, thus performing completely different operation on pieces, a further analysis was required. Concerning this fact, let's introduce the purpose of this 3D printer which is extremely useful to get to the root of the issue.

This printer is a breakthrough resin-based 3D printing process that uses digital light projection, oxygen-permeable optics, and engineering-grade materials to produce polymeric parts with exceptional mechanical properties, resolution, and surface finish. The process allows engineers and designers to iterate faster and radically reimagine their products by making possible consolidated parts, unmoldable geometries, and software-tunable lattices.

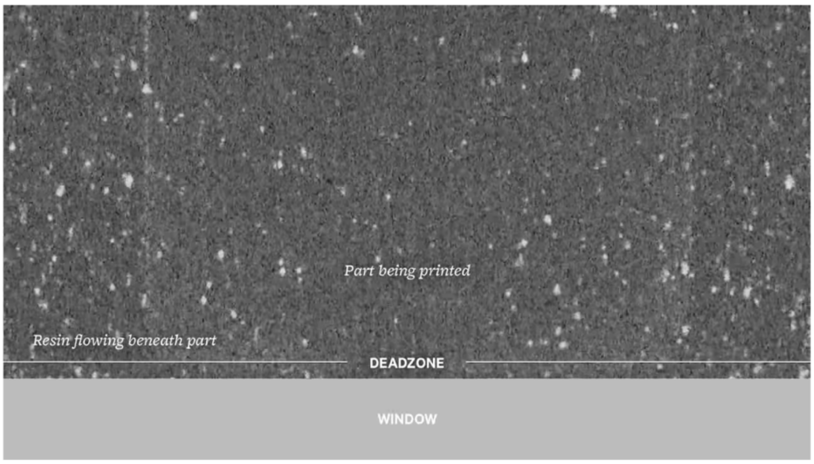
A: Build Platform, B: Resin, C: Oxygen Permeable Window,D: Dead Zone, E: Light Engine

The process is driven by a Continuous Liquid Interface Production™, or CLIP™. CLIP is a photochemical process that cures liquid plastic resin into solid parts using ultraviolet light. It works by projecting light through an oxygen-permeable window into a reservoir of UV-curable resin. As a sequence of UV images is projected, the part solidifies and the build platform rises.
Carbon® and Lamborghini produced a new textured Fuel Cap and a clip component for an air duct for Lamborghini's Super SUV, the Urus, first introduced in 2018. Carbon Digital Light Synthesis (DLS) technology uses light and oxygen to rapidly produce products from a pool of resin. The DLS equipment uses over-the-air software updates combined with connected, data-centric hardware and advanced materials to enable designers and engineers to produce products that previously could not be made, both economically and at mass scale.

Figure 35 Fuel Cap and a clip component for an air duct for Lamborghini's Super SUV Urus

6.1.1 Oxygen-permeable optics

The heart of the CLIP process is the "dead zone"—a thin, liquid interface of uncured resin between the window and the printing part. Light passes through the dead zone, curing the resin above it to form a solid part without curing the part onto the window. Resin flows beneath the curing part as the print progresses, maintaining the "continuous liquid interface" that powers CLIP and avoiding the slow and forceful peeling process that is inherent to many other resin-based printers.



Here is where the core of the problem comes out: what is the purpose of the oxygen subsystem?

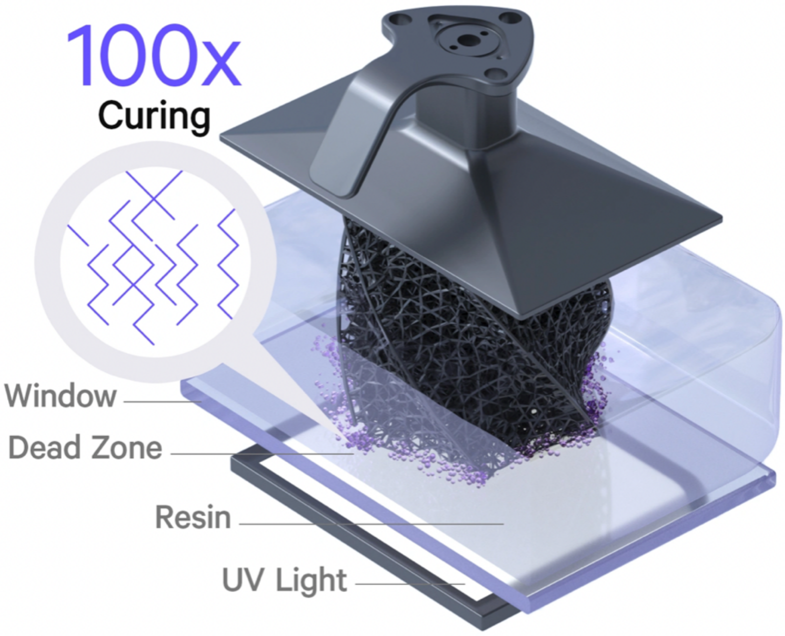
OXYGEN INHIBITION

Actually, the majority of light-curing adhesives in 3D printing are acrylic-based. The challenge is oxygen inhibition, i.e. oxygen reacting with the surface layer of the product as it cures. Oxygen inhibition can result in the surface of the adhesive or coating feeling "sticky" after curing.[5] Because oxygen inhibition is caused by cures conducted in open air, there are several solutions that have been explored:

- Increasing the cure temperature;
- Changing the type of material or the wavelength of the light;
- Introducing a physical barrier between the part and the air;
- Curing the part in a low-oxygen, closed environment;

6.1.2 A case study: monitoring oxygen levels due to supplier alert

Automobili Lamborghini was alerted by the supplier's remote telemetry that oxygen concentration supply was critical. Following this consideration, I needed to monitor oxygen levels for some 3D printing iterations, and I had the opportunity help. The simulation was to verify low oxygen levels during an empty resin 3D printing of plastic components. In order to ensure the creation of high-quality parts, the idea was to perform iteration with empty build platforms. In addition to verifying the accuracy of the humidity, heat and gas levels inside the chamber had to be constantly monitored. Monitoring the oxygen level is especially important: in particular, it is worth underlining the isotropic difference of parts printed on the platform is due in part to the dead zone. In this small region, a thin layer of oxygen prohibits curing closest to the window with its effect falling off to zero at ~20 µm from the surface of the window. Liquid resin begins to intersect and cure along the z-axis as light escapes the oxygen layer of the dead zone. SLA technology plastic components for automotives can take over 10 hours to print: to maintain a low oxygen level, nitrogen or argon is constantly pumped into the chamber. A single air leak or a failing oxygen supply can result in part worth hundreds or thousands of dollars to be ruined, only to be



discovered after the long printing process is complete. Since the insufficient oxygen supply has been a controversial repeated issue in Lamborghini's CFK centre, the necessity for a radical maintenance proactive action was needed. At this purpose, since the UPS implementation could not be considered sufficiently effective, the latest idea was to implement an external oxygen supplier, not only for "POLLY", but also for the other 3D printer present inside the department. This consideration was made based on the fact that there was a further gain in terms of reliability, since, following some simulations with the supplier, the external subassembly looked to be less affected by current peak. Concerning this fact, even in the case in which the UPS is not able to mitigate "unexpected" current loads, this event would less influence oxygen supply using an external subassembly, therefore ensuring continuous production process and diminishing scraps. The most important feature to point out is that, following the maintenance operation adopted in these two cases, no issues have been detected anymore relating to the 3D department in terms of power supply.

Scheda analisi guasto - Manutenzione Compositi L/P-4

INTERNAL

Ordine di lavoro			Ora chiamata	Ora arrivo manut.	Diagnosi (min)	Ricerca ricambio (min)	Riparazione/ sostituz. (min)	Riavvio + test (min)	Ora fine interv.
	Data intervento: 28-nov2022	Manutentore: NOTO / SARDO / CARBON3D / DE CAMILLIS							
	Equipment: **STAMPANTE CARBON3D "POLLY" M2568 5G00WT**		22-nov ore 16	28-nov ore 14.30	60 min (22-nov)	/	60 min	20 min	15.50

Intervento

Descrizione anomalia

DURANTE LA FASE DI SPEGNIMENTO DELLA STAMPANTE, TRAMITE INTERRUTTORE NERO POSTERIORE, SI E' VERIFICATO LO SCOPPIO DI UN FUSIBILE POSTO NELL'ASSIEME DELL'ALIMENTAZIONE. UNA VOLTA INDIVIDUATO E SOSTITUITO, ANCHE IL NUOVO FUSIBILE E' SALTATO, QUESTA VOLTA DURANTE LA FASE DI RIAVVIO

Descrizione intervento

SOSTITUZIONE ASSIEME ALIMENTATORE

Ricambi utilizzati

ASSEMBLY POWER DISTRIBUTION 102749-02

Schizzo (se occorre, usare/allegare altri fogli)

Definizione del problema e analisi della causa radice

Analisi 5W + 1H

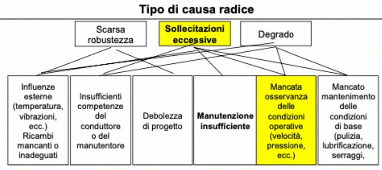
Che cosa (what)	FUSIBILE
Quando (when)	FINE TURNO DI LAVORO
Dove (where)	GRUPPO ALIMENTAZIONE
Chi (who)	ANOMALIA INDIVIDUATA DA OPERATORI SUL POSTO
Perchè (why)	NON CI SONO STATI SINTOMI PREMONITORI
Come (how)	FERMO MACCHINA DI 168 ORE FINO A SOSTITUZIONE GRUPPO ALIMENTAZIONE

Lista delle possibili cause

1	PICCHI DI CORRENTE INDOTTI AL CIRCUITO ALIMENTATORE
2	
3	
4	
5	

	Verifica delle possibili cause	OK / NOK
1	PRESA IN POSIZIONE CORRETTA	OK
2	SPEGNIMENTO/ACCENSIONE AVVENUTI SECONDO PROCEDURA INDICATA	OK
3	INTEGRITA' CAVI ASSIEME SCHEDA ELETTRONICA	OK
4	INTEGRITA' ASSIEME ALIMENTAZIONE	OK
5	CORRETTO MONTAGGIO ASSIEME O2 CONCENTRATOR	OK

Tipo di causa radice



Analisi dei 5 Perché (5 Whys)-individuazione causa radice

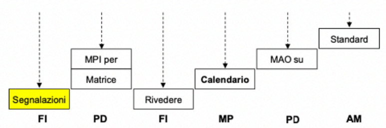
1° Perché	IL FUSIBILE E' SALTATO
2° Perché	PICCO DI CORRENTE IN ENTRATA/USCITA
3° Perché	PROBLEMI DI PICCHI RETE PRIVILEGIATA
4° Perché	
5° Perché	

	Azioni contro la causa radice	Resp.	Quando
1	MONTARE UNITA' UPS		
2	MONTARE FILTRO ARMONICO		
3			

Schizzo (se occorre, usare/allegare altri fogli)

	Azioni per il mantenimento	Resp.	Quando
1			
2			

	Azioni per miglioramento dell'efficienza di intervento	Resp.	Quando
1			



Validazione	Analisi eseguita da (Firma)	Verifica efficacia	Verificato da Capo reparto:	Data chiusura scheda
	Verificato da:		Firma Ing. Manutenzione:	

Figure 36 Analysis tab compiled for 3D printer "POLLY"

7. Kaizen team activities

The definition of a weekly kaizen team as been crucial in terms of organization of activities involving proactive maintenance operations. Kaizen as a behavioral strategy refers to a practice aimed at the constant improvement of manufacturing, engineering, and business management processes according to a bottom-up logic. The vision of the Kaizen strategy is that of renewal in small steps, to be done week after week, with continuity. The basis of renewal is to encourage each team member to make small changes every day whose overall effect becomes a process of selection and improvement of the entire organization. In the next two paragraphs, I will discuss two main activities (a small case study and a huge one) I worked on during my traineeship period, both extremely important not only in terms of maintenance operations performed, but also in terms of resulting Overall Availability of the plants.[6]

7.1 FPT DinoX carter customization

DINOX IAT is a Gantry-type moving beam machine, suitable for both heavy transport and high-speed finishing operations.

This machine tools used in Automobili Lamborghini's precision mechanics use 5 axes, i.e. three linear and two rotating. In this way it is possible to continuously orient the piece being worked on in the correct position, inclining it according to the needs, and to carry out the required milling operations. The advantage of the 5-axis milling machine is threefold. First, there is the possibility of carrying out particular and complex processes which otherwise would not be possible to complete. Secondly, there is an advantage in terms of versatility, as the five axes can be configured according to different needs.

Figure 37 FPT DinoX layout

As highlighted in the previous chapters, plant equipment is subjected to substantial customization process after its installation following supplier's directories. Processes like these can include enormous rework on the plant, such as a revamping activity, whose activities will be partly discussed in the next paragraph, or little "smart-ergonomic" operations as the one which I will describe in the following lines. As sharpened in the right picture, on the plant roof there is a parallelepiped carter whose aim is protecting the inside junction with distribution manifold of the various services (electric, hydraulic, and vacuum mainly). The operation carried out on the carter was to "divide" it. This work allowed us both to immediately open the latter, thus allowing a quick diagnostic (pipe/fitting leak, test any electrical cables). Furthermore, dividing the casing

Figure 38 DinoX highlight on carter's position

into two pieces allowed us to lighten it in terms of weight, to be able to call two maintainers for removal rather than a special crane. From the images, in fact, it can be seen that the carter is in a position not easy to reach, as the DinoX system and another CNC plant are attached.

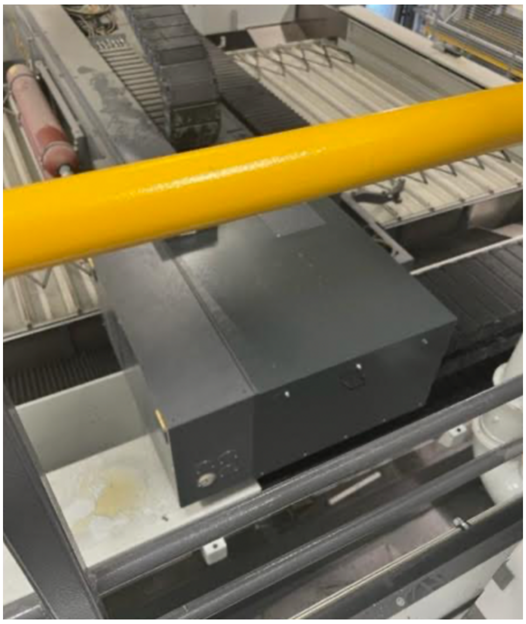


Figure 39 Customized carter splitted in two parts

7.2 Krauss Maffei revamping activity

One of the most critical issue (surely the most complex) to face during this traneeship period at Automobili Lamborghini's CFK centre concerned the revamping project of the Krauss Maffei press. The machine built by the company KRAUSS MAFFEI ITALIANA is used for the production of pieces with RTM technology.
The plant can be divided into 12 groups, main ones listed and described below:

- 1 mold storage station
- 2 mold loading/unloading shuttle (Shuttle)
- 3 presses 400 tons.
- 4 Vertical foaming head
- 5 Horizontal foaming head
- 6 Suction and press containment boxes
- 7 Platform
- 8 Thermoregulation system
- 9 Injection machine
- 10 Hydraulic unit
- 11 perimeter protections
- 12 Electrical panel

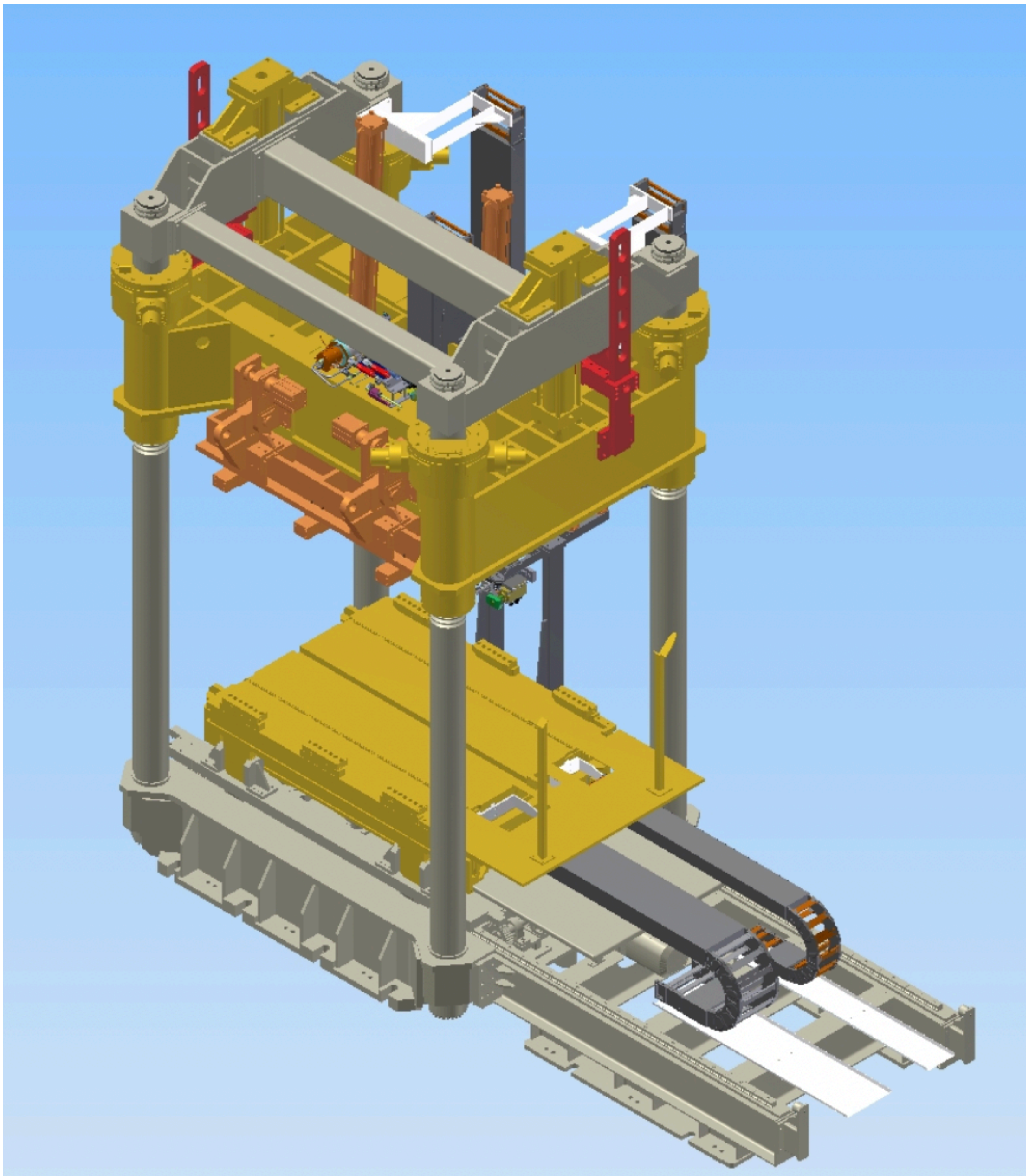


Figure 40 Krauss Maffei press

The mold translation unit is composed as follows:

1) Mold storage station

The storage station (was created as a mold warehouse; there workstation has a carpentry structure partly electro-welded (lower part), partly bolted (die guides); in addition, the supports are equipped with an adjustment system for level and adjust the height of the station itself; in this position the mold is connected via two plates (one for the upper mold and one for the lower mold) to a thermoregulator water which allows to thermoregulate it at a temperature of 55 °C. The thermoregulators are positioned inside the single station and have a thermal power of 18 kW. On such stations there are mechanical-pneumatic components (mould hooking rack) and components electrical, such as position sensors for automation and operator safety. The area of competence is separated from the system by manual sliding doors on two guides and controlled via sensors to start the mold picking and placing sequence. The whole area is suitably delimited by safety grids to prevent access.

2) Mold loading and unloading shuttle (shuttle)

The loading shuttle was designed to transport the molds from the choice at the press. It is composed of an electro-welded lower structure equipped with steel wheels and a rack which, through a motor with pinion, allows the guided translation on the tracks from one location to another. On the upper part of the shuttle there are guides made up of rollers; these rollers are shaped to extremity to allow the invitation of the mold in its translation.

3) Press

The press has been designed for molding with RTM technology; it allows to contain the thrust of the injection of the resinous mixture inside the mould, for a total force of closure (or pressed) equal to 400 tons. In the opening phase, the press is able to open with a maximum force of 100 tons.

The press was born with the need to receive 4 types of molds and is set up with two heads of foaming: one vertically (4), and one horizontally (5).

6) Suction box and press containment

The containment box of the press consists of a frame and fireproof panels and sound-absorbing. On the side walls there are glazed windows; this was done to make the work area visible too from the outside; in the two walls perpendicular to the direction of travel of the wagon, they are installed respectively an electric shutter, mold inlet side from the shuttle, and a sliding door, a two glazed doors, automated, operator entrance side; on the same side as the operator is provided also a hinged door always in glass. All glass is shatterproof.

7) Platform

The platform is built in electro-welded carpentry with support posts and crossbars bolted. The modules to create the walking surface are bolted above the crossbars.

8) Thermoregulation system

The thermoregulation system is divided into two parts:

- Fixed station thermoregulation
- Thermoregulation of the mold in operation

9) Injection machine

10) Hydraulic unit

11) Perimeter protections

The fence consists of electro-welded grid panels constructed in such a way as to make it visible the entire plant. They are placed at a distance that prevents parts from reaching dangerous. In the panel fence there are doors for access to the protected area maintenance case. These are equipped with a safety limit switch which intervenes in the event of an alarm and blocks the system. In particular: the security outside the box consists of physical barriers monitored via switches; if these signals are binding for the continuation of the cycle the system stops any movement; inside the box, security is a mix between physical barriers and controls with laser scanners. There are two laser scanners: one that controls the entrance to the box which intercepts the physical presence in the area in order to block the movement of the carriage bottom mould; the other is positioned in front of the tilting area and if this area is manned by presence the closing and molding cycle is blocked. Doors are planned in front of the work area of the operator of the lower half mold controlled by switches which inhibit the entrance of the wagon into the press if they are not closed.

12) Electrical panel
For information, see the operator manual 11.015.OPM attached to the following documentation.

The press in question underwent a huge revamping process during the Christmas closing break going from a water heating system to an oil one. This involved changing the system pneumatic and the addition of the hydraulic one by inserting new thermoregulators. Clearly, during such a revamping activity, it is common to face issues concerning failures, breakdowns, or subsystems malfunction. This happens because, in Automobili Lamborghini, plant equipment is extremely customized based on production requirements. Therefore, customization might lead to initially unpredictable failing behavior which have to be quickly mitigated in time to ensure satisfactory production flow process. Following this, here are reported some main aspects regarding this activity, in terms of problem identifications, hypotheses made, further analysis and eventual resolution. It is worth underlining that the complexity of the problem derived from the fact that we were dealing with different issues which were not only necessarily dependent one on the other, but also it had to be understood whether they could be related as a consequence of the revamping activity, or just as ordinary stops.[7]

7.2.1 Broken thermoregulation oil pipe

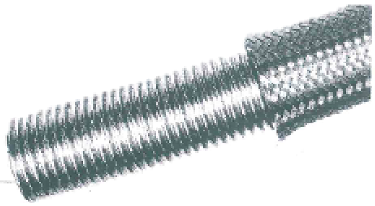
<u>DESCRIPTION</u>

During normal operation of the press, a pipe containing oil for heating the mold was torn causing oil to leak onto the operator station

<u>ANALYSIS</u>

As per the technical sheet on the side, the pipe has been defined as capable of withstanding pressures much higher than the operating pressure (about 4.5 *bar*) and very accentuated bending angles.

The hose in question is with the supplier for further analysis of the causes of the failure.



TRECCIA SINGOLA

SINGLE BRAID

Diametro nominale *Nominal Bore*	Diametro interno *Inside diameter* DN		Pressione di esercizio *Working pressure*		Pressione di collaudo *Test pressure*		Pressione di scoppio *Burst pressure*		Raggio di curvatura statico *Static bend radius*	Raggio di curvatura dinamico *Dynamic bend radius*
mm	mm	inch	bar	psi	bar	psi	bar	psi	mm	mm
6	6	1/4	154	2233	230	3335	616	8932	25	100
10	10	3/8	105	1522,5	157	2276,5	420	6090	40	150
12	12	1/2	88	1276	132	1914	352	5104	50	200
16	16	5/8	73	1058,5	109	1580,5	292	4234	50	200
20	20	3/4	64	928	96	1392	256	3712	70	200
25	25	1"	50	725	75	1087,5	200	2900	90	200
32	32	1"1/4	42	600	63	913,5	168	2436	110	250
40	40	1"1/2	32	464	48	696	128	1856	130	250
50	50	2"	31	449,5	46	667	124	1798	175	350
65	65	2"1/2	26	377	39	565,5	104	1508	200	410
80	80	3"	18	261	27	391,5	72	1044	205	450
100	100	4"	16	232	24	348	64	928	230	560
125	125	5"	16	232	24	348	64	928	280	660
150	150	6"	12	174	18	261	48	696	320	815
200	200	8"	10	145	16	232	40	580	435	1015

Figure 41 Single braid technical sheet

CORRECTIVE ACTIONS

1. Damaged hose replacement (1 day)

2. A 30-degree angle spacer was added to allow for a smoother bend to the tube subassembly where the damaged tube was present. (10min)

3. In the study a system to collect the pipes in a single bundle with no impact on production

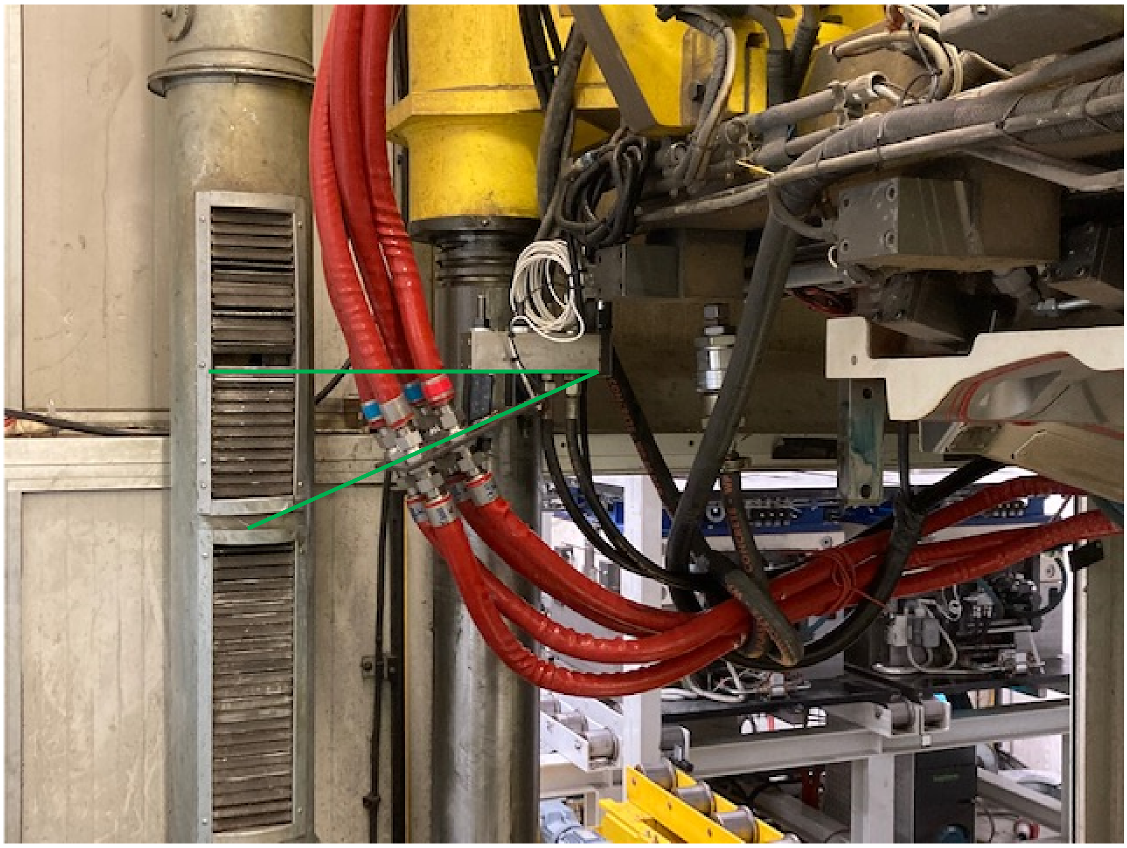


Figure 42 30-degree angle spacer on oil heating pipe area

7.2.2 Oil leak from thermoregulators

DESCRIPTION

Every time the heating started, oil leaked from the thermoregulators dedicated to the lower mould. The resulting oil appears foamy.

This caused the oil to be constantly topped up during these stages.

ANALYSIS

Identify three possible causes:

- Communication between the two thermoregulators of the lower mould
- Thermoregulator three-way valve incorrectly assembled
- Water contamination

CORRECTIVE ACTIONS

- **Communication between the two thermoregulators of the lower mould**

  which ensured the manual closing of the communication valves placed on the mould.

  Command controlled by PLC and stringent closing condition of the valve inserted as soon as the mold enters the press. Awaiting checks on the integrity of the solenoid valves, in the meantime it prepares for manual closure as per the Work Instruction.

- **Thermoregulator three-way valve incorrectly assembled**

  Fault confirmed by Piovan technicians. There was an error installing the two lower mold temperature controllers and the backup temperature controller. Fixed

  (3h per intervention) This led to possible emulsion with air entering the thermoregulator.

- **Water contamination**

Remote hypothesis, all the pipes are new, and the mold has been washed and treated by ALPEX before making the change from water to oil. The only possible passage is to be found in a micro-hole in the heat exchanger inside the thermoregulator. Awaiting verification if the intervention on the valves is decisive and therefore the cause is attributable to it.

<u>IMPROVEMENT ACTIONS</u>

Return oil filtering and cleaning system from the mould - on supplier's advice.
("nice to have" adjustment, although not necessary when fully operational as it is a closed circuit).

7.2.3 Staubli bindings ruined

<u>DESCRIPTION</u>

The Staubli attachments present in the press are damaged and cause the oil to leak from the thermoregulation circuit.

<u>ANALYSIS</u>

The damage appears to be due to blows inflicted over the years with a hammer or violent metal-to-metal contact.

<u>IMPROVEMENT ACTIONS</u>

The replacement of all the Staubli attachments present in the press (60 males and 40 females) was foreseen.

Figure 43 Ruined Staubli blindings and newer ones below

7.2.4 Oil leak on pieces

DESCRIPTION

A hydraulic oil leak has been detected coming from the upper press plane. This leak seeped into an opening in the front of the press and dripped onto the pieces which resulted in scrap pieces.

Figure 44 Highlight on oil leak point on press

ANALYSIS

An analysis was made both by Krauss Maffei and by maintenance to understand the causes of the leak attributable to the valve group.

IMPROVEMENT ACTIONS

1. Buffer solution made with a plate (cap) at the point where the oil falls so as to collect it in a container and not let it fall on the pieces being printed.

2. Maintenance is recovering the O-Rings to be replaced in the valve group in order to be able to replace them and eliminate the problem at its source.

Figure 45 Buffer solution implemented

8. Future perspectives and conclusion

As explained extensively in the previous chapters, 2023 has been an extremely ambitious year for Lamborghini. Working in a sector such as maintenance has been a fundamental element of growth, as it has allowed me to work on projects that are crucial to guaranteeing the health and efficiency of the company at the production level. Concerning this topic, a last (but not least in terms of importance) project has been implemented by our team in terms of failure analysis and intervention on site. Always relating to the goal of reducing the stop time when a failure occurs, there has always been the need of improving the maintenance team effectiveness with trainings and the release of procedures, instructions, and guidelines about how to repair a machinery once a certain failure occurs.

This may allow also to bring inside the company the knowledge and the ability to do some failure restorations that were usually demanded to the external supplier turning into the zeroing of the time for him to come on site for the maintenance activity. This time may be very huge depending on the type of maintenance contract that has been subscribed with that external company. Nevertheless, those activities are never for free but include huge expenses to let external technician to come on site, especially if their head quarter is far away and multiple days were needed to solve the problem. A crucial aspect that become relevant, is that from 2023 with the new car model arrival, CFK has been submitted to a huge site expansion with the introduction of new machines such as the presshop FPT Industries S.p.A.

For this reason, one of the task which has been carried out once I started the internship was to find a solution concerning the organization of a training for the Lamborghini internal maintenance team to let them to be autonomous in solving this problem. This training was done during summer August shutdown and carried out by both Technology department and suppliers, and after the preventive and extraordinary maintenance activities that in those days were usually carried out to every machine. The need to do it in this slot comes to the fact that this training was supposed to take from three to four days, during which the machine cannot be used and must be dedicated only to this activity. The first part of the process, already implemented, was related to the training and later introduction of standard procedures well documented and certified by the technology department leader to be used as reference in the future.

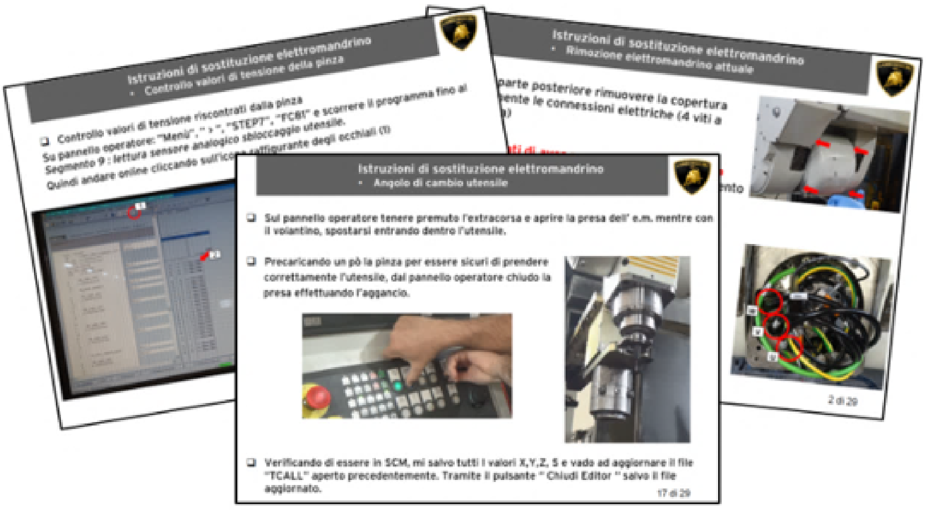


Figure 46 Autonomous maintenance procedures certified by technology team

During the traineeship period, I had also the responsible of taking care about the list of tools and component needed to perform the activity. This was important, in according to the SMED method, to create an intervention kit with all the instrument necessary in order to have all of them together and in the same place, minimizing the time in finding them.

It is worth underlining that, the effect of this implementation is not only related to the idea of increasing the percentage effectiveness of the plant, but it also has a radical impact in terms of costs. If we look at the table below, it is shown an example of company costs related to supplier's intervention on plant in case of failure.

Travel costs	Unit of measurement	Quantity	cost [€]	Total €
Hotel	night	1	€ 90,00	€ 90
Board	day	1	€ 63,00	€ 63
cost per hour/trip	hour	1	€ 80,00	€ 80
Expense allowance	day	1	€ 153,00	€ 153
Mileage reimbursement	km	1	€ 0,70	€ 1
on-site technical service Mon-Fri	**hour**	1	€ **80,00**	€ 80
on-site technical service Saturday/Sunday	**hour**	1	€ **115,00**	€ 115

*Figure 47 Example of costs related to external supplier maintenance (*actual number do not represent reality, shown as a comprehensive example)*

Bringing this activity inside, the cost to perform it will be 0€* and only a good organization is needed to ensure to have the human resources available to do this operation.
Now, considering 2023 evolution and perspective, the latest approach was to rearrange the maintenance team. The idea is to create some kind of hierarchy in the following way:

- A supervisor training, whose aim is to guarantee production continuity and plant efficiency by applying defined maintenance policies and improvement proposals, deal with the organization of collaborators and external companies, and develop skills of maintainers towards versatility and specialization;
- Hard skill tutors, who are actually specific reference maintainers for specific systems and acts as referent for training the rest of the team. The goal here is to reach a level of autonomy and competence «FEW BUT GOOD». Here the process extends to the technical aspect of maintenance, like mechanical, electrical, and software training related to digitalization and MES, as well as soft skills and safety intervention.

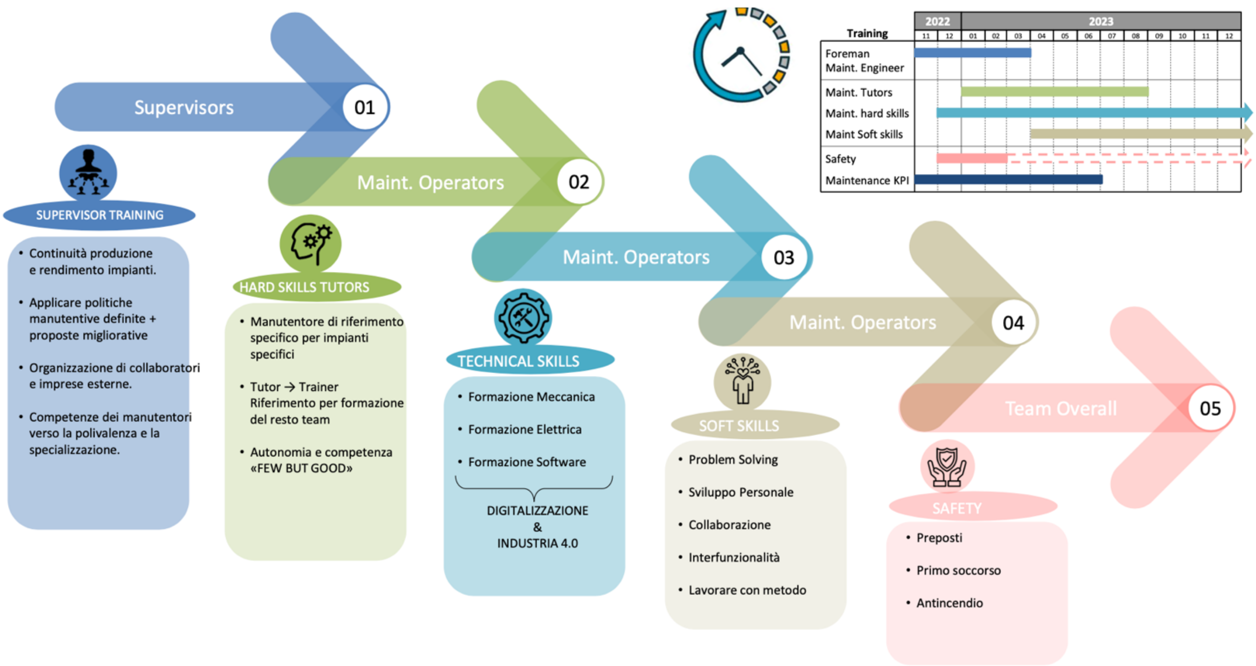


Figure 48 Maintenance autonomous training organization

This “tutor development project” has therefore also the aim of creating reference figures among the maintenance technicians for the individual plant equipment, able to intervene autonomously on machine stops, verify and implement preventive maintenance and make suggestions for improvement.

Since this last developing project has been clarified as well, it is important in conclusion to recall the intense period in which the traineeship has been done in the company. Plenty of activities has been set up, developing of older projects have been carried on. This shows that Automobili Lamborghini is a company in continuous growth and strongly focuses on keeping up with the plant technology evolution, as well as the environmental care and effectiveness in terms of costs. In this perspective, the basis set by our technology and maintenance team will surely help the progress of the company by working properly to be efficient on the actual machines that are continuing to work and meanwhile learn as much and as fast as possible how to act on the new installations to increase as much as possible their overall availability.

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ACRONYMS

CFK	*Carbon Faserverstärkte Kunstoffe (GER)*
CFRP	*Composite Fiber Reinforced Plastics*
CNC	*Computer Numerical Control*
Pre-Preg	*Pre-Impregnated materials*
RR	*Department Manager*
MIP	*Maintenance on Production Plants*
MEP	*Maintenance on Utilities Plants*
TL	*Team Leader*
MPI	*Internal Preventive Maintenance*
MPE	*External Preventive Maintenance*
MPA	*Preventive Maintenance of Equipment*
MAO	*Autonomous Operator Maintenance*
RDA	*Richiesta D'Acquisto / Work Order*
BiW	*Body in White*
OA	*Overall Availability*
OEE	*Overall Equipment Efficiency*
PPT	*Planned production Time*
MTTRepair	*Mean Time To Repair*
MTTRecovery	*Mean Time To Recovery*
MTTF	*Mean Time To Failure*
MTBF	*Mean Time Between Failure*
RTM	*Resin Transfer Molding*