DMAIC application on AW139's damper production process

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Contents

Acronyms

The following is a list of the acronyms used in this thesis project:

- APU: Auxiliary Power Unit;
- ATP: Acceptance Test Procedure;
- CTQ: Critical To Quality;
- DMAIC: Define, Measure, Analyze, Improve, Control;
- FOD: Foreign Object Damage;
- KPI: Key Performance Indicator;
- LCL: Lower Control Level
- LHD: Leonardo Helicopter Division;
- LT: Lead Time;
- MAG: Mecaer Aviation Group;
- MRP: Material Requirements Planning
- NCR: Non-Conformance Reports;
- OdI: Production Order;
- PCP: Production Planning and Control;
- PTFE: Polytetrafluoroethylene;
- Q.A.: Quality Alert;
- QN: Quality Notifications;
- SNCR: Supplier Non-Conformance Reports;
- UCL: Upper Control Level;
- VOC: Voice Of the Customer;
- VSM: Value Stream Map;
- WH: Warehouse;
- WIP:Work In Progress.

1 Introduction

1.1 Introduction to the project

This project has been carried out to reduce scraps, and, as a consequence, costs and problems related to them, in a particular process, which is the production of the piston flange, one of the core components for the assembly of the AW139's main rotor damper.

The instrument used to achieve this objective is the "Six Sigma"(Kumar, 2024)[1], a set of methodologies and tools used to improve business processes by reducing defects and errors, minimizing variation, and increasing quality and efficiency. This is achieved by using a structured approach called DMAIC (Pyzdek and Keller, 2000)[2] to identify and eliminate root causes of the crticalities detected and improve processes.

Using this instruments, with the help of other members of the firm and a continuous communication and exchange of information with the client, I analyzed all the reports of non-compliance during the year 2023, to understand the possible causes of scraps in the process and to understand in which point of the process an improvement could be introduced.

1.2 Work environment

The team was composed of four people: a representative of the Production Planning and Control office (me), two representative of the Quality Assurance office and a representative of the client (Leonardo Helicopters). The activities necessary to develop the project have been done mainly in three ways: internal surveys, internal meetings and meetings with the client, both online and through visits.

The most important point of the activity is the collecting and the exchange of information between us and the client, in order to develop the project in the smoothest and most accurate way possible. In order to understand problems and find potential solutions through communication with the operators, different activities through the production departments have been necessary. The activity was mainly conducted in two departments: the workshop and the hy-

[1] Kumar. (2024). *What is six sigma? explore its importance and benefits*. https://www.simplilearn.com/what-is-six-sigma-a-complete-overview-article#:~:text=The%20goal%20of%20Six%20Sigma,of%20variation%20and%20improve%20processes

[2] Pyzdek, T., & Keller, P. (2000). What is six sigma. *Pyzdek Institute: Retrived from http://www. pyzdek. com/six-sigma-revolution. htm*

draulic assembly. The first one because it involves some critical activities for the production of the piston flange, which caused many scraps, so talking with operators was crucial to understand causes, while the latter, being at the end of the process for the production of the damper, has been analyzed accurately and received several interventions to improve the quality of the finished product.

1.3 Structure

This thesis is composed, apart from this introduction and the conclusion, by six chapters: an introduction to the company and to the product, and the other five which follow the phases of the DMAIC approach. The first chapter introduces the company, the damper (explaining functions and main components) and DMAIC.

The second chapter defines in detail the problem analyzed in the project and the goals, explains the production process of the parts and the construction of the value stream map.

The third chapter explains the measurement of the specifications of the problem and how all the data regarding defects have been collected, using statistical and visual instruments as graphs.

The fourth chapter analyzes the results of the previous chapter to find all the critical issues of the process in the current state, using hypothesis testing and other tools to understand the causes.

The fifth chapter shows the corrective actions to the criticalities risen in the fourth chapter through a detailed and structured action plan organized by the company, in order to find and implement solutions at different levels of the process.

The last chapter aims to check the results obtained, showing if objectives have been reached or not, how the results will be maintained and monitored during time and conclude the project.

2 Company product and process analysis

2.1 The company

Figure 1: MAG's logo

This project has been developed in the company Mecaer Aviation Group (Figure 1), a leading international provider of solutions for aircraft systems and services in the helicopter, business aviation, general aviation markets and military sector, which has four main productive centers between Italy, Canada and USA.

Figure 2: View of Borgomanero factory

To be precise, I'm part of the production planning and control team in the Borgomanero factory (Figure 2), which focus is the production and support of actuation and flight control systems for helicopters and small/medium-sized air-crafts for civil and military use (producing, for instance, landing gears for aircraft models as M345 or Hurkus). This role involves the planning and the management of the production of different product lines (a product line is a set of components that will be assembled on a certain helicopter's model), the launch of production orders and taking all the actions needed to deliver the final product to the warehouse and ship it to the client.

2.2 The product

2.2.1 What is a damper and how does it work

Dampers are placed in the main rotor of the helicopter, between the blade and the hub (as you can see in Figure 3). There is one damper for every blade of the helicopter so, in the specific case of AW139 which has 5 blades, there are 5 dampers (Figure 4).

Figure 3: Position of a damper in the rotor

The main function of this hydraulic component is to reduce rotor damping. Rotor damping refers to aerodynamic and structural forces that counter blade vibratory motion, these forces are proportional to air density. The most important one is the aerodynamic damping of flap motion. As a blade flaps upward, the angle of attack is reduced (Aviation, 2021)[3], decreasing downward aerodynamic force.

[3]Aviation. (2021). *What is rotor damping and how does it affect helicopter stability.*

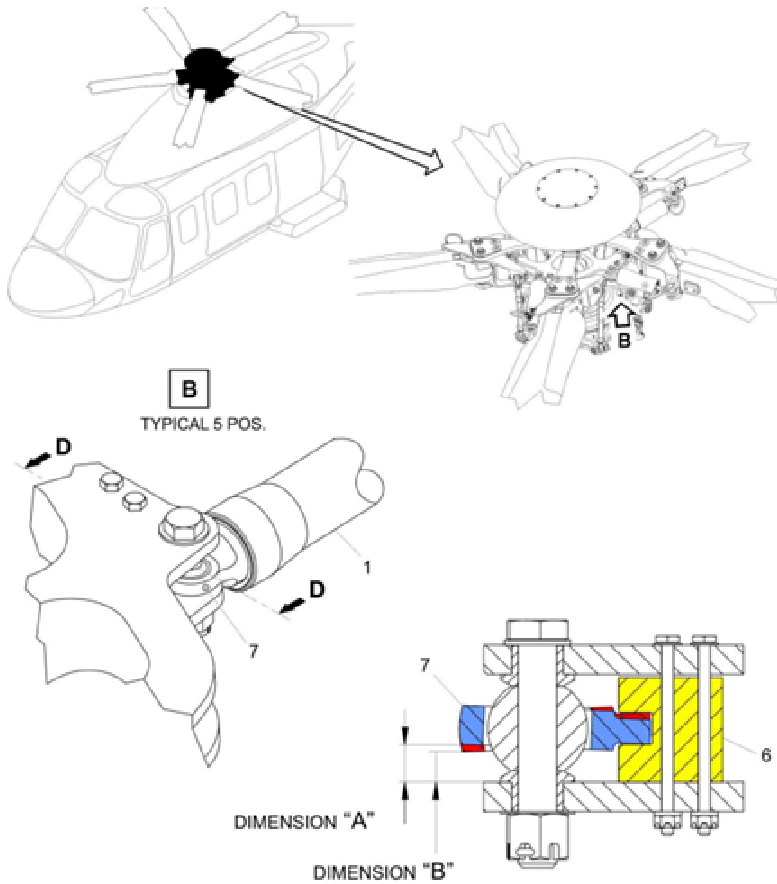


Figure 4: Dampers in the AW139's main rotor

This phenomenon always opposes blade "flap velocity", pushing the blade down when it's flapping up and vice versa.

An analogous thing happens with lead-lag motion (within the plane of the rotor, Figure 5): as a blade moves forward, drag increases to "push it back" ; on the contrary, when a blade lags, drag decreases to help "push it forward".

https://aviation.stackexchange.com/questions/81692/what-is-rotor-damping-and-how-does-it-affect-helicopter-stability

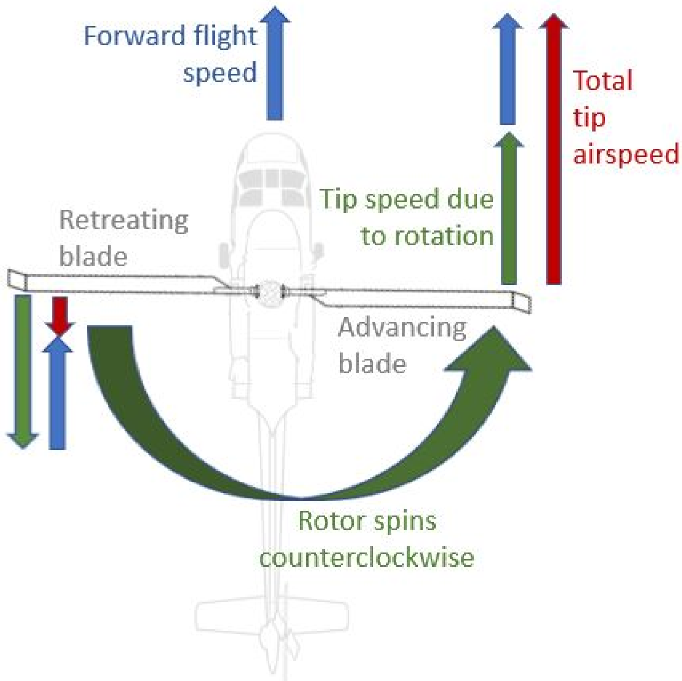


Figure 5: Blades movement during flight

Unfortunately, this variation in drag is very small and does not tone down lead lag motion nearly as much as the flap phenomenon (see scheme in Figure 6). It is for this reason that lead-lag damping is problematic, often resulting in dampers placed near the root of the blade in the lead-lag direction. Damping has to be equal on all the blades, in order to maintain them in the same position, because if this does not happen, vibrations could occur and the pilot could have difficulties in maintaining the control of the helicopter (Zaretzky and Da Silva, 1994)[4]. Dampers are critical parts, this means that serious malfunctions of these components could bring to catastrophic events, so they must resist to a very high number of cycles, while being subjected at very high forces and extreme weathering. Once the maximum number of cycles is reached, maintenance has to be performed on the parts.

[4]Zaretzky, C., & Da Silva, M. C. (1994). Experimental investigation of non-linear modal coupling in the response of cantilever beams. *Journal of Sound and Vibration*, *174*(2), 145–167

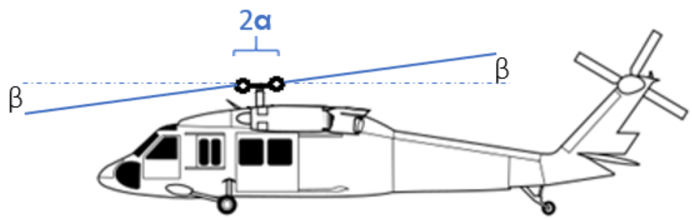


Figure 6: Scheme of flap phenomenon

A damper can be considered as a double-acting hydraulic jack equipped with a pressurized reservoir. This, in addition to providing an oil reservoir that can compensate for leakage, prevents depressions within the chambers. The two chambers of the damper are separated by a sealed piston and are connected to the reservoir through two fill (non-return) valves. On the piston, there are two adjustable valves that open at a predetermined pressure difference (corresponding to a known value of load on the stem) allowing oil to flow from one chamber to the other. This gap depends on the actuation speed of the piston itself and once a predetermined value is reached, there is the opening of a calibrated valve (relief valve) which allows, by the passage of hydraulic fluid through it, a limitation of the load as the speed of movement of the piston varies. Leakage occurs between the two chambers and toward the reservoir. Damper is also equipped with an attenuation system in the end-strokes (cushion) that is intended to brake the piston when the latter reaches one end of its stroke, thus preventing it to hit the flanges. To accomplish this damping, coaxial interpenetrating cylindrical surfaces are made in both flanges, outer and inner, and in the piston as shown in the diagram in Figure 7. These surfaces realize additional fluid leakage by slowing down the piston.

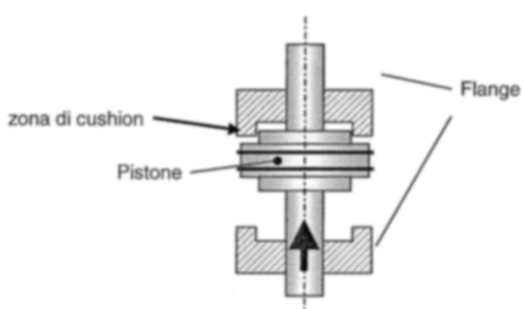


Figure 7: Cushion zone functioning

2.2.2 Main components of a damper

A damper (Figure 8) is composed of the following parts or assemblies of parts (A.A.V.V, 2002[5]):

- 1) body assembly with integrated fork coupling and hydraulic ports;
- 2) liner;
- 3) flange-piston assembly;
- 4) two valves (stop, plate, spring, spring guide retainer);
- 5) reservoir (reservoir piston and spring);
- 6) terminal assembly (terminal, bearing, broached ring nut, block);
- 7) body end assembly;

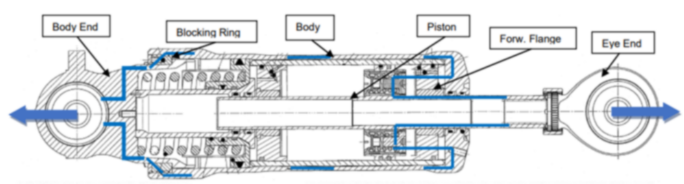


Figure 8: Enter Caption

1) The body (Figure 9) is designed to avoid stresses due to hydraulic pressure loads generated during the damper operation, in order to be subjected only to the pressure existing in the reservoir. The hydraulic loads are discharged to a special internal liner while the body absorbs the loads derived from the operation and which are discharged to the flanges.

[5] A.A.V.V. (2002). Descrizione damper rotore principale [Mecaer Aviation Group internal document]

Figure 9: Body's 3D model

2) The liner (Figure 10) is housed inside the damper and has the function of supporting the hydraulic loads (pressure) generated by the movement of the internal piston. The seal between the liner and the piston is provided by two metal rings that adhere to the liner itself. A surface hardening treatment is applied in the internal surface by the addition of hard materials to increase wear resistance. At each end of the liner is drilled a hole (see Figure 9) that allows the installation of a pin to prevent rotation of the liner and flanges, to allow leakage between the chamber and the reservoir and the drainage of the respective chamber during the filling with the pin removed.

Figure 10: Liner's 3D model

3) Piston flange assembly (Figure 11) consists of three main components:

- steel piston: as shown in Figure 12 the piston consists of a central part (constituting the thrust area) and the two rods. A surface hardening treatment by tungsten carbide coating is applied to the rods to improve the performance of the seals installed in the flanges and, more importantly, increase their reliability.

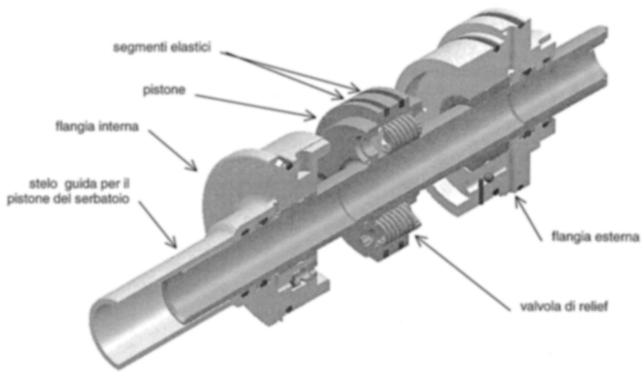


Figure 11: Section of the piston flange assembly

> The inside of the stems is hollow while one end is threaded for the connection with the terminal for attaching the damper to the blade. On the outer diameter of the piston are housed two rings which ensure the sealing between the piston and the liner during the movement of the piston itself. The metal contact with the liner promotes heat transfer and avoids burning or overheating phenomena even when the displacements are of small amplitude at high frequency. The elastic force typical of this ring is able to counteract the effects of the centrifugal force acting on the damper during the operation; in addition, the hydraulic pressure generated inside the damper chambers tends to increase the contact pressure between the elastic ring and the liner.

The latter effect is generated by the increase in fluid pressure present between the ring and the piston throat where it is housed; this rise generates an effect of "lifting" of the ring with a consequent increase in pressure. Piston rings are more reliable than traditional dynamic seals, offering a high capacity to absorb loads during operation, being very easy to handle and easy to install, thus reducing the risk of damages during installation. In addition, the appliance of two snap rings makes the piston seal redundant. The coupling of cast iron snap rings with hard sliding surfaces (aluminum alloy liner with carbide coating) reduces wear giving the damper a high durability.

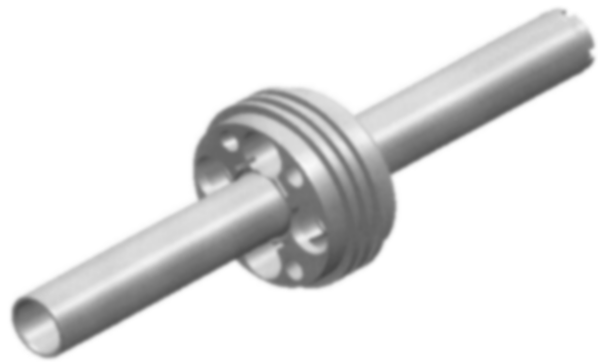


Figure 12: 3D model of the piston

- Internal and external flanges: the two chambers of the damper are bordered by two flanges made of titanium alloy in which the filling valves of the chambers and their supply lines are housed. A profiled zone is made on the flanges which, coupling with the piston, performs a braking action when the piston reaches the end of its stroke in order to prevent the piston from plugging against the flange (end-of-stroke damping, cushion). A valve is also installed in each of the two flanges for the purpose of preventing the formation of vacuum, gas, vapor, or otherwise fluid-free situations when the piston exits the end-of-stroke zone. These valves consist of a simple ball that is allowed to move within a channel. They are maintained in the closed position by the centrifugal force acting on the damper. A hole is drilled in each flange for the installation of an anti-traction plug. During the functioning phase, the volume of fluid flowing through the valves from the high-pressure chamber to the low-pressure one is less than the volume generated by the displacement of the piston.

The two valves are different, to take into account the centrifugal force that, acting on the masses of the valves themselves, alters their operation; in fact, the valve on the outer flange is normally kept closed by centrifugal force, so no spring is needed to keep it in the closed position. ln contrast, the one on the inner flange tends to be opened by centrifugal force, and is therefore formed by a movable crew (plate) held by a spring to overcome the centrifugal force.

The lower part of the inner flange also has the function of guiding the reservoir piston. Static gaskets are made using sealing organs in the standard type range. Dynamic gaskets are redundant and have different characteristics: on the innermost side of the seal is installed an in-range gasket, while on the outer side of the seal is installed a gasket with a plastic sealing ring energized by an elastomer, which also has the function of a dust scraper.

4) Relief valves: two pre-loaded “relief” valves are housed in the central part of the piston, which perform the damping action typical of the damper by acting on the dynamics of the passage of hydraulic fluid from one chamber to the other. These valves are symmetrical and are installed specularly inside the piston, ensuring the same behavior of the damper in compression and rebound. Each valve consists of the following components (schematized in Figure 13) : valve plate; counter spring; threaded retainer with spring guide functions, used for adjusting the pre-load of the contrast spring; valve plate stop screwed and locked into the piston. The closing element (plunger) can slide on the retainer and is held in the closed position by the spring; sealing relies on the good workmanship of the contact surfaces of the plate and the stop. The spring retainer is the element that determines the opening pressure of the valve. The spring-guide retainer is screwed inside the plunger and acts as a guide for both the closing element and for the counter spring. The very low mass of the moving crew and the high stiffness of the springs bring the mechanical frequencies to very high values, thus reducing resonance phenomena.

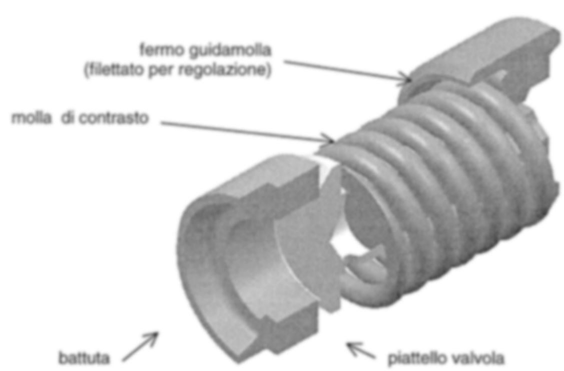


Figure 13: Valves’ scheme

5) Reservoir piston and springs (Figure 14): The seal is made with PTFE ring gaskets. The spring is made of stainless steel.

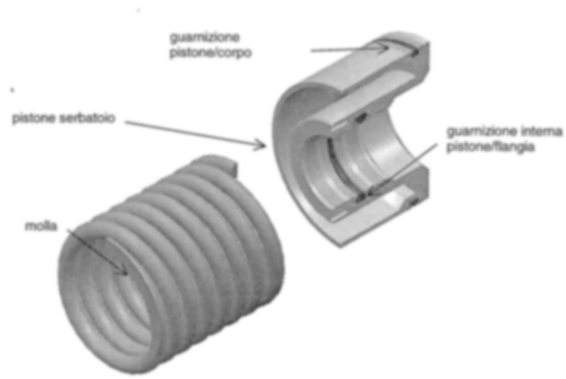


Figure 14: 3D model of reservoir piston and springs

6) The end assembly (Figure 15), which fix the damper to the rotor blade, consists of a self-lubricating type kneecap locked by a process of caulking into a structural part, the eye end (Figure 16) that is screwed and locked to the stem. Since the movement of the stem is of the helical type and considering that the friction loads are not indifferent, a coupling is made between the stem and terminal that can absorb and guarantee this type of motion even in the presence of high torque values without having the possibility of loosening and, consequently, of a possible unscrewing. Such a block is realized through a system of broached surfaces, one machined on the terminal and one made on a ring united with the stem by means of four teeth. An internally broached ring nut connects ring and terminal and is secured by means of a brake wire.

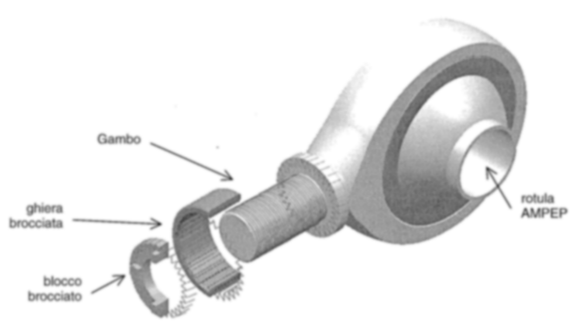


Figure 15: Components of the end assembly

Figure 16: 3D model of the eye end

7) The body end permits (see figure 17) the attachment to the hub and act as stops preventing rotation of the damper body. In the final assembly, a bearing is caulked into the circular part.

Figure 17: Body end

2.3 The DMAIC approach

DMAIC is the problem-solving approach that drives Lean Six Sigma. It's a five-phase method (Define, Measure, Analyze, Improve, Control, see Figure 18), data-driven, quality strategy used to improve process whit problems which causes are unknown (Goleansixsigma, 2017)[6]. More in detail, the five phases are (Laman, 2022)[7]:

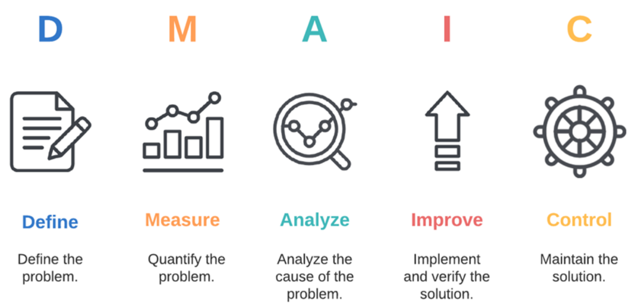


Figure 18: Scheme of DMAIC phases

- Define: the purpose of this step is to clearly pronounce the business problem, goal, potential resources, project scope, and high-level project timeline. This information is typically captured within the project charter document. At this stage, it is written down what is currently known, one seeks to clarify facts, set objectives and form the project team. In this phase will be defined the problem, the customer, the Voice of the customer (VOC) and the critical to quality (CTQs), the critical process outputs.

- Measure: the goal of this phase is to measure the specification of problem/goal. This is a data collection step, the purpose of which is to establish process performance baselines. The performance metric baseline(s) from the Measure phase will be compared to the performance metric at the conclusion of the project to determine objectively whether significant improvement has been made. The team decides on what should be measured and how to measure it. It is usual to invest a lot of effort into assessing

[6] Goleansixsigma. (2017). *Dmaic – the 5 phases of lean six sigma*. https://www.simplilearn.com/what-is-six-sigma-a-complete-overview-article#:~:text=The%20goal%20of%20Six%20Sigma,of%20variation%20and%20improve%20processes

[7] Laman, S. A. (2022). *The asq certified quality engineer handbook*. Quality Press

the suitability of the proposed measurement systems. Good data is at the heart of the DMAIC process.

- Analyze: this step focus is to identify, validate and select a root cause for elimination. A large number of potential root causes of the project problems are identified. The most important causes are selected are collected to establish the relative contribution of each root causes to the project metric. This process is repeated until "valid" sources of problems can be identified.

- Improve: the purpose of this step is to identify, test and implement a solution to the problem, either in part or as a whole depending on the situation. Identify creative solutions to eliminate the key root causes in order to fix and prevent process issues.

- Control: the last phase aims to embed the changes and ensure sustainability, this is sometimes referred to as making the change 'stick'. Control is the final stage within the DMAIC improvement method. In this step, the following processes are undertaken: amend ways of working, quantify and sign-off benefits, track improvement, officially close the project, and gain approval to release resources.

3 Define

3.1 Business problem and goals

Damper is one of the principal products of Borgomanero factory and one of the most critical component in an helicopter. The production of the piston flange represents one of the main criticality in the overall process, because it is a critical part produced in a very high volume, so it's necessary to reduce any kind of waste during the process.
The reduction of scraps has a series of important consequences for the company I'm working in:

- it reduces costs related to quality, increasing marginal revenue;
- leads to an improve in the quality of the product and of the process, as the project main focus is on the critical phases, in which scraps could be more frequent;
- reduce Quality Notifications (QN) by the client, which are problems related to the product reported by the client, a QN implies the Quality Supplier Assurance to apply corrective actions to the process. QN can be distinguished in two types: QF, which are quality notifications caused by problems encountered in incoming; QJ, quality notifications due to problems arisen after the damper is tested. The objective is the achievement of a percentage of $QF + QJ < 0,1\%$(the focus will be only on the reduction of QJ), which corresponds to a yield of the process greater than 0,95;
- in an industry where On Time Delivery (OTD) is mandatory to the client, due to the very fast growth of the demand in the actual market, guaranteeing a certain continuity in the supply of the product to the customer is very important, as this particular industry is suffering from a serious lack of raw materials that forces the firm to reduce the Lead Time (LT) for the production of the parts. This reduction of the scraps can help the supplier to guarantee the OTD.

For the client, indeed, the reduction of this problem could guarantee:

- avoidance of slowdowns during flying test;
- reduction of costs for the management of non-compliances.

3.2 The process

3.2.1 Piston flange assembly production process

The starting point of this project is the analysis of the overall process, starting from the order made by the client, until the final product leaves the warehouse. The process starts with an order made by the client: this request is elaborated by the software and charged on Supply-on, another software, from which Mecaer's commercial office can see all the orders made by the client. At this point, after both price and LT are checked, and the quality office gave its consent, the order is transferred to Infor, our management software. Infor is an MRP based software, which with a weekly based cycle, elaborates the sales order present in the system, exploding the material requirements, making visible what is necessary in order to complete the final product and, based on the commercial LT of the order, when is necessary to purchase or launch in production. To facilitate this work, a set of excel reports is extracted: through these files, production control and planning (PCP) office is able to see what is missing to complete a certain order, if it is necessary to launch a production order, monitor and guide the full production process; also, purchase office is able to see what, when and how much of a certain material (raw, semi-finished or finished) to buy.
This is the starting point for the production of a damper. The first step is the purchase of the raw material, needed for the construction of the piston, and of all the purchasing materials (busing, flanges and valves).
Once the raw material is disposable, PCP office creates and releases the production order, while the archives allege to the paper of the order the drawings and all the necessary documents useful to the operators during the different phases of the process.
Then, the warehouse takes in charge the order, picks up the raw bar, cut it with an hacksaw, and prepare it for the delivery to a subcontractor which performs a roughing and a drilling phase, checking also the roughness of the surface. Note that, to ship materials to a subcontractor, is necessary that the purchase office creates a purchase orders related to the operation that is going to be made by the supplier, otherwise, goods will be not allowed to leave the warehouse.
After this external operation, an incoming quality and dimensional check is performed: in this phase operators check the dimension of the material and that all the documents that certify the work made by the supplier are present.
The next operation is the conification: this process consists in reducing the cylindrical metal tubes from a larger diameter to a smaller diameter, to a con-

ical shape and in the desired length, thus obtaining conical metal tubes for conification. This can be done with special molds called die molds that press down the pipe till it reaches the desired cone-shape. In this case, the operation is done on the extremity of the stem, which diameter is then checked using a caliber.
Conification is followed by a first turning operation: during this phase the hole done in the first external operation is reamed and turned.
After that, a dimensional control and a non-destructive testing are performed: the first to control that the dimensions of the parts are between the tolerances established in the drawings; the second one is a magnetic particles testing, where a magnetic field is used for detecting surface, and shallow subsurface, discontinuities in ferromagnetic materials. Examples of ferromagnetic materials include iron, nickel, cobalt, and some of their alloys. To conduct a magnetic particle test, inspectors start by magnetizing the material they want to inspect. If the object has no defects, the magnetic field will transfer throughout the material without any discontinuities or interruptions, but when the current encounters defects it will be interrupted, causing it to spread out from that point and create what is called a flux leakage field where the defect is located and inspectors spread magnetic particles over the surface. The particles will be drawn to the secondary field, gathering around it and making it visible to the naked eye. The particles are typically either black or coated with some kind of fluorescent dye to make them easier to see (Betz, 1967)[8].
Once the parts are allowed to proceed, an internal thread rolling operation is performed in the internal diameters of the piston. Thread rolling is a cold-forming process that is used to create internal threads. It involves using a thread rolling die, which is a tool with a series of thread profiles that is pressed against the material to deform it. Thread rolling is commonly used for high volume production runs, and it can produce threads that are stronger and more precise than those produced by tapping or die cutting (GSR, 2023)[9].
The following step is a second turning operation, and a test part will be separated from the initial lot to be sent to the laboratory, where it will be used to perform some tests that will determine if the rolling has been done properly. As previously said, this item is critical, so this test is really important to check the quality of the part at this point of the process.
Going on, an adjustment operation is performed to remove eventual burrs due

[8] Betz, C. E. (1967). *Principles of magnetic particle testing.* Magnaflux Corporation
[9] GSR, 2023, “What Are the Processing Methods for Internal Threads?”

to the previous turning process, followed by a new quality check.
To proceed, an ultrasonic washing phase is needed. The principle of the ultrasonic cleaning machine is to convert the sound energy of the ultrasonic frequency source into mechanical vibration through the transducer. The vibration generated by the ultrasonic waves is transmitted to the cleaning liquid through the tank wall so that the micro-bubbles in the liquid can keep vibrating, destroying and separating the dirty adsorption on the surface of the object (Wikipedia, 2024b)[10]. A lot of attention is needed for parts with high FOD risk. In aviation and aerospace, the term foreign object damage (FOD) refers to any damage to an aircraft attributed to foreign object debris (also referred to as "FOD"), which is any particle or substance, alien to an aircraft or system which could potentially cause damage to it (Wikipedia, 2024a)[11].
Then, the process goes on with two more quality check, a simple visual inspection and a liquid penetrant examination, used to detect surface defects such as hairline cracks due to the previous machining operations, surface porosity, leaks and fatigue cracks.
The parts are now ready to perform the shot peening, a cold work process used to impart compressive residual stresses on to the surface of a component, which results in modified mechanical properties. This process is used to add strength and reduce the stress profile of components, helping to resist the development and propagation of cracks. Stress corrosion cracking is also mitigated internally as the plastic deformation caused by the various types of shot peening aids tensile stressed parts from the inside (Shukla et al., 2014)[12].
An eventual grinding operation is needed to correct measure that are not in the ranges of tolerances defined by drawings.
The parts are now shipped to another supplier, which apply a tungsten carbide coating. The fusion of tungsten carbide causes the coated metal to resist wear much better than unprotected metal, providing better performance and longevity. Another advantage is the reduction of friction: the tungsten carbide particles offer greater smoothness and better overall operation, offering better

[10] Wikipedia. (2024b). *Ultrasonic cleaning*. https://en.wikipedia.org/wiki/Ultrasonic_cleaning
[11] Wikipedia. (2024a). *Foreign object damage*. https://en.wikipedia.org/wiki/Foreign_object_damage
[12] Shukla, P. P., Swanson, P. T., & Page, C. J. (2014). Laser shock peening and mechanical shot peening processes applicable for the surface treatment of technical grade ceramics: A review. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *228*(5), 639–652

resistance to chemicals and high temperatures (Paganoni, 2022)[13]. Coated zone must be cleaned and over-spray is not allowed on the extremity of the steam of the piston. Note that another test part must be separated from the lot, to analyze the results of the operation performed.
Once that the parts are sent back to our factory, they are controlled together with all the documents requested and the test part. Here, also the diameters are measured, before the next grinding operations, where coated diameters and cushion diameters are processed to obtain the required measures and roughness. Then valves threads are calibrated. After these operations, grinded quotas are checked, together with valves threads.
Now, flanges are picked up from the warehouse and taken to the workshop, where the diameter is grinded, so that it can be coupled with the piston immediately afterwards. High attention to the tolerances of the concentricity is needed, or the coupling cannot be done.
Coming to the final phases of the process, an ultrasonic washing is performed again and, in the hydraulic assembly department, valves are mounted on the piston and bonded with a chemical adhesive. This operation has an high FOD risk. Once the final assembly is completed, the pistons are wrapped, and the bag is marked with all the information necessary to track the parts. Finally, after a last quality check, where the conformity of the pieces is controlled, together with the presence of all the documents and stamps that certifies internal and external operations have been done correctly, the production order is closed and the parts are shipped to the warehouse, ready for the assembly process.

3.2.2 Damper assembly process

The beginning of the assembly process is slightly different, as the PCP office brings the production order directly to the finished products warehouse without going through the archive. In the warehouse, all the pieces listed in the bill of materials are picked up and taken to the painting department, where the parts are painted following the schemes in the drawings that indicate the writings to paint, colors to be used and parts that must be protected.
After the drying, parts are washed and assembled, detecting all the data required and checking tightening torques values, which are critical. As in every assembly phase, FOD's risk must be considered and avoided.

[13] Paganoni. (2022). *Tungsten carbide coating: Why is it recommended?* https://www.paganoni.it/en/articles-blog/tungsten-carbide-coating-why-is-it-recommended/

To test the damper, an acceptance test procedure is performed, in which a certain torque is applied on the part and all the data are recorded. The assembly can now be completed with the last parts missing, as the plate, ring nut and o-rings, performing a final wire braking of the ring nut with the plate.
Information as part number, serial number and other data required to keep track of the part are marked on a tally, which is bonded to the damper in a specific zone.
After this process, if necessary, a painting touch-up is performed before the application of a product which is applied as a coating to protect metals commonly used in airframe structures and in aerospace components from corrosion. This coating is able to withstand continuous temperatures up to 150°C and short term exposure to temperatures up to 210°C. This product is colorless and can be applied to aircraft exterior surfaces exposed to high temperatures, for example adjacent to auxiliary power unit (APU) exhaust systems where hot gases are expelled. After the application of this product, the coif is applied and the parts are taken to the final acceptance department, where a last quality check is performed, to verify that all the markings are done correctly, the parts are not damaged, the weight is compliant and that all the documents are correct.
At this point dampers go to the warehouse, being packed in a specific box for FOD prevention and finally shipped to the client.

3.3 The Value Stream Map

In order to better understand the process and the flows of materials and information in the whole supply chain, the Value Stream Map can be a very useful instrument.
Value stream mapping is a lean (manufacturing) technique to analyze, design, and manage the flow of materials and information required to bring a product to a customer. Also known as "material and information-flow mapping", it uses a system of standard symbols to depict various work streams and information flows. It is a fundamental tool used in continuous improvement to identify and eliminate waste. A value stream is all the actions (both value-creating and non-value-creating) required to bring a product from raw material to the arms of the customer (Mukherjee, 2020)[14].

[14] Mukherjee. (2020). *Value stream mapping. learn how this analysis technique can optimize your cd pipeline.* https://www.atlassian.com/continuous-delivery/principles/value-stream-mapping#:~:text=Value%20stream%20mapping%20(sometimes%20called,a%20product%20to%20a%20customer

In this paragraph I'm going to show the construction of the VSMof the production process of a Damper.

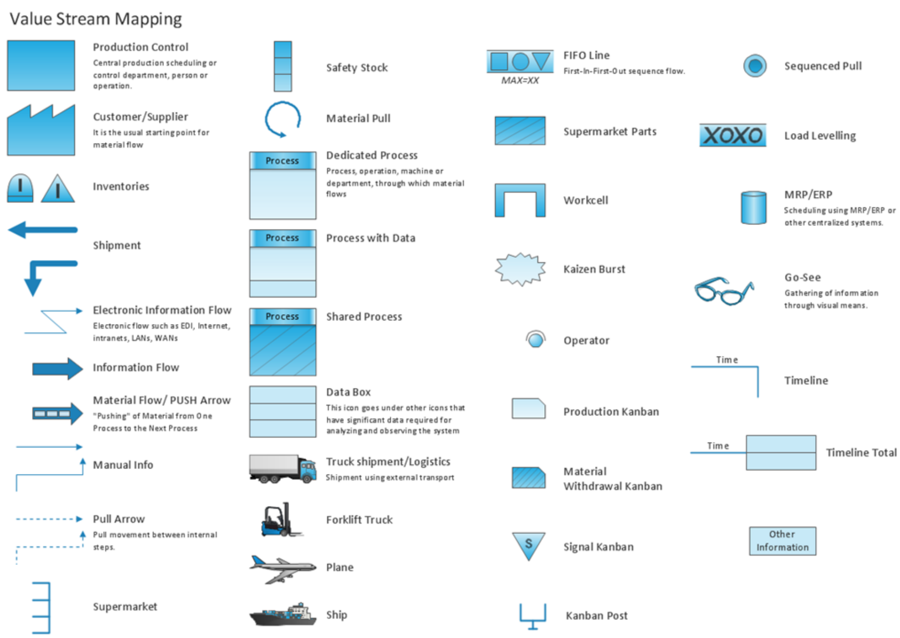


Figure 19: VSM symbols

In Figure 19 up here, most important signs utilized in the VSM are schematized. From now on, I'll use these signs to build the map, based on the process explained in the previous paragraph.
The starting point is the internal exchange of information of the client with his own MRP system (SAP), which is followed by an electronic exchange of information with Supply on, in which orders are charged and are visible for Mecaer. (Figure 20)

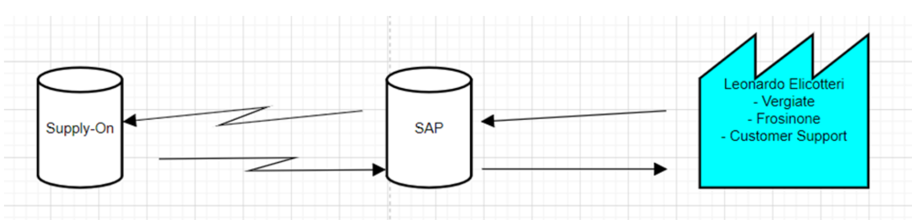


Figure 20: Loading of orders in Supply-On

Always by an electronic information flow, Mecaer's commercial department processes the orders (Figure 21), and accepts (or refuses) them, exchanging information with the quality department. If the order is accepted, it will be charged on Infor (Figure 22)

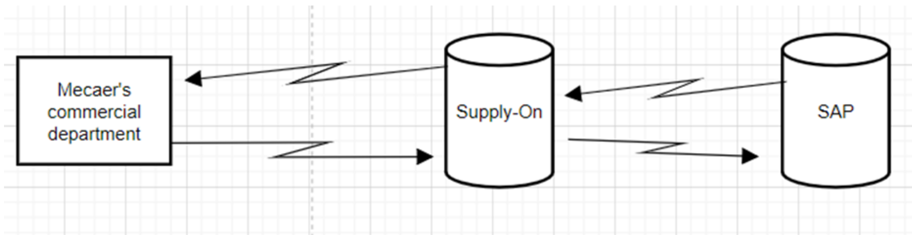


Figure 21: Processing of the order

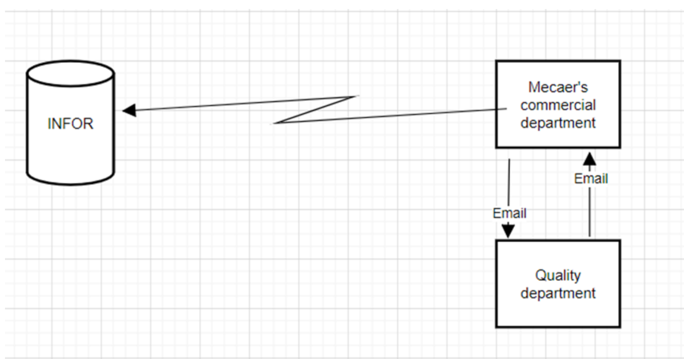


Figure 22: Loading of orders in Infor

Once the order is on Infor, after the weekly MRP run, all the material requests and excel reports are extracted from the system, so that PCP can launch production orders (in which archive has to add documents and drawings) (Figure 23).

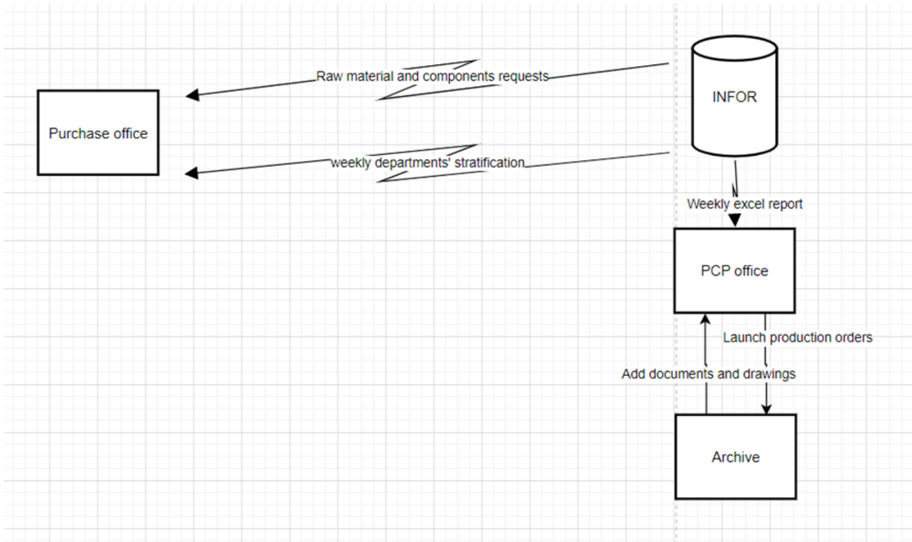


Figure 23: Extraction of excel reports and launch of production orders

Using these files, purchase office can buy raw materials and components from the various suppliers (to be clear, in the Figure 24 and 25 the components' flows are distinguished using different colors).

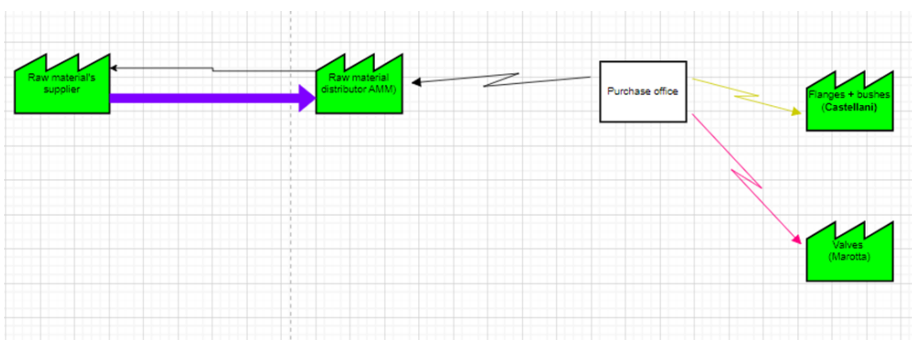


Figure 24: Purchase orders transmission to the suppliers

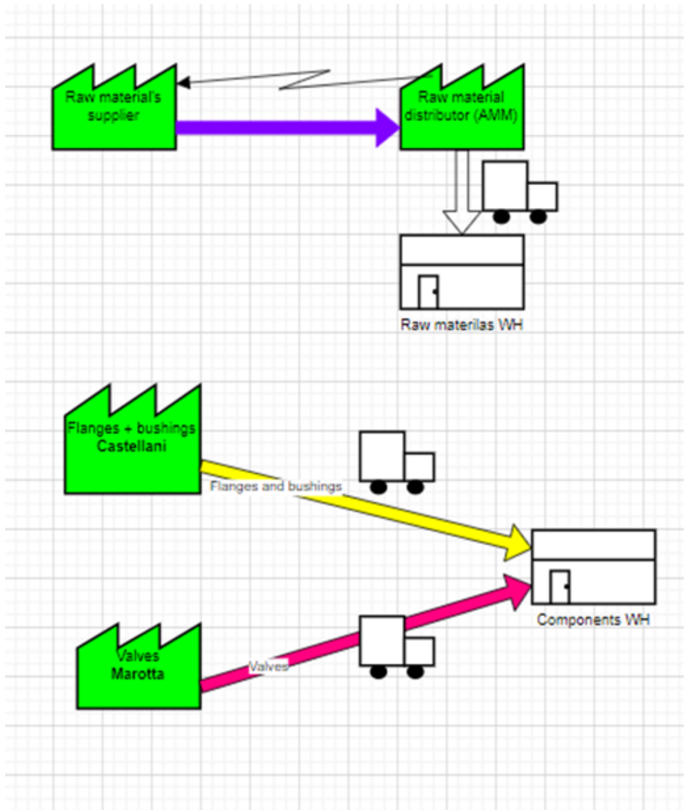


Figure 25: Shipping of the materials to MAG's warehouse

Before arriving in Mecaer's warehouse, raw materials are stored in the intermediator's WH (the transport is not specified, as it can be different based on where the raw material is purchased), where they are picked only if necessary; differently, parts are shipped directly to the components WH by truck. (Figure 25)

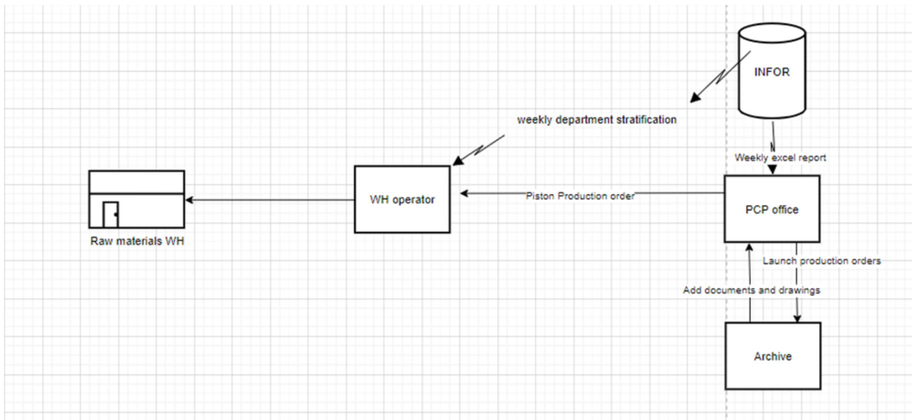


Figure 26: Picking of raw material

Based on the information on the production order, which indicates the quantity of material to be picked, and on the weekly departments stratification, that makes visible to operators the orders in a certain department, the operator prepares the material (Figure 26) which, after the order made by the purchase office (that can see, always through the stratification, orders that need to perform an outsourced operation) is sent by truck to the supplier. When the operation is completed, the material returns to Mecaer's inventory (Figure 27), but just temporarily, as it has to go through the other processes.

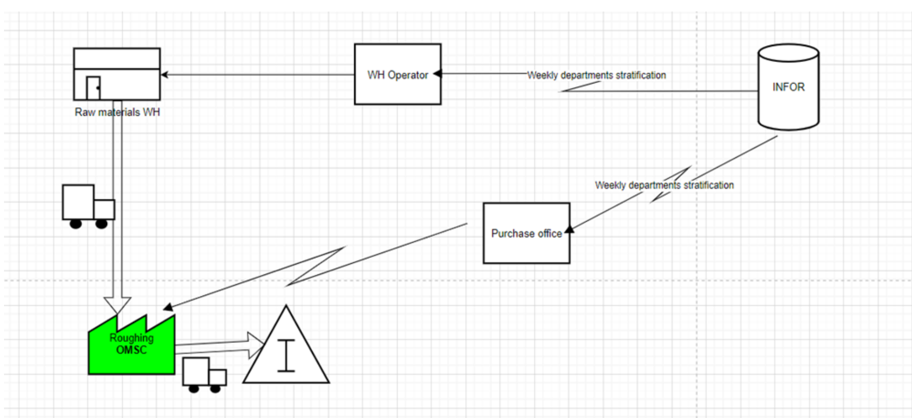


Figure 27: Shipping of raw material, outsourced process and return to the warehouse

At this point, the material is moved between several internal departments to perform all the quality checks and construction operations necessary: it starts from the incoming control, performs conification and turning processes and goes through another dimensional check before the magnetic particles testing (Figure 28).

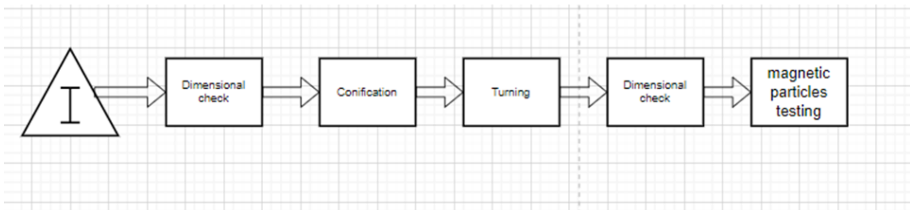


Figure 28: First set of internal operations

Then, the process involves a rolling and a turning, in which a test part is separated from the initial lot and will go to the laboratory. The rest of the lot proceed to the burrs removal and an ultrasonic washing, performed between two different quality checks (Figure 29).

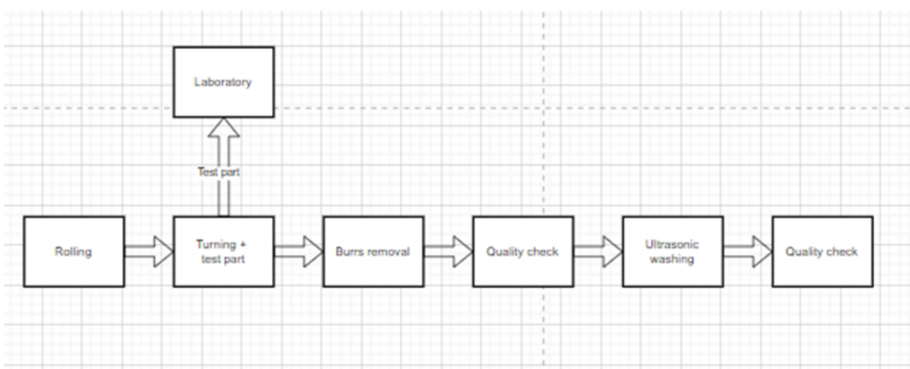


Figure 29: Workshop's operations and separation of the test part

The second control is followed by the liquid penetrant examination. Then, the material is transported to the shot peening department and to the workshop to perform a grinding operation. To proceed, the lot goes to the warehouse, waiting for the order to be done by the purchase office, in order to be shipped (by truck) to the supplier that will manage the tungsten carbon dioxide external operation, before taking it back to our inventory (Figure 30)

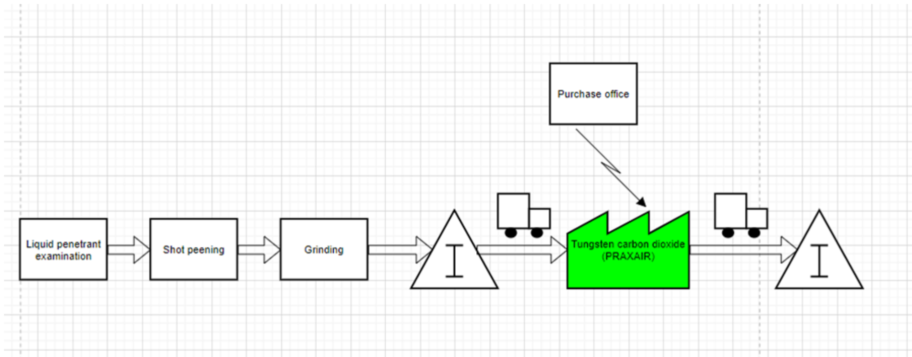


Figure 30: Second external operation

As after every outsourced operation, an incoming quality check is needed. The process goes on with the 4 grinding processes. Eventual burrs are removed afterward and then the material moves on to the non-destructive testing department to perform a dimensional check and another liquid penetrant examination, during which eventual defects could came out (Figure 31).

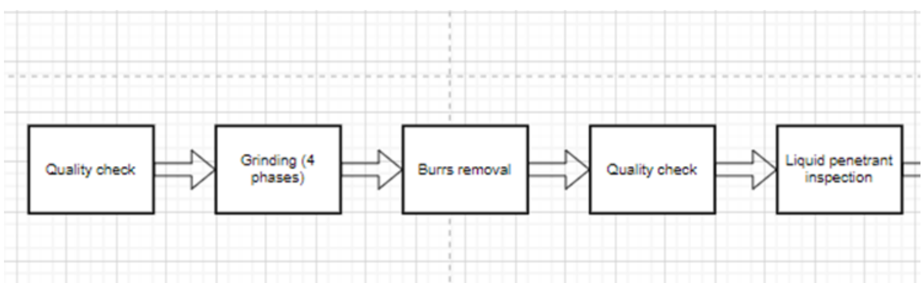


Figure 31: Other set of workshop's operation

Now, bushes and flanges are coupled with the piston in the workshop and then the assembly proceed to the next departments, where the ultrasonic washing is performed and the valves are assembled. Note that, before these phases, bushes, flanges and valves are picked up from the inventory and transported to the department using a forklift (the color of the arrow indicates the flow relative to the component that is transported, as indicated at the beginning of the paragraph).

To end the process relative to the piston flange assembly, marking and final acceptance are performed, and the product is stored in the warehouse (Figure 32).

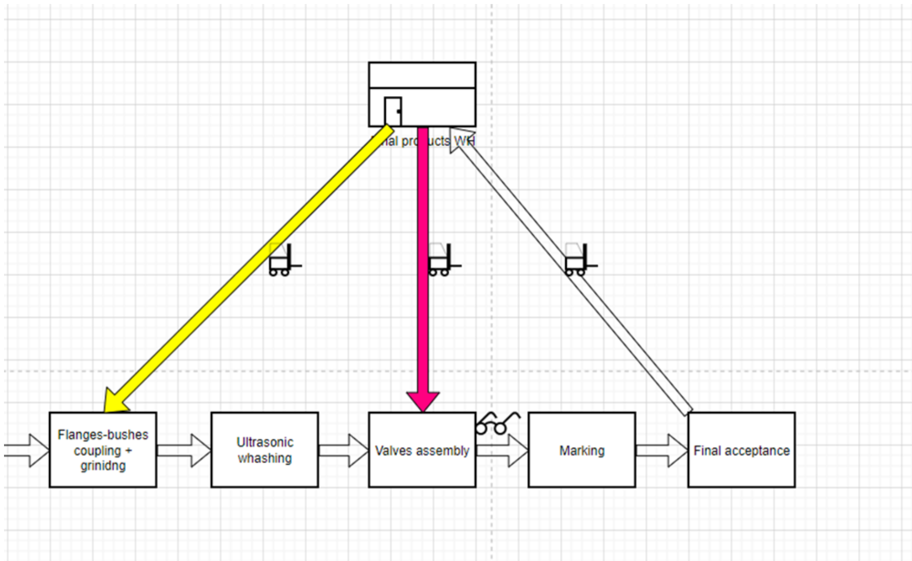


Figure 32: Distribution of components in the departments and ending of the process

At this point, the part of the process regarding the assembly of the damper begins.
PCP office launches the production order, which is brought to the warehouse, where all the parts needed are picked and moved to the department where the kit is assembled. After that, painting is performed and the acceptance test procedure can begin (Figure 33).

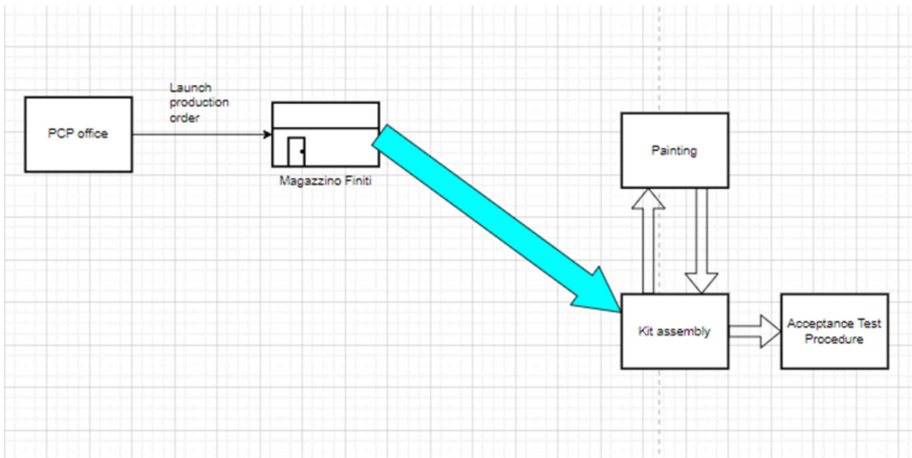


Figure 33: Beginning od damper's assembly process

Once the ATP is passed, the assembly can be completed with all the components missing. At this point the tally is marked and bonded on the damper. When the glue is dry, eventual painting touch-up is performed before the application of the specific product mentioned before in the hydraulic assembly department (Figure 34).

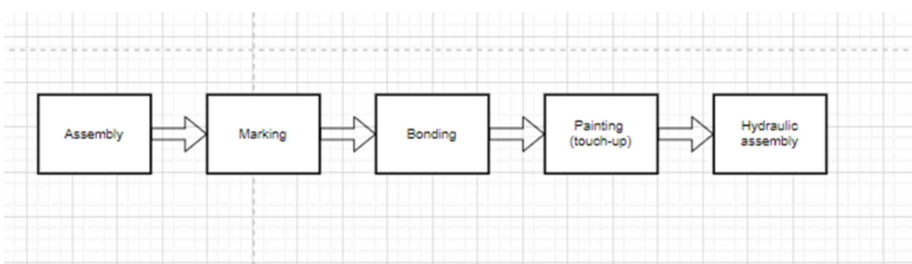


Figure 34: Assembly process of the damper

The damper now reaches the final acceptance, where all the documentation attached is checked and a last quality control is performed. If everything is fine the product can go to the warehouse. In the inventory the parts are prepared for the shipping, an outgoing check is done and all the documents necessary for the expedition are prepared, so that the parts can be charged on the truck that will transport them to the right client's plant indicated in the initial purchase order (Figure 35).

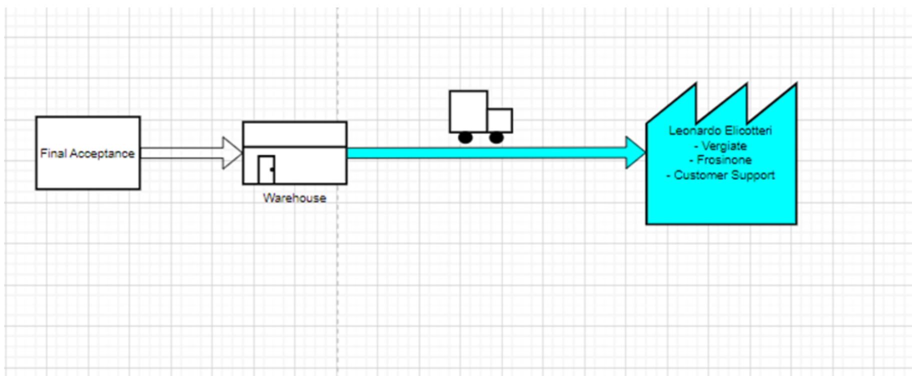


Figure 35: End of the process and shipment to the client

Putting together all the parts of the VSM seen until now, we can compose the final VSM with all the parts of the overall process (Figure 36, 37 and 38).

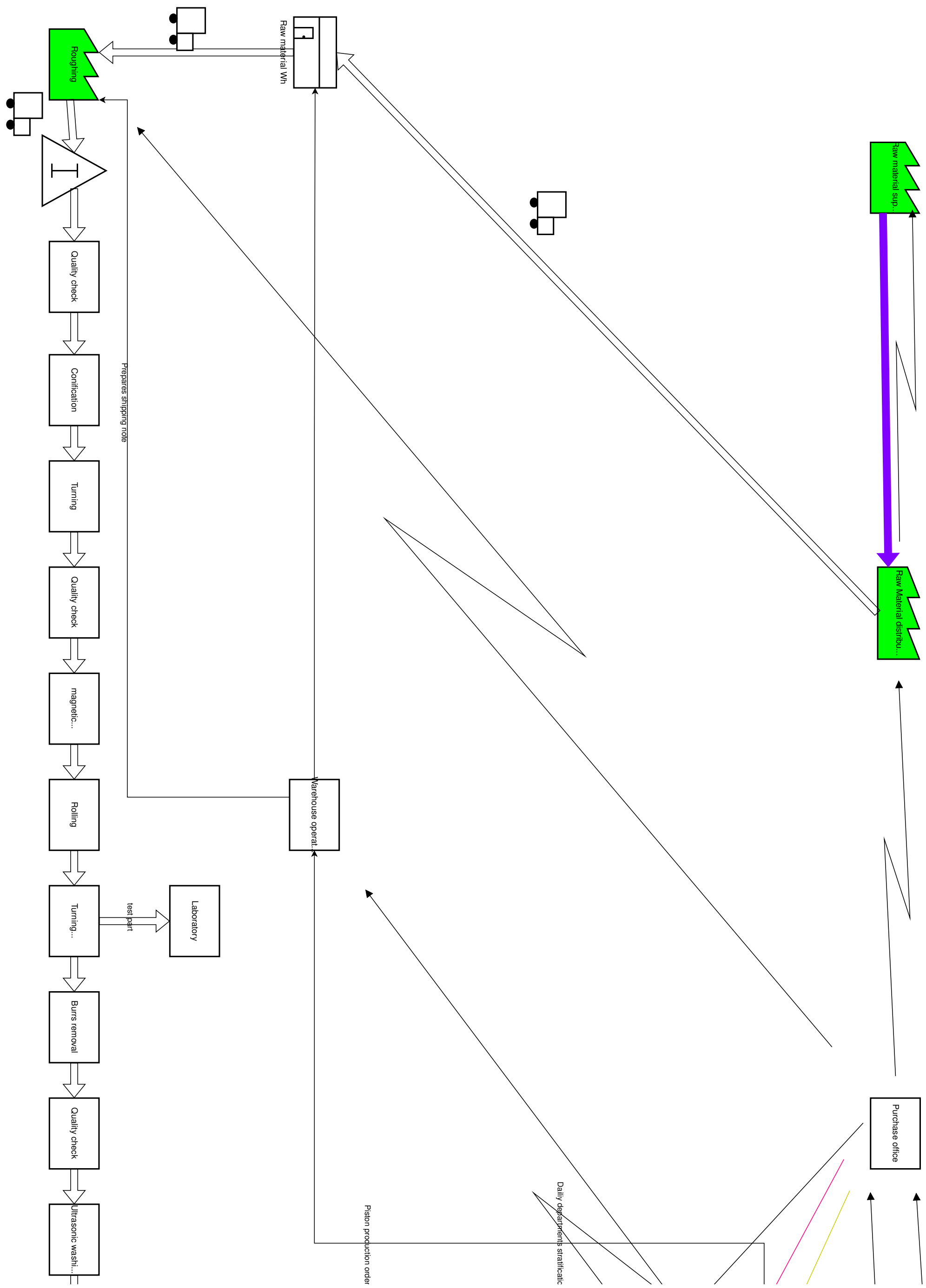


Figure 36: VSM section 1

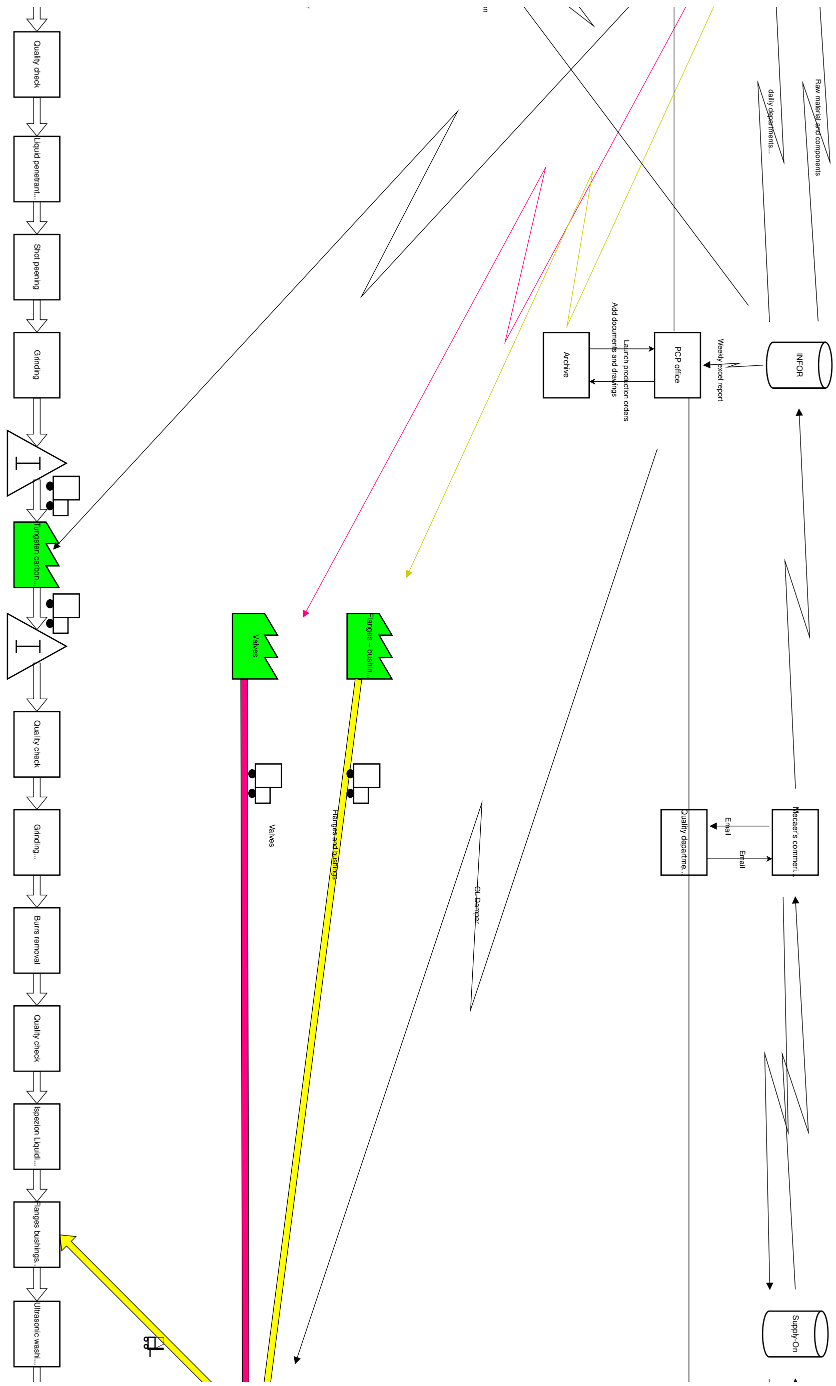


Figure 37: VSM section 2

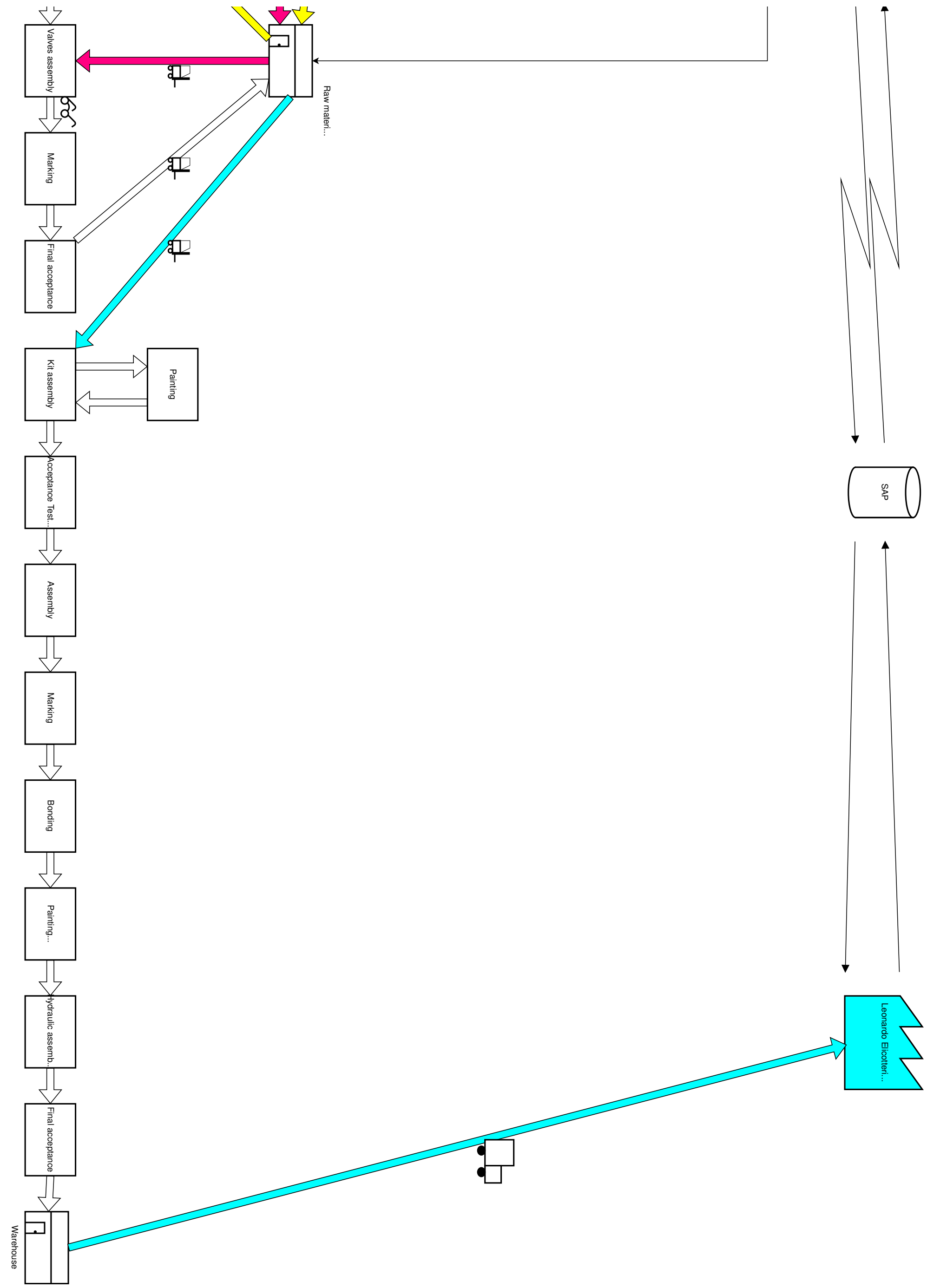


Figure 38: VSM section 3

From this kind of analysis, a series of criticalities that need particular attention came out: staff training, exhaustiveness of procedures, cleaning of the working environment, and the handling of products. In addition, two kind of variables must be taken in consideration, as they can have a strong impact on the quality of the final product:

1. The operator: process' automation is very low, and there is a very high presence of manual work. From the setup of the machines at the beginning of the process, to the final assembly, the operator has a crucial role in the final results, this means that, in some cases, a phase performed by a more experienced operator can be different from a phase done by a less experienced one.

2. The demand: dampers' demand during the year is not constant and it can fluctuate a lot depending on the month. In months with a very high demand, a very high volume of dampers is assembled, this means that some operations are done faster and quality can be lower.

4 Measure

4.1 Basic concepts

The Measure phase (Figure 39) is a data driven understanding of the extent of the problem. In other words, it measures the process performance in its current state in order to understand the issues (Hessing, 2019d)[15].

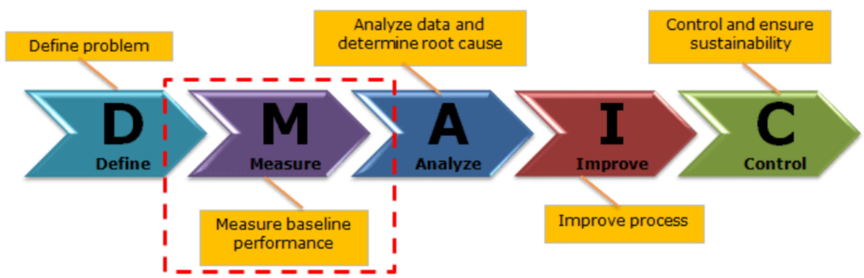


Figure 39: Progress of phases scheme

The goals of this phase are:

- Establishment of baseline performance of the process;
- Identification of process performance indicators;
- Development a data collection plan and then collect data;
- Validation of the measurement system;
- Determination of the process capability.

First, it is important to define the Critical To Qualities (CTQ), which are the factors that need to be focused to reach the target. In this case, the primary CTQ are QN's, divided into QF and QJ (Secondary CTQ): both data are discrete (integers or counts).
Other two important data that have been collected are the number of Non-Conformance Reports (NCR) and the number of Supplier Non-Conformance Reports (SNCR), both with the relative quantity of parts impacted by defects.

[15]Hessing. (2019d). *Measure phase (dmaic)*. https://sixsigmastudyguide.com/measure-phase-dmaic/

NCR is a report done when a defect, which fault could be internal to MAG or external (like a scrap due to an outsourced operation), is found by the quality department; SNCR is a report done by a supplier, if he notices defects due to MAG or to himself. In both cases, after the report is processed, there could be three outputs:

1. Use as is: the parts are accepted in their current state and can go on through the process.
2. Rework: the parts need to be reworked in order to fix them. After the reworking, the lot is checked again to understand if it can proceed or not.
3. Scrap: the parts are not considered acceptable and are discarded.

An important premise must be done about this two data (NCR and SNCR): even if they have been taken during the measure phase of the process, they have not been analyzed under a statistical point of view to understand the performance of the process and have been considered as secondary data. However, they have been really important to notice many problems in the process and played a crucial role to find solutions that have been analyzed in the improve phase.

4.2 Data collection plan

4.2.1 Piston flange assembly's NCR's and SNCR's

The first data collected were the number of NCR and SNCR issued from January to December 2023. The analysis is not limited only to the number of non-compliance but, in order to obtain a broader vision of the process, also the number of parts impacted by defects and the phase in which the non-conformity was detected. Moreover, in this case, the focus has been solely on the piston flange assembly, because this is the part with the highest number of non-compliance detected by MAG, while the other components of the damper have been impacted by a really small number of defects during the previous year.
All the data collected have been inserted in Table 1:

Typ	Quantity	Cause	Responsible	Work station	Month-year
NCR	1	Dent	Mecaer	Burrs removal	aug-23
NCR	1	Dent	Mecaer	Grinding	set-23
SNCR	1	Concentricity out of tolerance	Mecaer	Grinding	jan-23
NCR	1	Concentricity out of tolerance	Mecaer	Turning	jan-23
NCR	1	Concentricity out of tolerance	Mecaer	Turning	jan-23
NCR	2	Concentricity out of tolerance	Mecaer	Turning	feb-23
NCR	4	Concentricity out of tolerance	Mecaer	Turning	feb-23
NCR	1	Taper on stem's diameter	Mecaer	Grinding	jun-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	jan-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	jun-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	jun-23
NCR	4	Increased internal diameter	Mecaer	Burrs removal	dec-23
NCR	6	Diameter out of tolerance	Mecaer	Turning	oct-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	nov-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	dec-23
NCR	1	Diameter out of tolerance	Mecaer	Turning	dec-23
NCR	1	Diameter out of tolerance	Mecaer	Grinding	nov-23
NCR	3	Defects on the grinded stem	Mecaer	Grinding	may-23
NCR	1	Manufacturing defects	Mecaer	Turning	aug-23
SNCR	10	Defects on test parts	Supplier	Dioxide (ext)	jun-23
NCR	1	Defective carbide coating	Supplier	Dioxide (ext)	sep-23
NCR	3	Damaged fillet	Mecaer	Turning	nov-23
NCR	1	Defective cushion	Mecaer	Grinding	nov-23
NCR	1	Damaged fillet	Mecaer	Turning	nov-23
NCR	19	Defects on the grinded hole	Supplier	Roughing (ext)	may-23
NCR	7	Defects on the grinded hole	Supplier	Roughing (ext)	jun-23
NCR	3	Defective carbide coating	Supplier	Dioxide (ext)	sep-23
NCR	1	Tool breakage during masking	Mecaer	Conification	dec-23
NCR	2	Defect on the grinded stem	Mecaer	Grinding	may-23
NCR	1	Signs of grinding wheel	Mecaer	Burrs removal	jan-23
NCR	1	Damaged stem	Mecaer	Burrs removal	apr-23
NCR	1	Damaged stem	Mecaer	Turning	apr-23
NCR	2	Damaged stem	Mecaer	Turning	apr-23

Table 1: NCR and SNCR database

In the first column you can see the type of non-conformity (internal or external); in the second one there is the quantity impacted by defects; in the third the cause of the non conformity; in the fourth the responsible of the non-compliance; in the fifth the work station at which the non-conformity has been found; in the sixth the month in which the report was done.
For a better interpretation of the data, other tables has been constructed :

- Table 2: number of NCR and SNCR per work station:

NCR/SNCR 2023		**Typ**		
Item	**Work station**	**NCR**	**SNCR**	**Tot**
PISTON FLANGE ASSY	Burr removal	4	0	4
	Conification	1	0	1
	Grindng	6	1	7
	Turning	16	0	16
	External (roughing)	2	0	2
	External (tungsten- carbon dioxide)	2	1	3
Tot		31	2	33

Table 2: Defects per work station in 2023

As you can notice, the turning phase is the one with the highest number of non-conformity issued.

- Table 3: Quantity impacted by defects, distinguished by NCR and SNCR and then summed:

Defective parts 2023		**Typ**		
Item	**Work station**	**NCR**	**SNCR**	**Tot**
PISTON FLANGE ASSY	Burr removal	7	0	7
	External (roughing)	26	0	26
	External (tungsten- carbon dioxide)	4	10	14
	Conification	1	0	1
	Grinding	9	1	10
	Turning	28	0	28
Tot		75	11	86

Table 3: Defective parts per work station in 2023

Also in this case, turning is the most critical work station.

- Table 4: Defective quantity per month

Month	Quantity
Jan-23	5
Feb-23	6
Mar-23	0
Apr-23	4
May-23	24
Jun-23	20
Jul-23	0
Ago-23	2
Set-23	5
Oct-23	6
Nov-23	7
Dec-23	7
Tot	86

Table 4: Monthly defective quantities in 2023

- Table 5: Number of NCR and SNCR issued per month:

Month	Number of NCR	Number of SNCR	Tot
Jan-23	4	1	5
Feb-23	2	0	2
Mar-23	0	0	0
Apr-23	3	0	3
May-23	3	0	3
Jun-23	4	1	5
July-23	0	0	0
Ago-23	2	0	2
Sep-23	3	0	3
Oct-23	1	0	1
Nov-23	5	0	5
Dec-23	4	0	4
Tot	31	2	33

Table 5: Monthly number of NCR ad SNCR

From these last two tables it is clear that defects are not distributed equally between months, but there could be some peaks, particularly in the quantity impacted.

4.2.2 QF and QJ

Data collection plan: 100% of the parts delivered to LHD from January 2022 to October 2023 (all plants) were sampled (Sala, 2024)[16]. Number of dampers affected by non-conformity in reception (QF: 75) and post-acceptance (QJ: 86) have been compared to the number of dampers received (1217):

$$\mathbf{Significance} = \frac{\mathbf{QF+QJ}}{\mathbf{n_{dampers}}}$$

Are this data representative? Since 100% of the data has been sampled, all process conditions are intercepted.

Validation of the measurement system was done by qualitative considerations (check list). The collected data may be subject to imperfections related to the non-reimputation of responsibility from Mecaer to Leonardo in case this results in No Fault Fount in MAG. The monthly deliveries may also be inaccurate as the incoming activity in Leonardo (the generation of the incoming batch) may not be simultaneous with the receipt of the damper. With reference to the QJs, these are issued by Vergiate. The time between the entry and the generation of a possible QJ varies between 6 and 8 months (the damper arrives in Frosinone, is mounted on the hub that is sent to Cascina Costa where, in turn, it is installed on the Main Gear Box and shipped along with the transmission to Vergiate).

[16]Sala. (2024). Riduzione dei difetti su Damper AW139

4.3 Graphical summary QN

In order to measure QNs under a statistical point of view, the monthly percentage of defects from January 2022 to October 2023 has been measured, for a total of 22 observations (Sala, 2024)[17]. All data collected have been grouped in Table 6:

Month	QJ	QF	QF+QJ	Delivered	%Defects	%Defects QJ
2022-01	23	0	23	41	56%	56%
2022-02	0	0	0	21	0%	0%
2022-03	7	0	7	68	10%	10%
2022-04	16	0	16	73	22%	22%
2022-05	6	0	6	76	8%	8%
2022-06	0	2	2	65	3%	0%
2022-07	10	4	14	37	38%	27%
2022-08	2	4	6	44	14%	5%
2022-09	1	10	11	65	17%	2%
2022-10	5	16	21	59	36%	8%
2022-11	2	1	3	22	14%	9%
2022-12	0	7	7	14	50%	0%
2023-01	0	2	2	79	3%	0%
2023-02	1	0	1	22	5%	5%
2023-03	2	2	4	85	5%	2%
2023-04	4	10	14	54	26%	7%
2023-05	3	2	5	81	6%	4%
2023-06	2	5	7	71	10%	3%
2023-07	2	0	2	58	3%	3%
2023-08	0	0	0	60	0%	0%
2023-09	0	3	3	83	4%	0%
2023-10	0	7	7	39	18%	0%

Table 6: Data base for QJ and QN

- In the first column there are the months in which the observation has been done, for a total of 22;
- In columns "QJ" and "QF" there is the number of claims received in each month, which are summed in column "QJ+QF" (which is the QN);
- "Delivered" represent the quantity of dampers received in each month;
- "%Defects" indicates the total percentage of defects (QN) in the quantity shipped, calculated doing $\frac{QF+QJ}{Delivered} * 100$;

[17] Sala. (2024). Riduzione dei difetti su Damper AW139

- "%Defects QJ" indicates the percentage of QJ in the quantity of dampers delivered using the formula $\frac{QJ}{Delivered} * 100$.

The data have been plotted (using Minitab) to understand if the distribution is normal (using the Anderson-Darling normality test), and to find outliers. The Anderson-Darling normality test (Stephens, 1979) [18]rejects the hypothesis of normality when the p-value is less than or equal to 0.05. Failing the normality test allows you to state with 95% confidence the data does not fit the normal distribution. Passing the test only allows you to state no significant departure from normal distribution was found. The results are shown in the graphs in Figure 40:

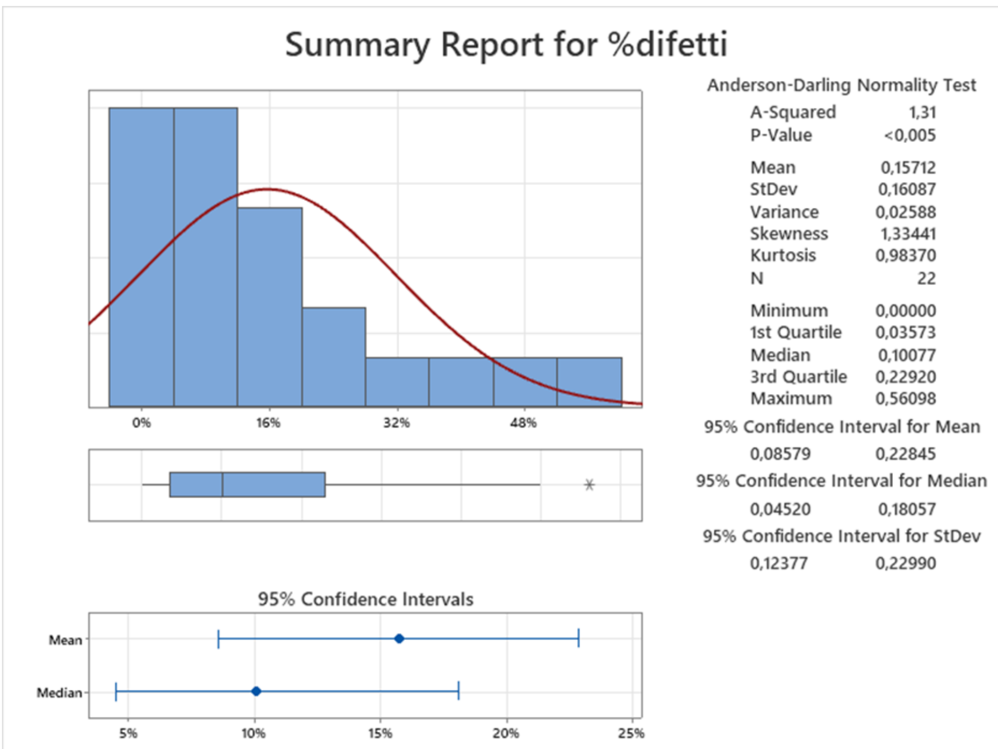


Figure 40: Graphical summary of QN

As the p-value is less than 0.05, the distribution is not normal, this is clear also from the curve in the graph. In the first quartile (which correspond to 25%

[18]Stephens, M. A. (1979). Tests of fit for the logistic distribution based on the empirical distribution function. *Biometrika*, *66*(3), 591–595

of total defects), defects are less then 3%. Moreover, looking at the histogram, there is only one outlier that corresponds to a defectiveness of 56%.
It's also useful to understand if there are some special causes for defects. This can be done analyzing the time pattern of defects with a run chart (Figure 41):

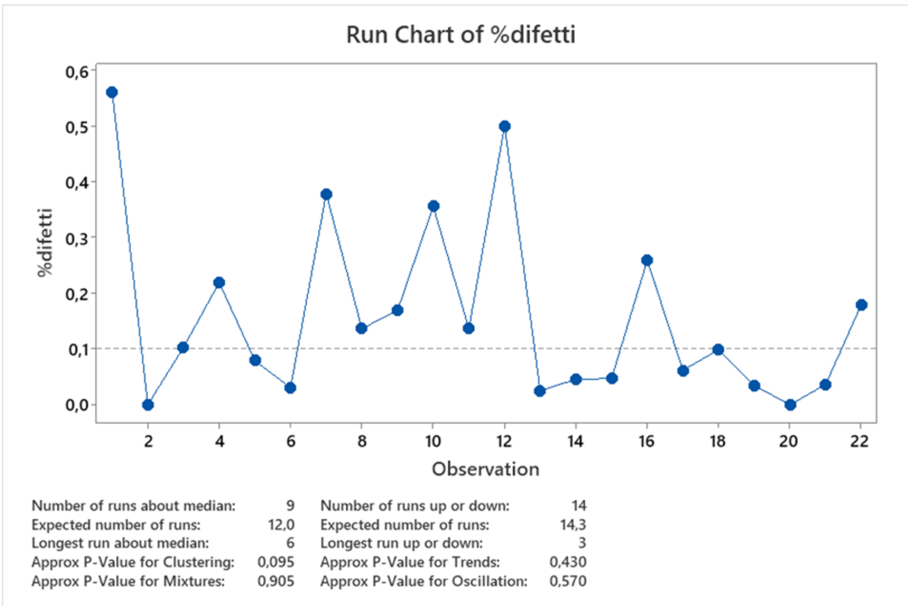


Figure 41: Enter Caption

Since the p-value is less then 0.5%, the hypothesis that there are special causes is rejected. Some oscillation can be noticed, but this could be due to the difference in quantity received between different deliveries. At this point, a P-chart (6Sigma.us, 2019)[19] (Figure 42) can be helpful to find eventual points of instability:

[19]6Sigma.us. (2019). *Six sigma terminology – p chart. what is it and how it works.* https://www.6sigma.us/six-sigma-in-focus/p-chart/#:~:text=P%20Chart%20Stability%20and%20Variation,process%20that%20should%20be%20improved

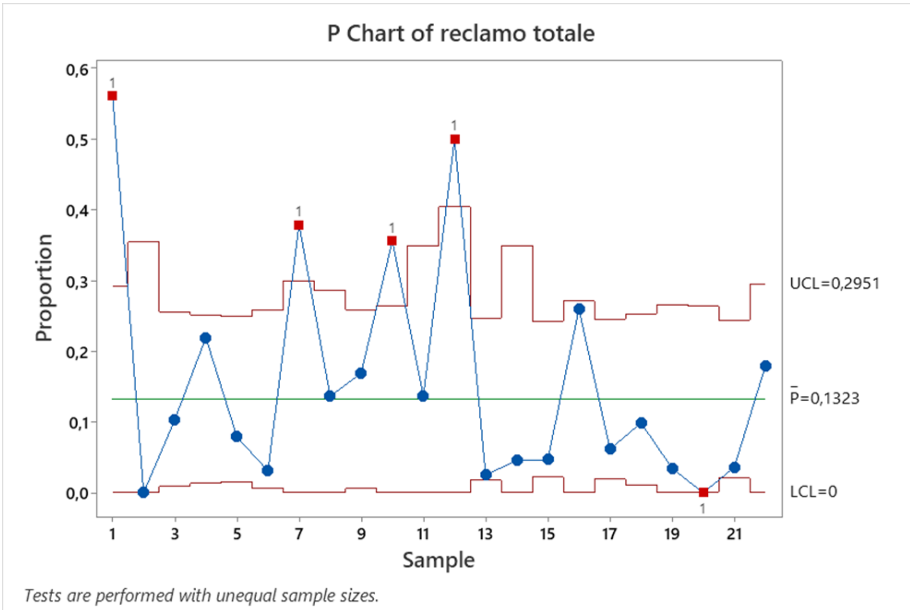


Figure 42: QN's P-chart

Looking at the graph, there are 5 points of instability (four negative and one positive), which are the ones that are beyond control limits. However, it was not possible to understand the cause of these outliers.

4.4 Graphical summary QJ

The same analysis done on QNs can be applied to QJs, using the same time frame and, as a consequence, the same number of observations, which is 22 (Sala, 2024)[20]. Exactly as before, the starting point is understanding if the distribution of the data is normal or not (Figure 43):

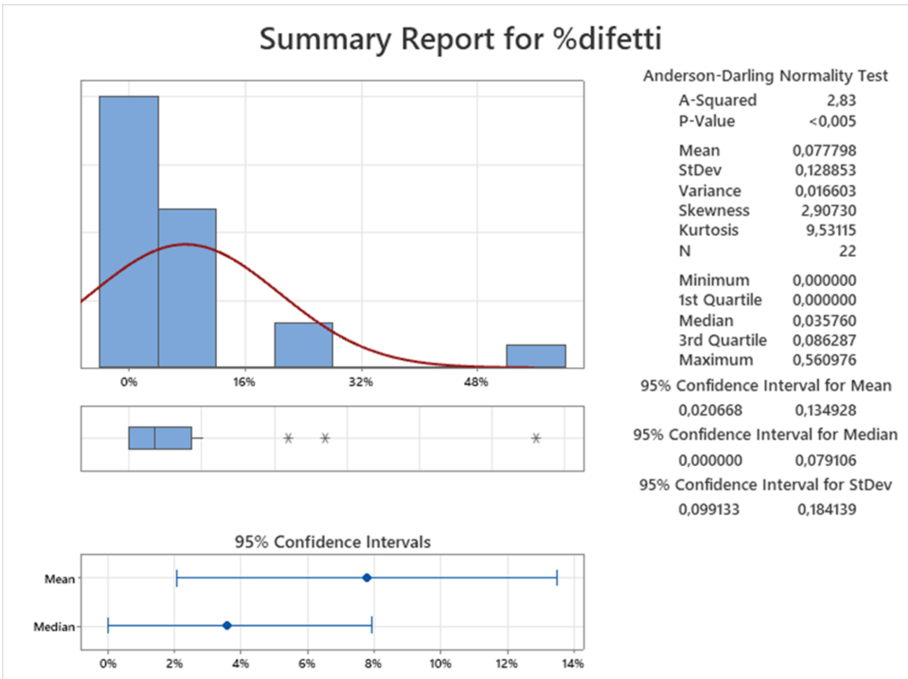


Figure 43: Graphical summary of QJ

First thing to be noticed is the p-value smaller than 0.05, which means that the hypothesis that the distribution is normal is rejected. In this case, in the first quartile dampers' defectiveness is 0 and there are three outliers, but, as before, no special cause has been found for them.

[20]Sala. (2024). Riduzione dei difetti su Damper AW139

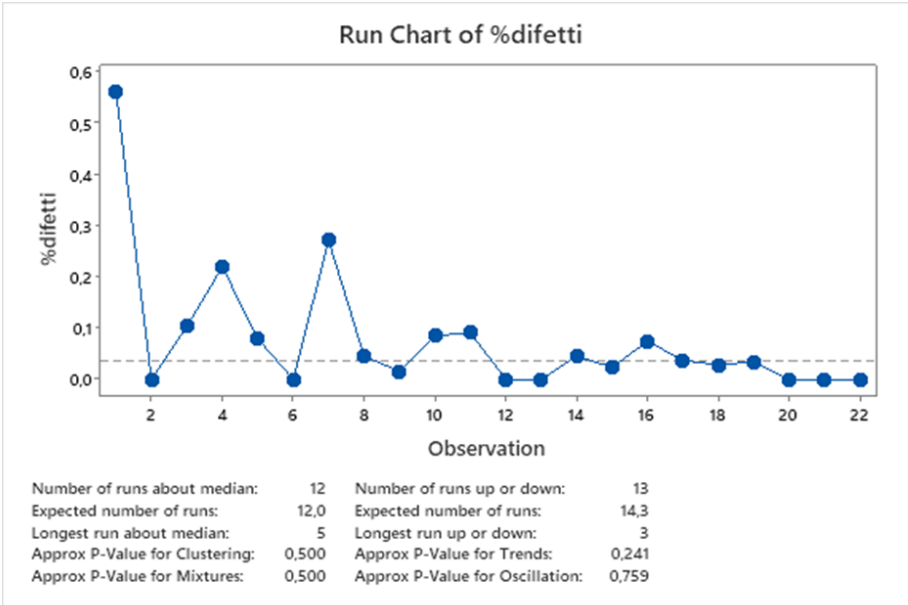


Figure 44: Run chart QJ

Figure 44 shows different oscillation but, since the p-value is less than 0.5, there are no special causes and these anomalies can be due to the different numerosity of deliveries during time.

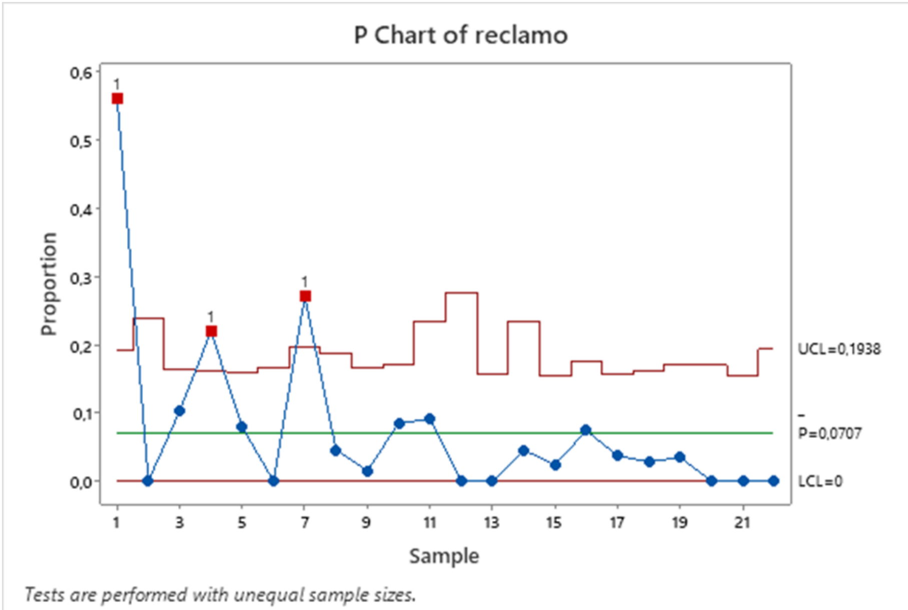


Figure 45: P-chart QJ

Finally, looking at the P-chart in Figure 45, three negative instability points are clearly visible, but no specific cause could be found.

4.5 Calculation of the Process Sigma

Since one of the objectives of this project is the reduction of defects in the process, it's necessary to increase process efficiency. A good indicator for the process efficiency is the Process Sigma (Terek, 2023)[21]: the goal of the Six Sigma methodology is to strive for a process with no defects in its output and the "level" sigma indicates how close a company is to an hypothetical zero defects scenario. For this calculation, the following information are needed:

- Number of opportunities for failure (O): in this case the part can be defective of not, so O=1;
- Number of units inspected (U);
- Defects (D);
- Number of defects per million opportunities (DPMO): $\frac{D}{O*U} * 1000000$

[21]Terek, M. (2023). How to estimate the sigma level of the process. *Quality Innovation Prosperity*, *27*(3), 126–140

- Efficiency: $1 - \frac{DPMO}{1000000}$

Process Sigma is a tabulated value and corresponds to the inverse of the cumulative normal distribution plus 1.5.
Starting from QN, initial data are: O=1, U=1217 and D=161. From the previous formula DPMO=132293 and Efficiency=86.77%, which correspond to a Process Sigma=2.62 (Sala, 2024)[22]. All this information are summarized in Figure 46:

PROCESS SIGMA QN	
Number of opportunities for failure (O)	1
Number of units inspected (U)	1217
Defects (D)	161
Number of defects per million opportunities (DPMO)	132293
Process efficiency	86,77%
Process Sigma	2,62

Figure 46: Calculation of process sigma for QN

Now, looking at QJ only, knowing that O=1, U=1217 and D=86 a DPMO=70666 is found, which correspond to an Efficiency=92.93%, which in turn is equivalent to a Process Sigma=2.97 (Figure 47):

[22] Sala. (2024). Riduzione dei difetti su Damper AW139

PROCESS SIGMA QJ	
Number of opportuinities of failure (O)	1
Number of units inspected (U)	1217
Defects (D)	86
Number of defects per million opportunities (DPMO)	70666
Process efficiency	92,93%
Process Sigma	**2,97**

Figure 47: Calculation of process sigma for QJ

Since this project has been done to reduce product's defects, the focus was only on QJs.

5 Analyze

5.1 Theory

Analyze phase is the third phase of DMAIC (Figure 48): the main activity is to identify the potential cause of the problem and arrive at the actual root cause, using the data obtained in the previous phase. At the end of this phase, the most significant impact on CTQs is identified.

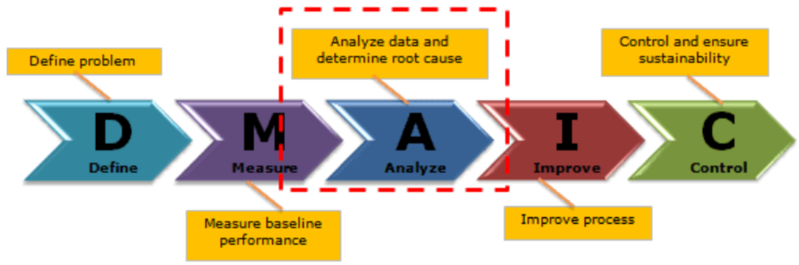


Figure 48: Progress of phases scheme

The Analyze phase is all about reviewing the process map to improve efficiency, listing the probable root causes (Root Causes Analysis)(Robitaille, 2010)[23], and identifying important factors/inputs that greatly impact the output using statistical tools like hypothesis testing (Hessing, 2019a)[24].

5.2 Quantitative analysis: Hypothesis Testing

Hypothesis Testing is a key procedure in inferential statistics to make statistical decisions using experimental data. It is basically an assumption made about the population parameter. The Chi-Square test is a statistical procedure for determining the difference between observed and expected data. This test can also be used to decide whether it correlates to our data categorical variables. It helps to determine whether a difference between two categorical variables is due to chance or to a relationship between them. The Chi-Square Test of

[23]Robitaille, D. (2010). *Root cause analysis.* Paton Professional

[24]Hessing. (2019a). *Analyze phase (dmaic).* https://sixsigmastudyguide.com/analyze-phase-dmaic/

Independence (Plackett, 1983)[25] is a derivable (also known as inferential) statistical test which examines whether the two sets of variables are likely to be related with each other or not.
The P-Value in a Chi-Square test is a statistical measure that helps to assess the importance of the results. Here P denotes the probability; hence for the calculation of p-values, the Chi-Square test comes into the picture. The different p-values indicate different types of hypothesis interpretations:

- $P \leq 0.05$: Hypothesis interpretations are rejected;
- $P \geq 0.05$: Hypothesis interpretations are accepted.

In this case the Chi-square hypothesis testing is performed to see if the month is an impacting element, in other words, if there is a correlation between peak defects and months of delivery (Figure 49):

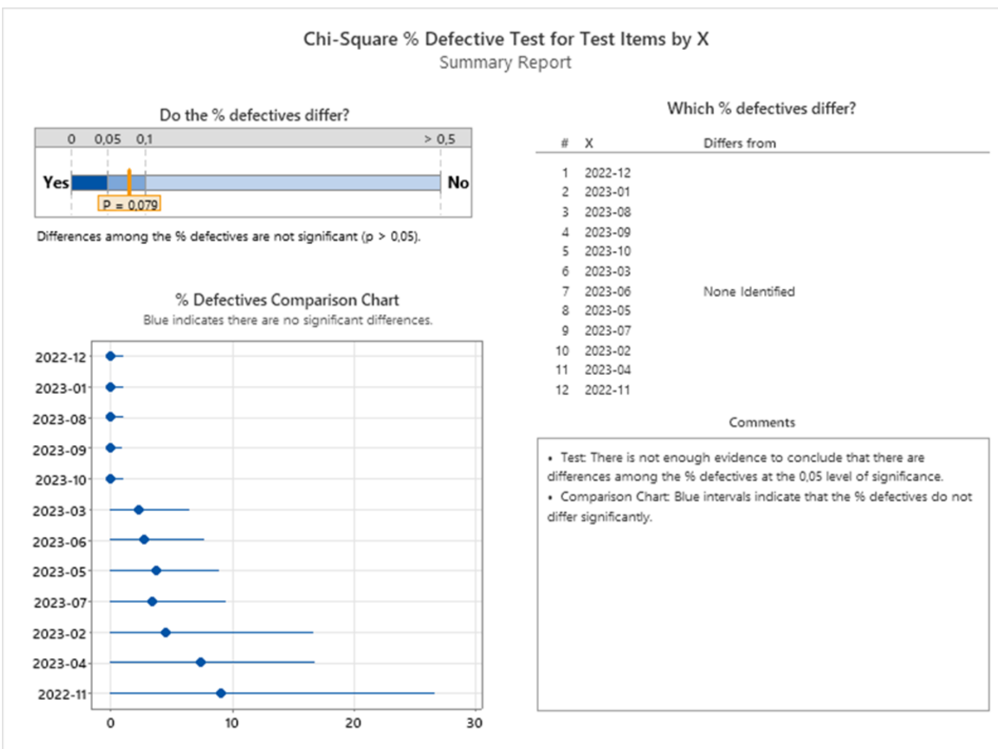


Figure 49: Chi-square analysis for QJ

[25] Plackett, R. L. (1983). Karl pearson and the chi-squared test. *International statistical review/revue internationale de statistique*, 59–72

Since P=0.079 > 0.05, there is not enough evidence to conclude that there are differences among the %defects at the 0.05 level of significance, this means that the month appears to be a non-significant element (Sala, 2024)[26]. The Comparison chart shows that there are not significant differences between %defectives.

5.3 Root Cause Analysis

Starting from all the NCRs grouped in the measure phase, an analysis has begun to understand direct causes of all the defects, in order to identify the root causes of the problem. This is a *Root Cause Analysis*(Robitaille, 2010)[27], which is a collection of tools and processes that can be used to determine the most important causes for the issue that the project aims to resolve. To reach this goal, two different types of qualitative analysis have been performed: the Cause and Effect Diagram and, to follow, the 5 Whys method, to analyze the causes individuated before.

5.3.1 Cause and Effect Diagram

A cause and effect diagram, also known as an Ishikawa or "fishbone" diagram (Ishikawa, 1982)[28], is a graphic tool used to explore and display the possible causes of a certain effect. This diagram is used when causes group naturally under the categories of Materials, Machine, Measurement, Nature, Methods and People.

This method is useful for the team to understand that there are many causes that contribute to an effect, it graphically displays the correlation of the causes to the effect and to each other and it helps to identify areas for improvement. The final diagram (Sala, 2024)[29]is visible in Figure 50:

[26]Sala. (2024). Riduzione dei difetti su Damper AW139

[27]Robitaille, D. (2010). *Root cause analysis.* Paton Professional

[28]Ishikawa, K. (1982). *Guide to quality control.* New York: Asian Productivity Organization

[29]Sala. (2024). Riduzione dei difetti su Damper AW139

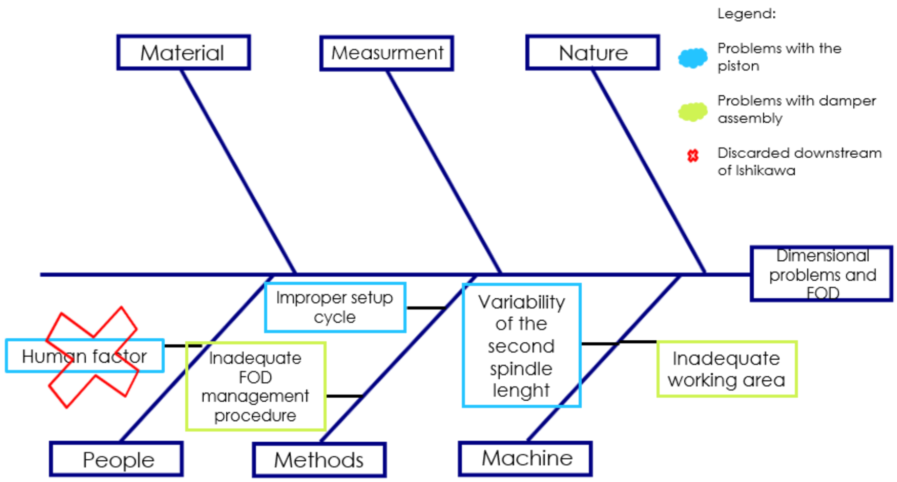


Figure 50: Fishbone diagram

To each of the categories a possible cause to the main problems (dimensions and FOD) has been found. The human factor has been discarded afterwise, since it is the most difficult to control.

5.3.2 5 Whys method

According to Ohno (Ohno, 2019)[30], it is a simple tool to ask "Why" until we can't ask "Why" again. Five is a good rule of thumb (of course arbitrary). By often querying "Why", we can quickly reach the underlying causes of a problem. This method aims to go beyond the obvious symptoms to discover the root cause of an issue.
With reference to the 4 possible causes identified (Sala, 2024)[31]:

1. Improper setup cycle (dimensional problem):
    - 1st Why: the tool used was not suitable;
    - 2nd Why: the operator was not aware of the appropriate gear to be used;
    - 3rd Why: the setup cycle was not exhaustive about the tool to be used (**Root cause**).

[30] Ohno, T. (2019). *Toyota production system: Beyond large-scale production.* Productivity press

[31] Sala. (2024). Riduzione dei difetti su Damper AW139

2. Variable length of second spindle's jaw (dimensional problem):
   - 1st Why: the second spindle is made of a less hard material than the first spindle;
   - 2nd Why: it is a support tool and therefore the material of which it is made cannot be modified (**Root cause**).
3. Inadequate FOD management procedure (FOD problem):
   - 1st Why: the internal procedure, which was established in 2000, did not yet cover the concept of FOD;
   - 2nd Why: there were no FOD problems to the point where they could see that the procedure was not appropriate;
   - 3rd Why: as the FOD concept began to spread, the need for a procedure that implements international standards became clear (**Root cause**).
4. Inadequate working area:
   - 1st Why: assembly area was obsolete in terms of tools and benches;
   - 2nd Why: the update of the FOD procedure has highlighted some shortcomings in terms of access regulation and management of the area, also in terms of tools and equipment (**Root cause**)

5.3.3 Application to NCRs

The root causes founded, have been compared to the NCRs to find a single cause to every defect, in order to have a more specific situation of the problems, as you can see in Table 7:

NCR description	Workstation	Direct Cause	Root Cause
Concentricity of the piston out of tolerance	Grinding	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Defects on the grinded stem	Grinding	Operator error in grinding wheel approach activities	Human factor
Taper on stem's diameter	Grinding	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Dent	Grinding	Fall of the part	Human factor
Signs of grinding wheel	Grinding	NA	Setting new grinding wheel
Defective cushion	Grinding	Operator error in grinding wheel approach activities	Human factor
Stem's diameter out of tolerances in the unthreaded part	Grinding	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Diameter out of tolerances	Turning	Error in positioning second spindle	Variable length of the second spindle's jaw
Concentricity of the piston out of tolerance	Turning	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Concentricity of the piston out of tolerance	Turning	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Concentricity of the piston out of tolerance	Turning	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Damaged stem	Turning	Presence of chips during threading	Chip not properly evacuated
Damaged stem	Turning	Presence of chips during threading	Chip not properly evacuated
Diameter out of tolerances before rolling	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Diameter out of tolerances before rolling	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Damaged stem	Turning	Presence of chips during threading	Chip not properly evacuated
Concentricity of the stem out of tolerance	Turning	Operator misset up of the measuring instrument	Procedure for setting up the tool not exhaustive
Manufacturing defects	Turning	Error in the positioning of the second spindle	Human factor
Increased internal diameter	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Damaged fillet	Turning	Tool breaking	Breaking of the tool occurred before the time set
Increased external diameter	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Diameter out of tolerances	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Diameter out of tolerances	Turning	Error in the positioning of the second spindle	Variable length of the second spindle's jaw
Signs of grinding wheel	Burrs removal	Error by the operator	Human factor
Damaged stem	Burrs removal	Error by the operator	Human factor
Dent	Burrs removal	Error by the operator	Human factor
Valve seat inner diameter increased	Burrs removal	Error by the operator	Human factor

Table 7: Root and direct cause analysis

As you can see, here the "Human factor" discarded in the Cause and Effect Diagram has been maintained, to understand which of the defects was caused by an human error. Note that in some cell the root cause is "Chip not properly evacuated": this is a more specific case of FOD problems.

5.3.4 Conclusions of the Root Causes Analysis

The analysis has raised some critical issues that need to be improved:

- Regarding dimensional problems, the generality of the causes provided makes it difficult to properly analyze root causes and, as a consequence, to find a solution;

- The problem of FOD in dampers was due to a lack of attention and prevention during assembly operations and an environment not suitable for this kind of activity. This was due also to a lack of proper procedure to follow at the time in which the analysis has been done.

- The cause of slow improvement process in the past may be due to poor root cause analysis done before by MAG, so there wasn't a clear idea of the real problem behind the high number of complaints and rejects.

6 Improve

6.1 Introduction

Improve phase is the fourth phase (Figure 51) of DMAIC. The main activity of this step is determining the solutions for the problems identified previously. In other words, during this phase, the team focuses on eliminating the root causes and implementing the improvements. Additionally, the team designs the action plan to monitor continuous improvements (Hessing, 2019c)[32].

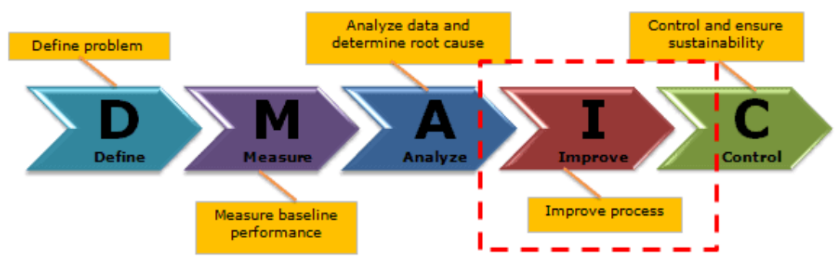


Figure 51: Progress of phases scheme

6.2 Process improvement plan

The improvement plan regarding AW139's damper (Vassallo, 2024)[33] is part of a wider plan shared with the client, which aims to improve general quality of products and processes and, moreover, to solve problems regarding different products critical for LHD.

The plan is divided in 5 steps:

- Step 0: Immediate actions
- Step 1: Recognize
- Step 2: Analyze and identify
- Step 3: Redesign and implement

[32]Hessing. (2019c). *Improve phase (dmaic)*. https://sixsigmastudyguide.com/improve-phase-dmaic/

[33]Vassallo, B. E. (2024). Improvement Plan LHD [Mecaer Aviation Group internal document]

- Step 4: Monitor and review

This steps are in common for all the products involved in the plan, but, for the purposes of this thesis, the focus will be only on the damper. Each step, on its own, is divided into some main points.

6.3 Step 0: Immediate actions

The first step regards all the actions to be taken in the short term. The three main points of this phase are:

1. *Detailed recurrent training*: Increase the awareness of all MAG team on quality aspects (occurrences happened, filling in documents, importance of own stamp, stamp management, FOD prevention, corrections management, maintenance cards, products expire date). Moreover,recurrent training (1 hour/session) has been planned for all the operators in a time frame of five weeks.

2. *Continuous monitoring on manufacturing documents*: Production records have been strictly controlled with the use of dedicated KPI.

3. *Detailed actions on open points*: open points are all the problems reported by the client that need an immediate resolution. Regarding dampers: issue of a Q.A. (Quality Alert: a document which states that some defectives products received by the client are returning to MAG to be repaired); inspection of 5 dampers impacted by a QJ; control of 100% of piston flange assembly's WIP; performed an analysis on all NCRs issued on piston flange assembly from January 2023 to December 2023 (as seen in Paragraph 3.2); revision of piston control method and issuance of a new Control Sheet.

6.4 Step 1: Recognize

This short step aims to pinpoint all the process that need improvements. This phases of the process have been selected through internal surveys. Technical and quality audits (noticed and not noticed) were developed in all areas, with particular attention to those that came out from the surveys cited before. The departments that needed to be prioritized were:

- Assembly areas;

- Mechanic's shop;

- Painting Area;
- Incoming Inspection (Customer Subcontracted activities, this means that the client sent to MAG some operators to check incoming control procedures);
- Final Inspection;
- Review of records in manufacturing documents.

To ensure quality also from a documentary point of view, a continuous monitoring on manufacturing records is needed (this activity is still ongoing).

6.5 Step 2: Analyze and identify

In this step, a method is defined to analyze the process and to understand what needs to be improved. More precisely, a dedicated check list has been developed and used as a guideline to improve the audit effectiveness and standardization. The process has been analyzed and, as anticipated in Step 0 (and in the Analyze phase), all NCRs on the piston flange assembly have been checked to find a direct and a root cause to each of the problems identified. This information will be useful to find solutions in Step 3.

6.6 Step 3: Redesign and implement

This is the core phase of the plan, in which the solution are implemented to improve the system. The objectives of this step are: design for process improvement; engage team members in re-design; set timelines and deadlines for implementation.
The main actions done to enhance the process and reach the objectives are the following.

Improvement of the control sheet: the control sheet (Figure 52) explains how to check the part and the quotas to be measured. A more accurate and standardized document could help the operator to be precise and find eventual defects. To this aim, the control sheet has been modified adding many specific indications:

- control all the parts of the lot with P/NP swab;
- control of internal diameter dimension of all the parts of the lot;

- control with a profilometer on first and last pieces of the batch and in case of male replacement;
- uninterpretable understanding of the tools to be used;
- verification and validation of required measurement accuracy (decimal places);
- Updating the booklet (no spaces for registrations) and confirming traceability of planned registrations.

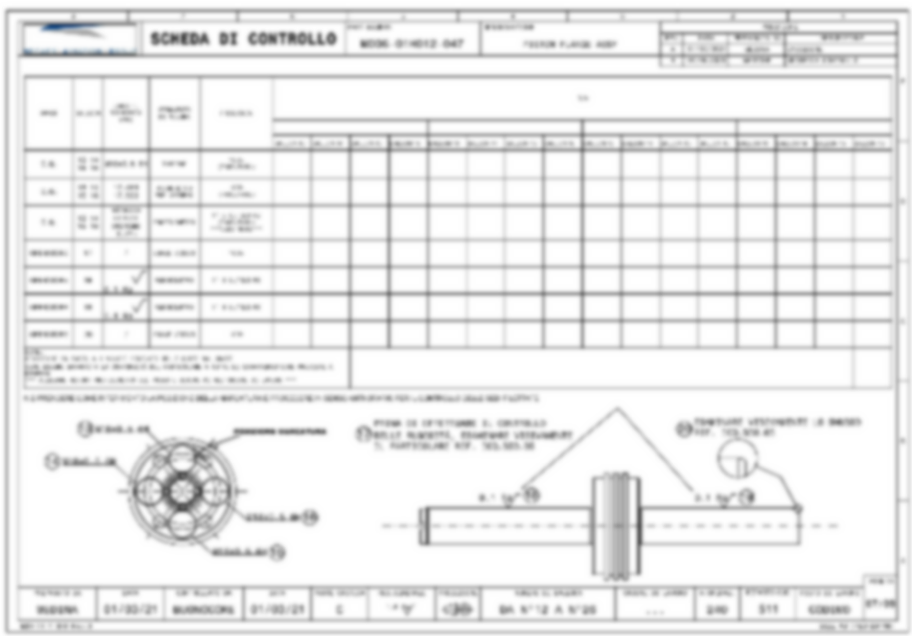

SCHEDA DI CONTROLLO

Figure 52: Control sheet

Improvement of FOD risk phase identification: In the general plan all the products (mechanical and hydraulic) with zone that could be sensible to FOD, have been taken into consideration and, as a consequence, also piston flange assemblies and dampers. To enhance prevention, a set of technical, documentary and layout improvements have been implemented:

1. *Re-layout of hydraulic assembly department (Figure 53)*: the hydraulic assembly department has been modified, to make the flow of the parts

more linear (Figure 54), adding new cells (Figure 55 and 56) with anti FOD surfaces.

Figure 53: New cells of the hydraulic assembly department

Figure 54: View of the re-layout

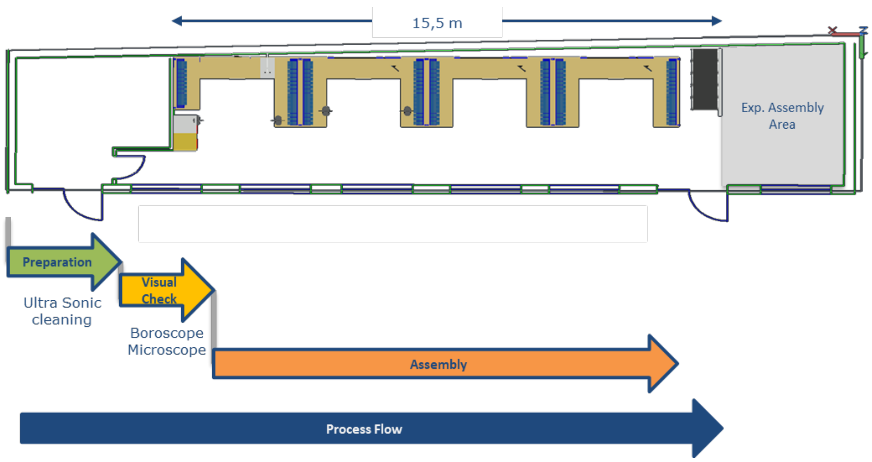


Figure 55: Scheme of the flow after in the new layout

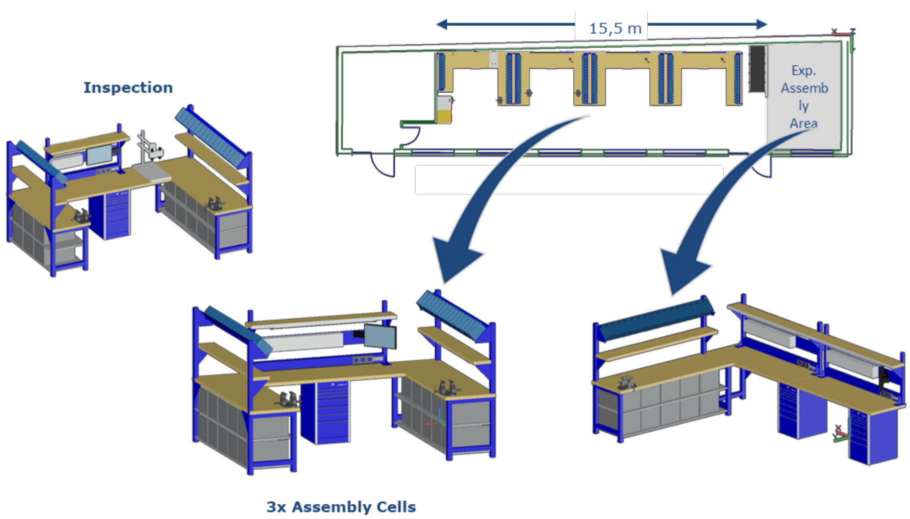


Figure 56: Scheme of the new cells

2. *Protections for pistons*: in order to protect pistons from eventual damages and from FOD during handling and movements between departments, a protection (Figure 57) and a dedicated box (Figure 58) are now used.

Figure 57: Piston's protection

Figure 58: Dedicated box for the handling of pistons

3. *Internal FOD prevention activity*: another series of actions have been taken for the prevention of FOD internally. For example anti-FOD entrance in the hydraulic assembly department, which are carpets that retain FOD (Figure 59).

Figure 59: Anti-FOD entrance

Also special boxes in which FOD can be thrown have been added to departments (Figure 60).
In addition, training on prevention and raising awareness on this problem have been done to the operators.
Moreover, MAG issued a dedicated operational procedure that shall be applied by Manufacturing Engineering Team on the current and future program to standardize the process on FOD prevention topic. Guideline of this procedure (Figure 61) comes from the experience gained during the development of this improvement plan.

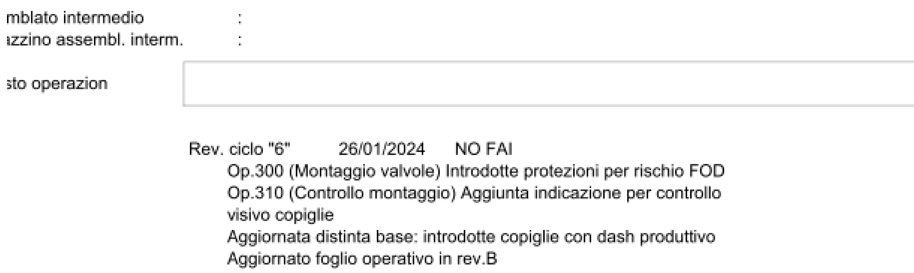
Figure 60: Anti-FOD box

e) tubazioni, connettori, filettature esposte e qualunque foro, apertura, area di difficile ispezione, devono essere adeguatamente protetti alla fine di ogni fase di lavoro;	e) Pipes, connectors, exposed treads and whatever holes, areas with difficulties to be inspected, shall be adequately protected at the end of any working phase;
f) tutte le parti che presentano le caratteristiche citate al punto e) devono mantenere l'adeguata protezione anche durante le operazioni di movimentazione all'interno della stessa area critica (cassette coperte, imbustaggi singoli, ...);	f) All the parts having the characteristics mentioned in the point e) have to keep the adequate protection also during handling operation inside the same critical area (covered boxes, single packaging, ...);

Figure 61: Points of the FOD prevention procedure

Also documents as production orders have been changed, adding details in some phases performed in departments where there is FOD risk, as you can see in Figure 62.

4. *Supplier FOD prevention activity*: A dedicated activity for FOD avoidance (Figure 63) has been introduced to 8 main suppliers to improve the awareness. This plan will be extended to all suppliers, which shall agree with the "FOD prevention Plan" proposed by MAG.
The supplier shall identify a dedicated activity to improve the FOD pre-


mblato intermedio :
ızzino assembl. interm. :
sto operazion

Rev. ciclo "6" 26/01/2024 NO FAI
Op.300 (Montaggio valvole) Introdotte protezioni per rischio FOD
Op.310 (Controllo montaggio) Aggiunta indicazione per controllo visivo copiglie
Aggiornata distinta base: introdotte copiglie con dash produttivo
Aggiornato foglio operativo in rev.B

Figure 62: Detail of an updated production order

vention for each part manufactured.
All information and decisions taken should be shared and agreed with MAG, to check if actions taken are have been done according to the plan.

Figure 63: Front of the presentation of the plan

Improvement of production documents: in general the improvement of production documents can be reached making them more clear, detailed and standardized, in order to avoid errors due to lack of comprehension or also, in very rare cases, due to mistakes in the text. Things to be improved can be found by the client during audits or by operators and the document will be changed with the new issue (the issue is immediate in case of errors). Moreover, also records regarding products on which this kind of analysis has already been done can be used as an example to improve quality under the documentary point of view.

Dedicated incoming check lists: incoming check lists define a method to control pieces in incoming. Having a standardized check list can help to increase quality in incoming of components and parts that come back from suppliers, intercepting defects earlier in the process. In this case, is very important to have a very well detailed list of activities to do, because the operator needs to follow all the passages with precision. Lack of details or of precision can lead the worker to commit errors or to skip passages.
As in the previous point, audits, operators and old cases can help to improve check lists.

Alternative operations: a production order contains the list of the operations to be done to make the product, the details of each phase and work stations, departments or machines on which operation are performed. An alternative phase gives the option to certain roles, if it's feasible, to switch the machine on which the operation is done, the department or also perform internally an operation usually done by external suppliers (and vice-versa).
Alternative phases are to control production capacity: allocating a certain operation elsewhere can help a department to better manage high workloads, lowering the risks of errors or inaccuracies due to haste, reducing waiting times in queues, accelerating the flow of the parts and making the process more efficient.

Corrective actions to the NCRs: in Step 2, a root cause to all the NCRs analyzed in the *Measure* phase has been found. The following step is finding, if feasible under a technical or economical point of view, a corrective action which can avoid, or reduce the probability, that a certain error can be committed again in the future. To this aim, an internal survey, with the collaboration of the quality department, quality assurance, industrial engineering and operators has been performed, and the results are showed in Table 8:

NCR description	Workstation	Corrective action
Concentricity of the piston out of tolerance	Grinding	Issued procedure/training for the set up of the tool
Defects on the grinded stem	Grinding	Raise awareness of the operator
Taper on stem's diameter	Grinding	Issued procedure/training for the set up of the tool
Dent	Grinding	Raise awareness of the operator
Signs of grinding wheel	Grinding	Piece utlized as a test part in subsequent activities
Defective cushion	Grinding	Raise awareness of the operator
Stem's diameter out of tolerances in the unthreaded part	Grinding	Non-economically sustainable corrective action
Diameter out of tolerances	Turning	Non-economically sustainable corrective action
Concentricity of the piston out of tolerance	Turning	Issued procedure/training for the set up of the tool
Concentricity of the piston out of tolerance	Turning	Issued procedure/training for the set up of the tool
Concentricity of the piston out of tolerance	Turning	Issued procedure/training for the set up of the tool
Damaged stem	Turning	Non-economically sustainable corrective action
Damaged stem	Turning	Non-economically sustainable corrective action
Diameter out of tolerances before rolling	Turning	Non-economically sustainable corrective action
Diameter out of tolerances before rolling	Turning	Non-economically sustainable corrective action
Damaged stem	Turning	Non-economically sustainable corrective action
Concentricity of the stem out of tolerance	Turning	Issued procedure/training for the set up of the tool
Manufacturing defects	Turning	Raise awareness of the operator
Increased internal diameter	Turning	Non-economically sustainable corrective action
Damaged fillet	Turning	NA. Early tool breakage
Increased external diameter	Turning	Non-economically sustainable corrective action i
Diameter out of tolerances	Turning	Non-economically sustainable corrective action
Diameter out of tolerances	Turning	Non-economically sustainable corrective action
Signs of grinding wheel	Burrs removal	Awareness raising (training) of adjustment workers
Damaged stem	Burrs removal	Awareness raising (training) of adjustment workers
Dent	Burrs removal	Awareness raising (training) of adjustment workers
Valve seat inner diameter increased	Burrs removal	Awareness raising (training) of adjustment workers

Table 8: Corrective actions for the NCRs analyzed

There are different rows in which the corrective action is not economically sustainable: all these are referred to damages due to problem related to the second spindle. As the material of which the spindle is made is an intellectual property of the supplier of the machine, the sizing and equipment of the machine was made at the time of purchase according to the parameters of the workpiece and, since the number of defects produced is not high, any kind of corrective action analyzed wasn't considered sustainable from an economical point of view. Since the fourth step aims to monitor and control the results of the previous phases, it will be analyzed in the next chapter.

7 Control

7.1 Theory of the control phase

This is the last step of the DMAIC process (Figure 64). The main activity in the Control phase is to monitor the improved process, ensuring that the new process is implemented and doesn't revert to old ways.

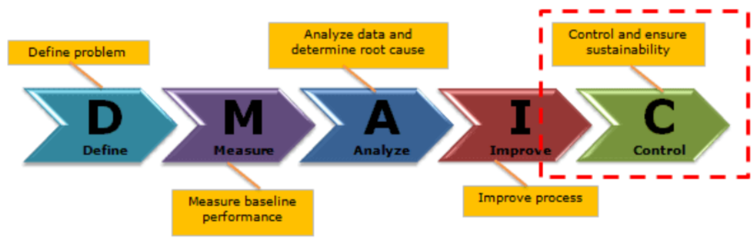


Figure 64: Progress of phases scheme

The activities in this phase are to create and update standard works or work instructions, quantify savings and get the financial controller's concurrence, create and fulfill a process monitoring mechanism using control charts, prepare a control plan and reaction to maintain an effective mechanism to monitor the process, gain the management's approval, check that the new process is strictly implemented, institutionalize the improvements by developing procedures/work instructions,transitioning the improved process to the operations team and finally update lessons learned and formally close the project (Hessing, 2019b)[34].

[34] Hessing. (2019b). *Control phase (dmaic)*. https://sixsigmastudyguide.com/control-phase/

7.2 Step 4: Monitor and review

The last step of the Process Improvement Plan shared with LHD (Vassallo, 2024)[35] has the objective to see if the new (updated) process is being executed as intended. To this aim internally MAG meetings has been planned on biweekly basis; also, monthly meetings with LHD has been scheduled to share KPIs:

1. Traveler monitoring KPI or Work order monitoring KPI (remarks detected/work order checked);
2. Progress KPI (Audit planned / Audit done);
3. Progress KPI (Action Open-Closed / Total Action).

Traveler monitoring KPI: During the year a lot of work orders has been analyzed casually to check eventual error or imprecision under a procedural point of view (all the phase completed are stamped correctly, all the procedures have been followed, there are no errors in the text and data are clear and accurate). Obviously, in this case, the analysis hasn't been limited only on dampers and their components, but also on other products of the firm, to have a wider vision of the situation. The results are shown in Figure 65:

Data	Total	W 20	W 21	W 24	W 27	W 30	W 34	W37-W39	W40-W41	W45-W46	W49-W50	W5	W9	W13	W16-W18
# OdL analysed	428	41	19	37	32	38	29	35	32	27	24	22	23	26	43
# Remarks (2&3)	16	3	1	2	2	1	0	1	1	1	1	1	1	0	1
# Improvement	24	3	2	3	4	3	2	0	1	2	1	0	0	1	2

Figure 65: Production orders analyzed, with respective remarks and improvement done

On a total of 428 work orders analyzed in about one year, the percentage of remarks is just:

$\frac{Remarks}{OdlAnalysed} * 100 = \frac{16}{428} * 100 = 4\%$.

On the other hand the percentage of improvements is:

$\frac{Improvement}{OdlAnalysed} * 100 = \frac{24}{428} * 100 = 6\%$.

[35]Vassallo, B. E. (2024). Improvement Plan LHD [Mecaer Aviation Group internal document]

Both are quite low results.

Progress KPI: the two progress KPIs are related to the number of Audit done and the action planned that has been done. In the first case, a strict audits plan (Figure 66) has been done during a period of three months. In each of these audits, different departments have been controlled (Figure 67) and, in case of remarks, corrective actions have been agreed:

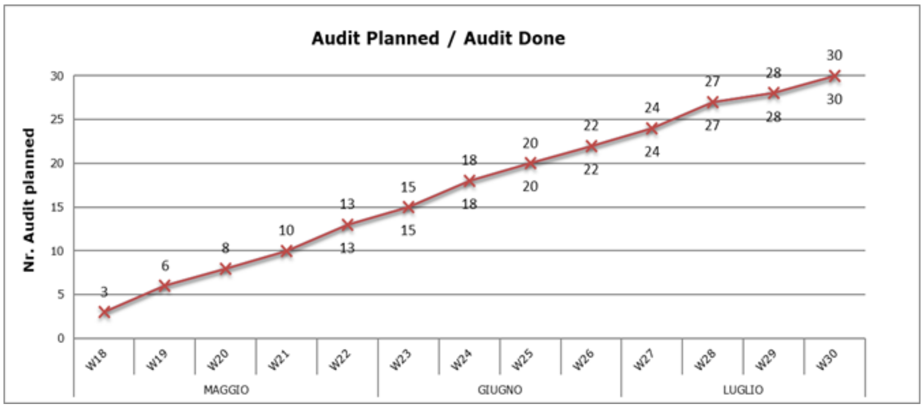


Figure 66: Audit planned/Audit done during time

IP	SISTEMA QUALITÀ / QUALITY SYSTEM	MAGGIO					GIUGNO				LUGLIO			
		W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30
01	Montaggi meccanici e idraulici e CQ (Controllo finale) *(Mechanical & Hydraulic Assembly) + QC (Final Inspection)*	OK		OK		OK		OK		OK		OK		OK
02	Meccanica + Controllo Qualità *(Machining) + (Quality Control)*		OK		OK		OK		OK		OK		OK	
03	Verniciatura + Controllo Qualità *(Painting)* + (Quality Control)	OK			OK			OK			OK			OK
05	Controllo Qualità - Ricezione QC - Incoming Inspection		OK				OK							
08	Processi Speciali - CND, TT, Swaging, Galvanica, SE (Special Processes)		OK			OK			OK			OK		
09	Verifica registrazioni in produzione *(Quality Records on travellers)*	OK		OK		OK		OK		OK		OK		

Figure 67: Departments controlled during time

To notice that the plan has been followed as agreed and how areas with higher FOD risk (hydraulic and mechanical assembly), together with quality departments, have been controlled more often in respect to the others, as they are the most critical for the client.

7.3 Process Sigma: Before vs After

In order to understand if the solutions implemented have helped in mitigating the problems risen during the study, the first thing to be checked is the Process Sigma: an increment in this value means that the process is more efficient and scraps, or defects, are reducing. To understand this, all the QNs from November 2023 to July 2024 (9 observations) have been taken unto consideration, leading to this results (Table 9):

Month	**QJ**	**QF**	**QN (QJ+QF)**	**Delivered**	**%Defects**	**%Defects QJ**
2023-11	0	1	1	44	2%	0%
2023-12	0	1	1	17	6%	0%
2024-01	1	2	3	76	4%	1%
2024-02	1	0	1	68	1%	1%
2024-03	0	3	3	65	5%	0%
2024-04	0	2	2	81	2%	0%
2024-05	0	3	3	85	4%	0%
2024-06	0	1	1	104	1%	0%
2024-07	0	0	0	88	0%	0%
Tot	**2**	**13**	**15**	**628**		

Table 9: QNs data from November 2023 to July 2024

It's clear that the number of claims is slightly reduced in respect to the data analyzed in the previous time frame (January 2022 - October 2023).
Starting from QJ, it's immediately visible that, between 628 dampers delivered to the client, only 2 defects came out, which is a very low number, considering the high number of products supplied in this time frame. To better understand this improvement, just notice that before, with 22 observations, for a total of 1217 dampers shipped, 86 were defectives. To prove that performance have been really improved, let's calculate Process Sigma again. Remember that the data needed for this calculation are:

- Number of opportunities for failure (O): in this case the part can be defective of not, so O=1;
- Number of units inspected (U);
- Defects (D);
- Number of defects per million opportunities (DPMO): $\frac{D}{O*U} * 1000000$
- Efficiency: $1 - \frac{DPMO}{1000000}$

While Sigma is a tabulated value. Comparing the result before (Figure 68) and after (Figure 69) the corrective actions, the results are the the following (Sala, 2024)[36]:

PROCESS SIGMA QJ (BEFORE)	
Number of opportunities for failure (O)	1
Number of units inspected (U)	1217
Defects (D)	86
Number of defects per million opportunities (DPMO)	70666
Process efficiency	92,93%
Process Sigma	***2,97***

Figure 68: QJ's Process Sigma before

PROCESS SIGMA QJ (AFTER)	
Number of opportunities for failure (O)	1
Number of units inspected (U)	628
Defects (D)	2
Number of defects per million opportunities (DPMO)	3185
Process efficiency	99,68%
Process Sigma	***4,23***

Figure 69: QJ's Process Sigma after

Results show a very high improvement in process efficiency, which lead to an improvement in process sigma.
In Table 9 seen before, it's visible also an improvement relative to QNs: in 9

[36] Sala. (2024). Riduzione dei difetti su Damper AW139

observations, for a total of 628 dampers delivered, 15 resulted defective, while before, in 1217 observations, 161 were defective, so is fair to expect an improvement in Process Sigma. Repeating calculations for QN, the results before and after the improvements are shown in Figure 70 and 71 :

PROCESS SIGMA QN (BEFORE)	
Number of opportunities for failure (O)	1
Number of units inspected (U)	1217
Defects (D)	161
Number of defects per million opportunities (DPMO)	132293
Process efficiency	86,77%
Process Sigma	2,62

Figure 70: QN's Process Sigma before

PROCESS SIGMA QN (AFTER)	
Number of opportunities for failure (O)	1
Number of units inspected (U)	628
Defects(D)	15
Number of defects per million opportunities (DPMO)	23885
Process efficiency	97,61%
Process Sigma	3,48

Figure 71: Enter Caption

The improvement is clear also in this case: the proportional reduction in the defects leads to an increase in process efficiency, which resulted in a consequent increase in Process Sigma.

7.4 Graphical Summary

Another point that needs to be analyzed is the change of the process under a statistical point of view, to understand if the conclusions of the Analyze phase are different and the process is really improved.

7.4.1 Summary report QJ

Let's see how the histogram of QJ changed in Figure 72, using the data in Table 9:

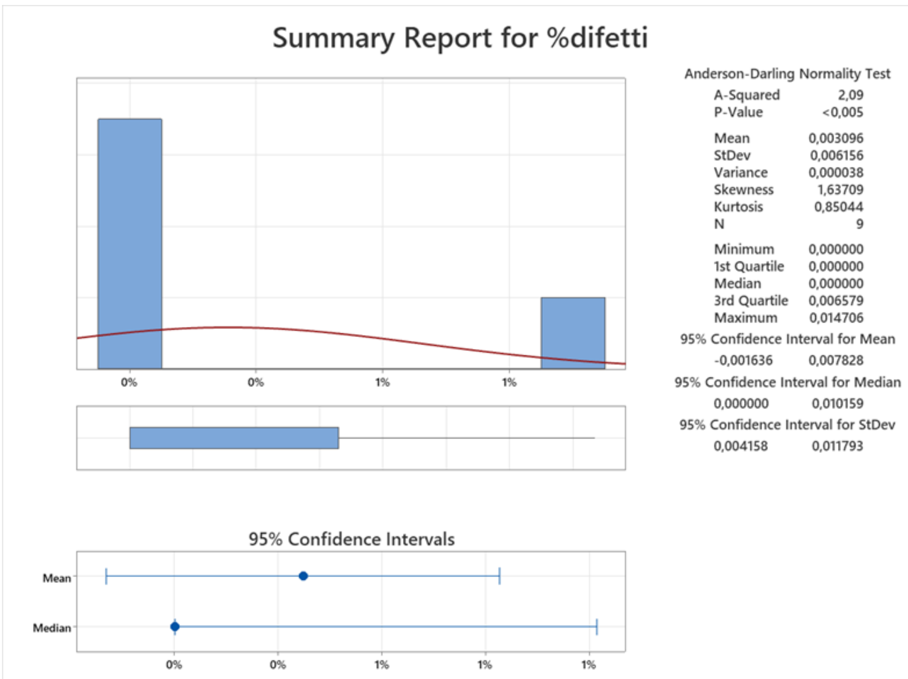


Figure 72: QJ's histogram

The distribution of the data is always not normal as $p - value < 0.005$, but this is not the main point to be noticed: in fact, in the nine observations done, there is an high rate of 0 defects and there aren't outliers anymore. As a consequence the median is 0, the mean is really near to 0 (and the variance too) and defectiveness starts to increase only after the 3rd quartile, which is the set of data between the median and the upper quartile. Overall, there were only two cases of defectiveness between the 628 dampers shipped in the nine months taken into consideration, which means that only 0.3% of dampers were defective. This is a huge improvement, especially considering that from January 2022 to October 2023, there were 86 defects between the 1217 products shipped, which correspond to 7% of the total (Sala, 2024)[37]. This conclusions are clear also from the chart in Figure 73:

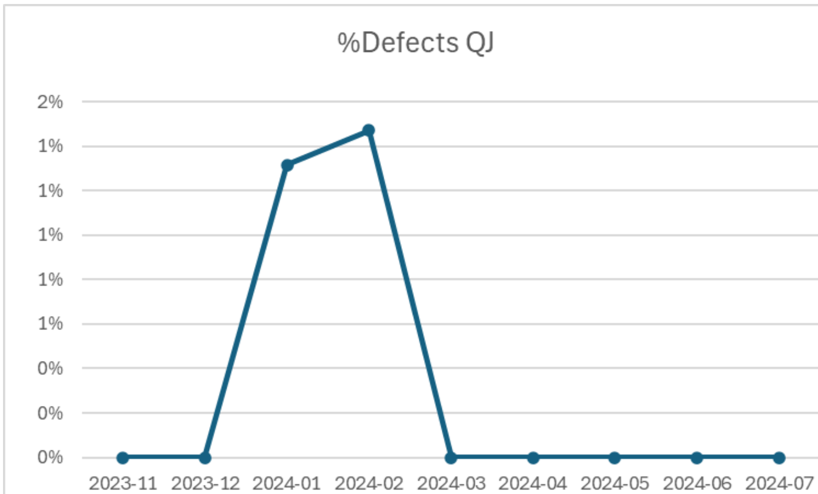


Figure 73: Percentage of defects during time

The value is not oscillating during time anymore and, as seen before, there are only two cases of defectiveness detected.
It is useful also to compare P-charts relative to QJ before and after the corrective actions (Figure 74) to check if now the data are between the control limits and the process is stable. A stable graph will have points randomly dispersed above and below the center line within the control limits. Excessive variation, with points constantly bouncing between the upper and lower control limits, indicates an unstable process that should be improved (6Sigma.us, 2019)[38]. If the process is still unstable or out-of-control the causes of variation need to be investigated and removed again. In the new chart, the percentage of defects is slightly lower than before and not only, in fact all the values are between the control lines, there are no instability points and the process is stable. Moreover, also the new p-value needs to be checked: now values are so low that $p < 0.001$, this is just another confirm of the significant reduction of defects.

[37] Sala. (2024). Riduzione dei difetti su Damper AW139

[38] 6Sigma.us. (2019). *Six sigma terminology – p chart. what is it and how it works.* https://www.6sigma.us/six-sigma-in-focus/p-chart/#:~:text=P%20Chart%20Stability%20and%20Variation,process%20that%20should%20be%20improved

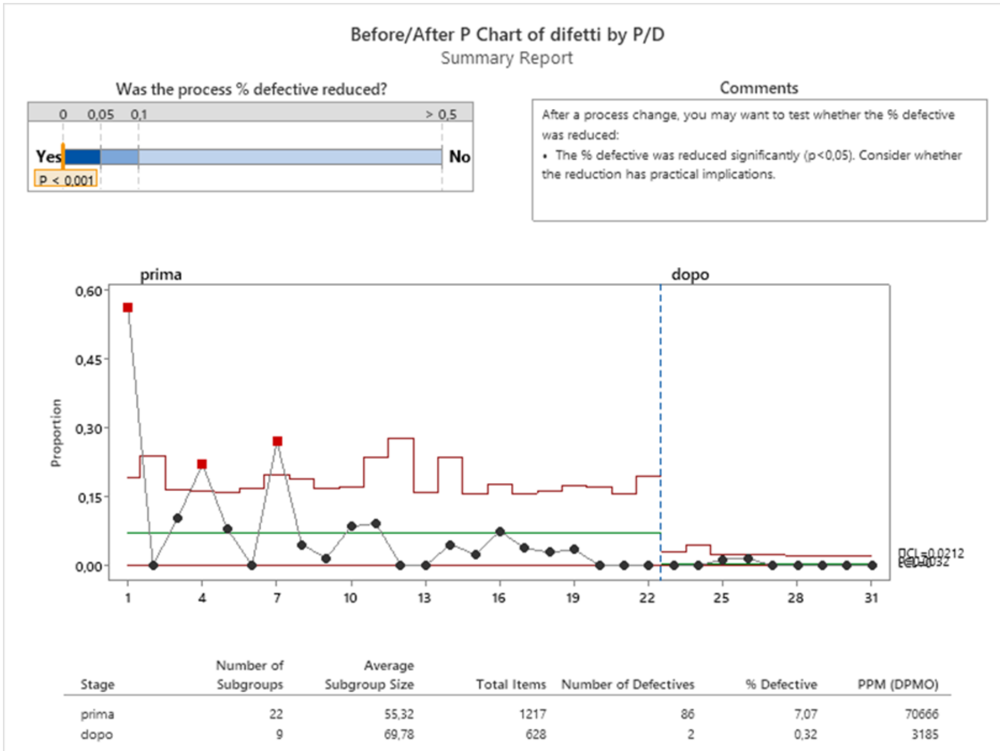


Figure 74: P-charts of QJ before and after

7.4.2 QN's P-charts

Even if the focus of the improve phase was on QJs, it's important to analyze how the reduction in this number affected QN (Figure 75). The first thing to note is the decreasing trend over time, even if there is still some oscillation, but with lower values of defects detected. In fact now in a total of 628 dampers delivered, 15 defects have been detected, while previously, 161 dampers out of 1217 resulted defective.

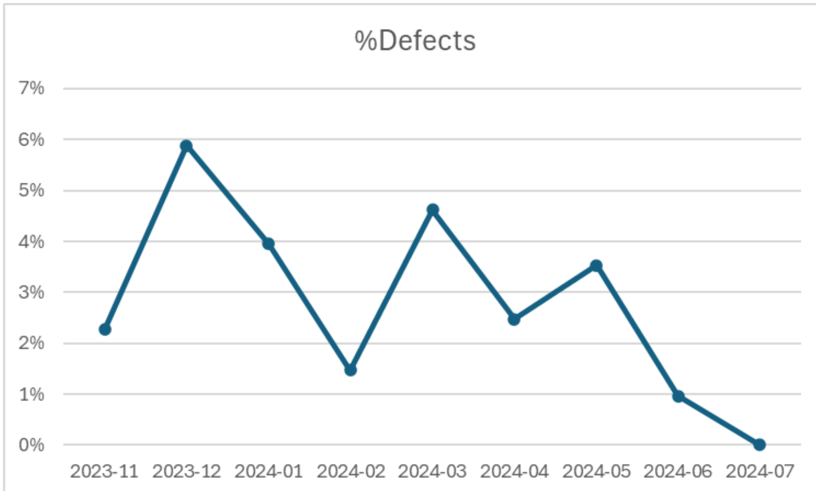


Figure 75: %Defects (QN) over time

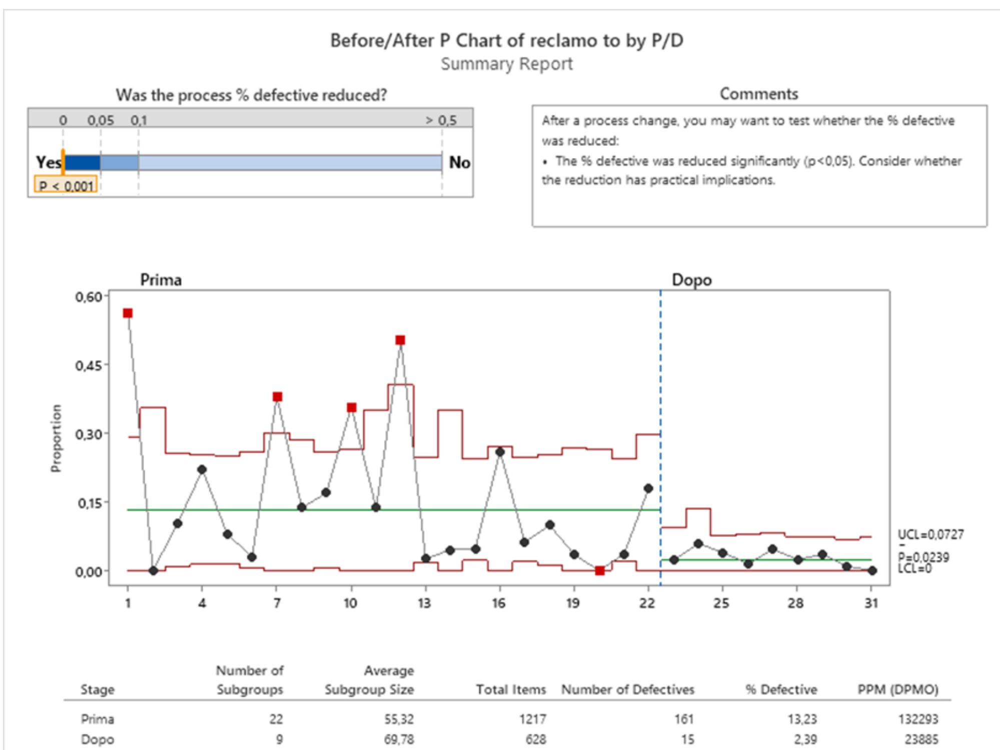


Figure 76: QN P-chart before vs after

As before, P-charts before and after the implementation have been compared to check if now values remain between control limits and process is stable (Figure 76). Also in this case, the process now is more steady, there are less oscillation between the mean value, all the points of the graph remain between UCL and LCL (there aren't instability points) and defects are now way lower. To confirm this, just look at the p-value that, also in this case, is lower than 0.001 (Sala, 2024)[39], meaning that defects have been reduced significantly.

7.5 Monitoring, handover and conclusions

To summarize, the results of the project are the following (Sala, 2024)[40]:

- Process Sigma:
  - QN: from 2.62 to 3.48;
  - QJ: from 2,97 to 4.23.
- Process efficiency:
  - QN: from 86,77% to 97,61%;
  - QJ: from 92,93% a 99,68%

To guarantee the stability of the results reached, a joint monitoring between LHD and MAG is planned. Non-compliant parts in post acceptance (QJ) out of total dampers delivered monthly will be analyzed on a quarterly basis, staying under the threshold of 5%. If at a certain point, for any kind of reason, QJ will result greater than this percentage, the rate of the monitoring will be intensified to a monthly basis, adding joint investigations with the client. This "alert" regime will be maintained until 8 months have passed since the restoration of a value of $QJ < 5\%$.

The results obtained will be shared with the client, in order to highlight the causes and the solutions adopted, emphasizing the importance of signaling as soon as possible any problems that may occur on the damper, so that a joint investigation can be conducted. Downstream of the activity, even if it was successful, is important to highlight root causes: improper management of documentation available to operators, procedures for FOD management not adequate, assembly area not suitable for FOD prevention and Root Cause Analysis

[39] Sala. (2024). Riduzione dei difetti su Damper AW139

[40] Sala. (2024). Riduzione dei difetti su Damper AW139

not enough accurate. These issues may not be isolated to MAG alone, but could also be present at the supplier level so, after this experience, would therefore be useful, during the auditing activities, to take into account these potential criticalities that might exist but which are currently latent, before they could cause problems or inefficiencies in the future.

8 Conclusion

8.1 Activities division

Each member of the team had a central role in different activities. Regarding quality assurance office, its contribution has been crucial in the communication with the client, internal surveys and analysis to find cause to the various defects detected and in the implementation and monitoring of the solutions decided.
Regarding the representative of the client, he collected all the data regarding QNs and QJs and carried out all the statistical analysis in the measure, analyze and control phase. Most of all he also directed the activities of the project, as the idea was born from a necessity of the client itself.
Talking about me, my contribution was central particularly in the initial phases of the project: thanks to my role in the firm, I have access to a lot of different information, so I was responsible for the collection of data regarding NCRs and SNCRs; having a complete visibility of components, processes and flows of information through the supply chain, I collected all the information regarding the production process and the operation involved of piston flanges and dampers, and all the other information about the purchase of materials, in order to construct the VSM seen in the define phase. I also had a role in the communication and in the exchange of information with the representative of the client.

8.2 Practical implication, advantages and limitations

The results of this activity, as you have seen in the improve phase, changed many aspects of the process, in order to ensure quality at every level. Making the documents more standardized, the changing in the layout and the continuous communication with the customer made the process easier to be monitored and causes to eventual problems easier to be detected and resolved. Moreover, the increasing of awareness also through operators, made clear the central role of quality at every level of the firm.
The biggest limitation to this project has been the difficulty to find information regarding some causes and, in some case, to find a valid solution to the problem and, even if the solution exist, it cannot be convenient economically to be implemented. In addition, this must be contextualized in a company with a very high product differentiation and a very high variability in the production lead time, which are all factors that have made this work more onerous.

8.3 Future perspectives

This project made clear the importance of making this kind of analysis. As anticipated, MAG's intentions are to implement similar solutions also to suppliers, in order to guarantee a high product quality at every level of the supply chain. This kind of approach, if necessary, could be applied also to other products, in another hypothetical case in which scraps become a serious problem for both MAG and the client.

This case is a demonstration of the effectiveness of lean solutions in a firm belonging to a sector completely different from the automotive, in which lean was born, and show how this approach can lead, also in this context, to great results. As a consequence, in future, different improvement projects which aim to implement lean solutions in different areas of the firm will be developed.

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