LOTO Development and Implementation in the Automotive production line Maintenance activities

DENSO THERMAL SYSTEMS S.p.A.

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Summary

Images list

PREFAZIONE

Nel mondo d'oggi, il lavoro rappresenta una parte molto importante nella vita di un uomo. Per questo motivo l'impegno di tutti lavoratori deve essere ripagato dalle aziende con la fornitura di condizioni adeguate di lavoro, compresi diritti, doveri e la sicurezza. Quest'ultimo è un aspetto che diventa sempre più fondamentale a livello aziendale: la vita dei dipendenti è un qualcosa che non può essere messa in secondo piano e deve essere trattata col giusto rispetto.

Alla luce di questo, l'azienda Denso Thermal System risulta essere molto meticolosa su questa questione: in questo frangente si colloca la mia esperienza di tirocinio per tesi. L'obbiettivo è quello di contrastare qualsiasi circostanza che possa arrecare danno alle persone coinvolte nello stabilimento: grazie all'implementazione e allo studio di questa nuova procedura riguardante la sicurezza si vuole raggiungere una situazione in cui gli incidenti di varia natura siano portati su dati tendenti allo 0. Infatti, purtroppo, attualmente nonostante tutte le contromisure prese bisogna ricordare che in un ambiente del genere il rischio di poter incorrere incidenti è sempre dietro l'angolo come spesso accade.

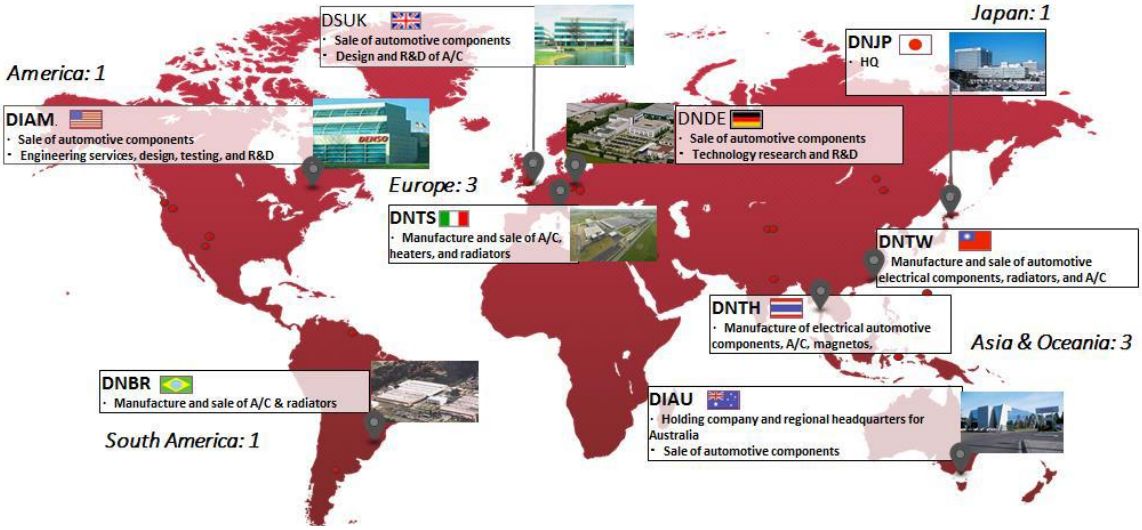
Durante la mia permanenza nell'azienda ho cercato di dare il meglio affinché le situazioni ''pericolose'' siano solo eventi legati al passato, e con il buon auspicio che il mio lavoro possa essere d'aiuto a raggiungere l'obbiettivo prefissato, ovvero il più basso livello di rischio possibile per tutti i lavoratori che, giorno per giorno, mettono la passione per quello che fanno.

1 DENSO Thermal Systems S.p.A.

The origins of Denso Thermal Systems can be traced back to the 1980s when the FIAT Group, recognizing the future potential in the vehicle air conditioning business, decided to establish a dedicated organizational unit. This unit was created by separating a series of molding and assembly activities for heaters and radiant mass production from the Stars company in Villastellone (Turin), which were then transferred to Poirino. The first commercial, product development, and administrative functions were also located in Poirino. Thus, Riscaldatori s.r.l. was born.
In 1986/1987, during the reorganization of all component activities within the FIAT Group and the establishment of the Magneti Marelli Sector, a specific Product Division was formed. This division, under the name Borletti Climatizzazione, brought together the resources from Riscaldatori, Autoclima, F.lli Borletti, and Comind Sud in Naples, which had all become part of the Fiat Components Sector. Starting from 1988, activities were consolidated in two locations (Poirino and Avellino), and the business development phase and personnel growth within the company began.
In 1992, an agreement was signed with Nippondenso, which later became simply DENSO Corporation. As part of the agreement, Nippondenso acquired a 25% stake in the company, and Borletti, in turn, acquired a stake in Nippondenso's two units in the UK. The objective of the joint venture was to provide a strong impetus for the development of air conditioning systems by leveraging the extensive expertise and know-how of a global industry leader.
Over the following three years, the contribution from the Japanese group led to a significant acceleration in both product and production process development. Starting from 1995, a substantial investment program was planned and implemented to

introduce strategically important technologies for new productions in the company, such as evaporators in Avellino and condensers (and future compressors) in Poirino.

During this period, there was also an expansion of customers and markets internationally. Orders were acquired from Renault and Peugeot, licenses were granted in Turkey, Morocco, and South Africa, and new production sites were established in Poland, Argentina, Brazil, and India, aligning with the globalization trend.



Additionally, the acquisition of Joao de Deus, a Portuguese company with a long-standing tradition in the aftermarket sector, took place.

In 2001, as part of Fiat's rationalization policy, the company officially became part of the DENSO Group. The company, previously known as Tazi-cieeien Thermal Systems S.p.A., adopted its current name, DENSO Thermal Systems.

Finally, in 2004, two strategic projects were launched by the company. The first project involved the establishment of a Business Unit based in Carmagnola (Turin), entirely focused on the Aftermarket. The second project aimed at developing projects for Special Vehicles and Off-Road applications.

Figure 1. Denso plants around the world

Figure 2. Poirino Denso Thermal System Plant (TO)

In Poirino, in the province of Turin, the largest and most important European facility of Denso TS is located. It covers an area of approximately 100,000 square meters, with 54,000 square meters dedicated to covered areas. However, an ongoing project aims to increase this area by about one-third. The facility consists of two buildings connected by elevated tunnels.

The smaller building houses the R&D department, sales department, and all the testing and product development activities. Two renowned European climatic chambers are also part of this building. The larger building accommodates the production lines, company offices, and storage areas. Additionally, on the lower side, there is a small area known as the pilot area, which is essential for achieving the "process capability" objective of the new lines. The facility employs approximately 1,200 people, with 800 of them working in production.
The Poirino facility is divided into Operational Islands, each dedicated to a specific type of process.

These islands are as follows:

Molding Department:

In this department, components such as centrifugal fans, collector tanks for masses and radiators, and dashboard controls are produced. It is divided into two zones, A and B. The first zone houses the "large presses," which refers to high-tonnage machines. The largest machines, from the Italtech series, can reach up to 1500 tons. The material used for component production in both areas is thermoplastic polypropylene granules. However, polyamide (for radiator tanks) and polycarbonates (for knobs and control panel buttons) are also used. One main difference between the two zones, besides the different tonnage of the machines used, is the presence of robotic manipulators. In the large presses, a robot retrieves the finished piece and places it on a conveyor belt. From there, the piece goes to an operator who checks its quality and places defect-free pieces on carts. Adjacent to the molding department is the buffer area, which accommodates the molded components.

Assembly Department:

In this department, various components from other production areas are assembled to create fully assembled thermal units. For example, the assembly operational area dedicated to heaters consists of:

- Manual air conditioning production lines
- Manual production lines for engine cooling units, including the fastening of plastic and metal parts to the radiator and fan unit, followed by end-of-line testing
- Ultrasonic welders
- Brazing turntables

The assembly department demonstrates practical application of the "kanban" methodology. In-line, there is an "assembly line feeder" responsible for monitoring material inventory and, when necessary, retrieving required quantities from the aforementioned buffer or buy component warehouses, following the kanban logic.

Compressor Department:

This is one of the newest units in the plant and can be considered the company's flagship. It is a highly delicate department located in enclosed spaces maintained at slight positive pressure and specifically air-conditioned. These measures are essential for assembling compressors that require extremely tight tolerances. The positive pressure prevents dust deposition, ensuring smooth component assembly. Compressors for vehicle air conditioning systems are assembled here, with components purchased from external suppliers. Additionally, components such as aluminum blocks and fittings are also produced.

Heat Exchanger Department:

This department, located in the center of the facility, is responsible for producing water/air and gas/air heat exchangers for heaters/air conditioners, engine radiators, and refrigerant condensers. The heat exchangers are assembled using the traditional mandrel assembly process. This process involves mechanically deforming the tubes, after they are inserted into the fins, by compressed air to maximize adhesion and ensure efficient heat transfer. Only recently, a fully automated assembly line for heat exchangers has been put into operation.

O.R.S.A. Department:

This department is entirely independent from the others and focuses on producing air conditioners for limited series, such as those used in buses, agricultural vehicles, and construction machinery. The assembly in this area is predominantly manual.

Nocolok Department:

This is one of the most interesting but challenging areas for the company to manage. Heat exchangers (masses, air conditioning condensers, radiators) are produced here, and their cores are bonded together through chemical reactions during the brazing process in ovens. The name "Nocolok" comes from the flux used in this brazing process. In this department, "washers" are used to remove oils and accumulated dirt from the components during various processing stages. It is worth noting the high level of automation in the assembly of radiant masses in this production unit.

Tubes and Fittings Department:

In this department, bending and processing of aluminium tubes and fittings used to connect heat exchangers and refrigerant circuits in vehicles take place. The tubes start as large rolls and are unwound, cut according to requirements, and then bent and connected as per the design. This is done using fully automated lines that deliver virtually finished products.

1.1 Company Mindset

One notable characteristic that immediately catches your attention when coming into contact with this type of company, especially Denso, is their ability and eagerness to follow a strict model both in production and behaviour. The "Japanese" influence is evident in every corner of the company, in every guideline to be followed, and in every individual employee, starting from their behavioural aspect and commitment and dedication to their work. Here are some specific methodologies that shape the atmosphere prevalent in these environments.

1.1.1 ‘’KAIZEN’’

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

Japanese method encourages and describes the small daily improvements that can be made in a continuous manner. The most important aspect of Kaizen is the process of continuous improvement that underlies it. It is a soft and gradual approach that contrasts with the Western habit of discarding anything that does not seem to work well and starting anew. In Japan, where the concept of Kaizen originated, this approach is applied to all aspects of life, not just the workplace.

Figure 3. Kaizen principles

System, meaning "doing things the way they should be done." It means creating an atmosphere of continuous improvement by changing one's perspective and way of thinking to do things better than before. In practical usage, Kaizen describes an environment where the organization and its employees proactively engage in improving processes. The foundation of improvement lies in encouraging individuals to make small daily changes in their work areas. The cumulative effect of these small changes over time becomes significant, especially when all individuals and their supervisors personally commit to following this philosophy.

Improvements are usually not accompanied by sophisticated or costly techniques or the use of special materials. Instead of investing more money in acquiring new machinery or equipment, Kaizen encourages the organization to pay closer attention to important details that are often overlooked. Managers are encouraged to improve the efficiency of existing infrastructure rather than invest in new resources. Simplification involves focusing on streamlining processes by breaking them down into subprocesses and striving to independently improve each one. The driving force behind applying Kaizen is dissatisfaction with the current situation in the company, regardless of its external reputation. Standing still and not striving for improvement would allow the competition to gain an advantage.

Being creative in problem-solving and striving for self-improvement not only develops individuals but also motivates them to go beyond their limits. The fundamental idea behind Kaizen is closely related to the Deming Cycle (or PDCA cycle):

- A person has an idea to improve something (Plan)
- Tests and simulations are conducted to verify the validity of the idea (Do)
- The results are evaluated to determine if the idea achieved its intended goal (Check)
- If so, procedures are changed, adopting the new method (Act)

Kaizen involves every employee in the company, from the factory director to the production and maintenance workers. In particular, the management should make an initial effort to help employees provide suggestions for improving individual work and the company as a whole, regardless of their accuracy. This approach will help individuals become more critical and examine how they perform tasks more thoroughly. In the second phase of implementing the methodology, employees need to be taught to provide better and more accurate suggestions. However, to achieve this, employees must be provided with the necessary knowledge and foundation to analyze problems and their environment.

The main areas where suggestions for improvement are valuable include:

- Individual work
- Energy, material, and resource savings
- Work environment
- Machinery, equipment, and processes
- Office work
- Product quality
- Customer service

Comparing the two philosophies, the Western philosophy can be summarized as "if it's not broken, don't fix it," while the Japanese or Kaizen philosophy is "do it right, make it better, improve it even if it works because that's the only way we can compete with anyone." This approach has allowed Toyota, one of the companies that have extensively utilized Kaizen throughout their history, to receive 75,000 suggestions from 7,000 workers in just one year, implementing nearly 99% of them.

1.1.2 The Toyota Production System: Hunting for 'Muda'

The Toyota Production System, also known as "Toyotismo" in some academic publications, is a method of production organization derived from a different and, in some aspects, alternative philosophy to mass production, which is based on Henry Ford's assembly line and often carried out on a large scale. The name derives from the fact that it was invented in the 1940s-1950s at Toyota by Sakichi Toyoda, Kiichiro Toyoda, and especially by the young engineer Taiichi Ohno. At the core of the TPS lies the idea of "doing more with less," meaning to use the (limited) available resources in the most productive way possible with the goal of dramatically increasing factory productivity. Toyota, immediately after the war, faced extremely challenging conditions of resource scarcity, as did most of the Japanese industry, which had emerged defeated and devastated from a war.

The TPS is based on five principles, focusing on a seemingly simple concept: the elimination of all types of waste (Muda) that inevitably accompany every phase of a production process. More precisely, there are seven types of waste:

1. Defects (lack of quality)
2. Overproduction (more than what is currently required)
3. Transportation (unnecessary movement)
4. Waiting (materials standing idle waiting to be processed)
5. Inventory (generally, stock is always considered waste)
6. Unnecessary operations (those that do not add value)
7. The process itself

The TPS aims to identify and eliminate these wasteful activities, allowing for the optimization of resources, reduction of costs, and improvement of overall efficiency.

By focusing on continuous improvement and involving all employees in problem solving and waste reduction, the TPS has been a key factor in Toyota's success and has influenced manufacturing practices worldwide.

Figure 4. The Muda process

To pursue the elimination of Muda, the TPS operates on all aspects of the production process with an approach based on continuous and incremental improvement, known as Kaizen, mentioned earlier. The extraordinary results achieved through this new production philosophy have led to the global recognition of the TPS, also renamed as Lean Production, highlighting the aspect of eliminating everything that is unnecessary and burdensome to the system, generating costs instead of value.

A fundamental aspect of the TPS, aimed at eliminating stock and inventory in the factory, is the Just-in-Time (JIT) system. It is a logistics flow control system based on the concept of producing only when needed, that is, when customer demand immediately downstream requires it, following the flow of the process. This way of organizing production launch, combined with the adoption of smaller batch sizes made possible by quick setup techniques (SMED), eliminates or drastically reduces the idling of material waiting to be processed, thus reducing the total lead time from days to hours.

This production method is defined as a Pull system, in contrast to traditional Push systems based on fixed production schedules determined in advance, which inevitably do not reflect actual demand. The practical tool used is "kanban," a system based on the standardization of produced and transported units, using a card that accompanies the full container. When material is consumed from the container, the card is released, serving as a signal to the upstream station to indicate the immediate need for a new delivery of a full container. This system prevents overproduction because it is limited by the total number of circulating cards for each individual item.

A distinctive feature of Just-in-Time is the extension of the logistical mechanism to suppliers, who are fully integrated into the Pull system. It is evident that the system functions effectively when the supplied material complies with quality requirements; otherwise, it would be halted. Hence, the need for a high level of quality, as if Just-in-Time and Quality were two sides of the same coin.

1.1.3 The 5S

The methodology for improvement called "5S" is a methodological approach that originated within the principles of Lean Production. It aims to initiate and maintain a process of reducing and eliminating waste within an organization, thereby continuously improving work standards and product quality.

The five S's correspond to Japanese words, which mean:

- **Seiri**: Sorting and eliminating unnecessary items, while keeping only the essential ones.

- **Seiton**: Organizing and arranging workstations in an efficient and ergonomic manner.3.
- **Seiso**: Cleaning and regular maintenance of the work environment and equipment.
- **Seiketsu**: Standardizing work procedures and practices to ensure consistency and efficiency.
- **Shitsuke**: Sustaining and continuously improving the implemented standards by establishing monitoring systems and promoting adherence to the rules.

By implementing the 5S methodology, organizations create a structured and organized work environment, reduce waste, increase productivity, and enhance the overall quality of their operations.

Figure 5. The 5s

The main areas on which the program focuses are:

- **Safety**: Having a place for everything and everything in its place reduces the likelihood of accidents.
- **Personnel efficiency**: The more attentive and engaged people are in their work, the more efficient their results will be.

- **Facility efficiency**: Clear labeling helps to avoid mistakes. Dirt can cause damaging wear and tear on machines, leading to breakdowns and reduced availability.
- **Quality**: Dirt can lead to defects, resulting in an increased percentage of rejects.
- **Work environment**: A clean and organized system promotes better work.

Hiroyuki Hirano, who made it famous, refers to it as the cornerstone of "visual work," the visual control that allows for a quick assessment of the situation in a production area.

In reality, this methodology is now used in many contexts, not just limited to production. Its application can involve reorganizing equipment, tools, materials, computer files, and more.
The underlying motto for implementing this methodology could be "a place for everything and everything in its place." While order is essential at home, it is even more critical in the workplace, as offices or production areas are frequented by many individuals, each with their own habits, work methods, and systems for retrieving or "organizing" things.

Without established rules, a significant amount of time can be wasted searching for necessary items instead of performing value-added activities for the product or service provided to customers. Waiting hours for an approval signature, being unable to find crucial information to start a task, searching for all the necessary people to begin a meeting, moving between offices to retrieve needed documents, or repeatedly recording the same data are just a few examples of unproductive activities that organizations face when they underestimate the importance of the 5S.

SEIRI:

This is the most important rule, essentially involving separating what is truly necessary from what is superfluous and unnecessary in the workplace. To identify what is not needed, it is important to thoroughly clean the work area, and then decide what to do with items deemed useless or unusable. Rational classification of objects (tools, equipment, materials) in the work area and addressing the sources of dirt are essential actions. Tools used to achieve this goal include visual management, applicable to every department or office (Visual Factory).

SEITON:

The main point of workplace organization is defining a system for arranging tools and equipment so that they are readily available when needed. The goal is to minimize the number of items to keep without causing production delays or disruptions.

SEISO:

The cleaning activity involves not only removing dirt from machines and equipment but also inspecting and eliminating any problems. Cleaning activities can be divided into three phases: general cleaning and identifying sources of dirt, cleaning the workplace and all equipment, and preventive cleaning and monitoring of machines, equipment, and tools.

SEIKETSU:

Defining and formalizing cleaning activities through standard procedures and using verification tools (checklists) and visual management.

SHITSUKE:

Maintaining the achieved results through periodic audits to ensure compliance with standards. Continuously analyzing problems, identifying countermeasures, and monitoring performance allow for setting new goals based on the principle of continuous improvement.

2 Maintenance: definition

Seeking to provide an effective definition, "Maintenance is the combination of all technical, administrative, and managerial actions carried out throughout the life cycle of a work area, equipment, or transportation means, aimed at preserving it or restoring it to a state where it can perform the required function, in order to ensure a safe and productive working environment." This is a clear message given by the European standard UNI EN 13306, which aims to highlight the importance of this type of activity. In fact, it is essential to guarantee the products commissioned to the company in question and, above all, to maintain a high level of quality in production, in order to preserve the competitiveness of the plant.

2.1 The descriptive processes

Nowadays, in the vast majority of companies, safety issues are not related to machinery failures or non-compliance on the production line and in the facilities, but they are closely linked to operational and organizational matters. This is the scenario in which accidents leading to various types of injuries can occur during operations, especially when interventions are related to corrective maintenance, which is the phase where safety controls need to be removed to identify and resolve the issue. The scientific literature EU-OSHA 2011 is based precisely on this, establishing the fundamental importance of the role of maintenance and its work in planning the tasks that must be carried out to ensure the health and safety of workers.

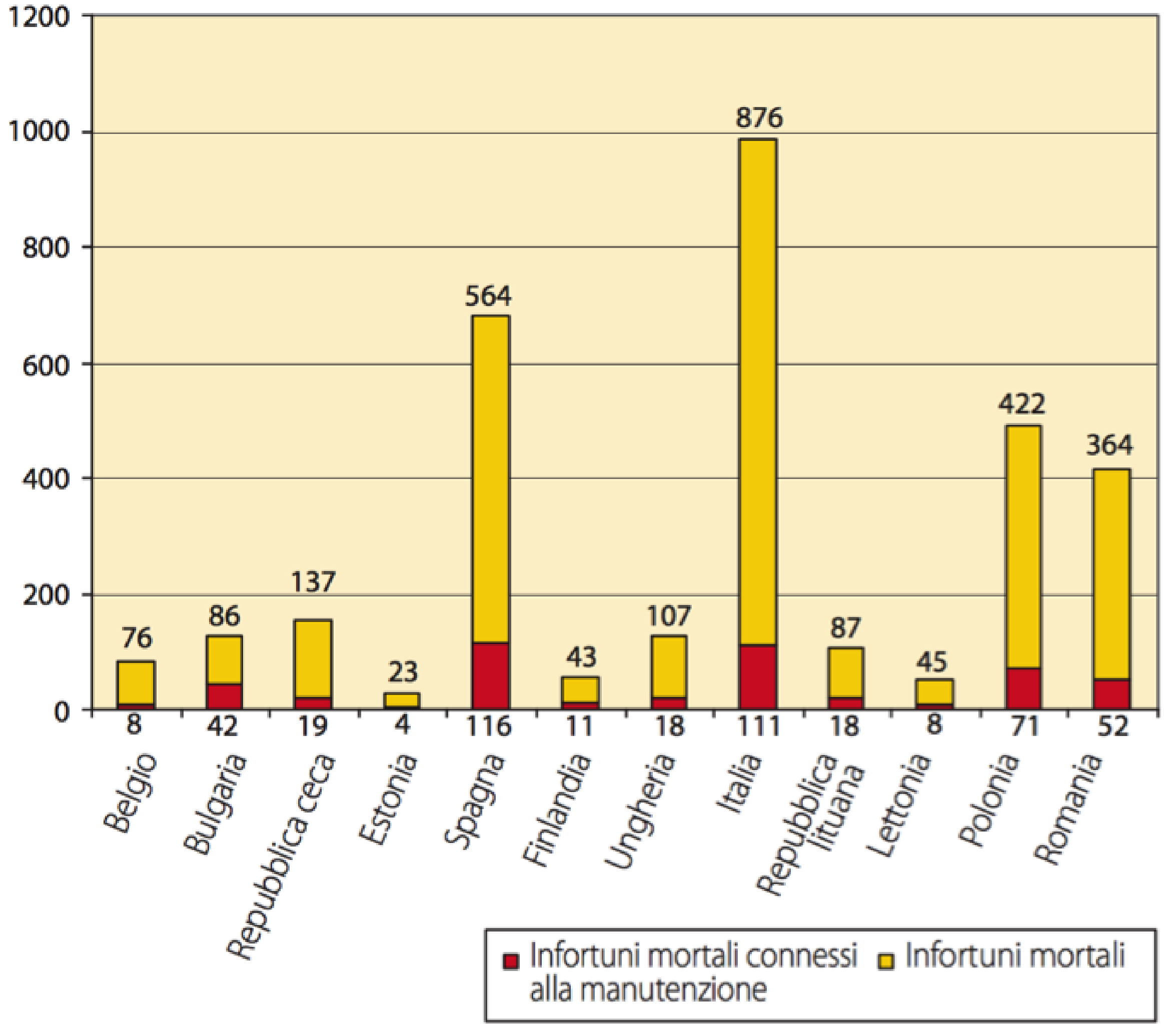


Figure 6. Work world INAIL data

Due to these dynamics, the European Agency for Safety and Health at Work (EU-OSHA) carries out a major awareness campaign targeting large enterprises to highlight the importance of key aspects of the maintenance department. For this reason, an approach based on risk assessment has been promoted in order to reduce the number of people injured or harmed during maintenance processes.

From the data and a thorough analysis of the statistics, one can become aware of the impact that workplace accidents have, especially in the maintenance department.

According to studies, approximately 20% of accidents are related to maintenance, and furthermore, 15% of fatal accidents in Europe occur in this sector. The causes of accidents can vary, but among the most common are fractures, bruises, amputations, and electrical shocks, leading to more extreme cases, including fatalities. This demonstrates the critical nature of the maintenance environment, emphasizing the need for extreme caution.

To this end, four categories have been identified to classify both the circumstances and causes of accidents, specifically related to common maintenance operations:

- Preparation, installation, configuration, assembly, dismantling;
- Maintenance, tuning, repair, adjustment;
- Cleaning of machinery and workstations;
- Monitoring, inspection of work areas, transportation, and equipment.

Considering all these variables, it is imperative to view maintenance as a process, which requires not only proper execution and planning but also comprehensive documentation of each activity performed. This documentation allows for a complete overview of the work carried out at every moment. Undoubtedly, this approach significantly impacts the safety and health of employees. Therefore, regular maintenance is organized to ensure adequate working conditions for machinery, equipment, and work environments. Among the most frequent causes of accidents on production lines are unintentional reactivations or the presence of unexpected energy sources.

Maintenance for facilities is also divided into two types:

- **Routine maintenance**: This category includes all types of interventions necessary to address normal wear and tear and events that do not involve modifications to the structure, performance, or intended use of the facility.

- **Extraordinary maintenance**: This encompasses all types of interventions aimed at restoring the facility to operational conditions.

2.2 The role of maintenance in the plant

The maintenance of the entire plant is managed by the Production Technologies department. Various aspects of the production line and the facility are handled here, from warehouse supplies to required mechanical processes, from facility inspections to machinery control. Maintenance is specifically managed by the Maintenance and Safety department, which is further divided into two areas:

- **Facilities Area**: It handles the management of the plant's facilities, specifically focusing on routine and extraordinary maintenance. For routine maintenance, the staff performs repairs on electrical and fluid networks and general facility maintenance. Daily inspections are conducted to check for alarms and manage them through computer systems.

- **Services Area**: It oversees warehouse management and the maintenance of the facility's structures. The warehouse serves as a bridge between the two areas, as the Services Area responds to the needs of the Facilities Area by placing orders and reporting any shortages. This area also manages internal traffic, such as forklifts, and external traffic, such as employee vehicles.

To meet various needs, specialized maintenance teams are formed in different fields due to the wide range of interventions and the need to handle different types of machinery. Two key roles are distinguished:

- **Mechanical Maintenance Technician**: They perform mechanical maintenance interventions, both preventive and corrective, and provide assistance to ensure the proper functioning of machinery and production systems. Their key activities include repairs, preventive maintenance to prevent breakdowns and abnormalities, and equipment improvement.

- **Electrical Maintenance Technician**: They specialize in the installation, compliance, and repair of electrical systems and equipment. They conduct electrical maintenance activities on production systems to ensure their efficiency through restoration, preventive measures against malfunctions and abnormalities, and improvement activities. They also ensure the efficiency of auxiliary systems.

2.3 The International Safety Regulations

"To better understand the importance of safety in industrial plants, it is necessary to refer to the applicable regulations, taking into consideration the Italian legislative context, but especially the European and North American contexts, with specific reference to the **Occupational Safety and Health Administration (OSHA)**.

OSHA plays a crucial role in ensuring the best safety conditions for workers by disseminating regulations that serve as mandatory legislative references and by managing the training of all entities involved in the sector.

OSHA standards are very similar to European regulations, but they have more technical aspects that are examined. One of these aspects is the control of hazardous energy, known as "The control of hazardous energy (lock-out/tag-out)," which establishes parameters and methods for identifying and isolating hazardous energy sources. This standard serves as a guideline for the minimum efficiency requirements for controlling hazardous energy during maintenance procedures for machines and equipment, where the activation, start-up, or release of stored energy could harm workers. The standard requires employers to establish an intervention program and apply procedures to disable machines and equipment and apply locking devices.

Employers are required to train each worker to ensure that they are familiar with, understand, and able to follow the applicable provisions of the hazardous energy control procedures. Workers must be trained on the purpose and function of the energy control program and possess the necessary knowledge and skills to safely apply, use, and remove control devices. Furthermore, the role of the employer is to plan maintenance, taking into account the locations and timing of interventions, ensuring that the intervention takes place in a safe environment for all involved parties and that they use appropriate equipment and personal protective equipment to avoid exposure to hazards. Additionally, the employer must ensure that safe work practices developed during the planning phase are followed. Once the work is completed, the locks can be removed, and supervisors can be notified. Finally, a management report is prepared, describing the work performed, including observations on any difficulties encountered, and recommendations for future improvements.

Regarding the Italian legislative context, the "Unified Text on Health and Safety in the Workplace" consolidates all the previous regulations on health and safety in the workplace. Comprising 306 articles and 51 annexes, the decree proposes a management system for safety and health in the workplace, including the identification of risk factors and sources, the reduction of risks to a minimum, the continuous monitoring of preventive measures, and the development of a corporate strategy that clearly defines the roles and responsibilities of individuals responsible for workers' safety and health.

Specifically, Article 17 of the decree suggests that the maintenance manager prepare a **Risk Assessment Document (DVR),** which is a "comprehensive and documented assessment of all risks to the health and safety of workers within the organization in which they carry out their activities, aimed at identifying adequate preventive and protective measures and developing a program of measures to continuously improve health and safety levels."

Article 71 establishes the maintenance manager's obligations regarding technical standards, which involve taking certain precautions to ensure that:

- Equipment whose safety depends on installation conditions undergoes initial checks and checks after each assembly to ensure proper installation and functioning.

- Equipment subject to influences that could lead to deteriorations susceptible to causing hazardous situations undergoes regular checks by competent personnel, as well as extraordinary checks.

From these elements, it is evident that the requirements placed on employers regarding maintenance are diverse, and there are also numerous risks associated with this type of intervention for those who perform it. Maintenance, by its nature, is a hazardous activity because it involves phases such as fault finding, performance checks, and testing, where those involved may sometimes operate in reduced safety conditions. Maintenance operations also include activities that are not repetitive and always different, exposing employees to variable and unpredictable risks that cannot be fully covered by the Risk Assessment Document due to the high number of existing variables.

There is a significant difference between planned maintenance and maintenance in response to requests (due to malfunctions). The latter, unlike the former, arises from an impromptu need, often characterized by urgency, unpredictability, and a lack of available company personnel. Consequently, maintenance in response to requests is often carried out without sufficient "planning," meaning that there is not enough time to analyse all the factors and risks. This is a crucial point for safety, primarily concerning the personnel involved in the interventions. Each company, based on its structure and characteristics, must find an answer to safety needs through proper maintenance management.

To meet all these requirements, certain indispensable characteristics must be present in the maintenance personnel, including:

- **Problem-solving skills**: Those who work with a certain degree of autonomy should have corresponding decision-making abilities based on appropriate analytical and evaluative processes, ideally replicable among employees at the same level.

- **Competence**: In order to make informed decisions, one must understand the operating context and possess adequate expertise. This characteristic is essential for identifying the risks to which the work team may be exposed.

- **Capability**: This includes not only problem-solving skills but also the ability to manage critical situations without resorting to risky solutions that could be avoided.

- **Teamwork**: Those working in maintenance must be able to coordinate with colleagues in related functions (electrical and mechanical maintenance) as well as personnel from other departments.

With the experience gained over time, a maintenance supervisor can make important decisions regarding safety and exchange information that can have a significant impact. Currently, in Italy, there is no specific law or regulation that specifically addresses the issue of hazardous energy sources, as it is still a relatively unknown topic, with the exception of companies operating in multinational contexts that adhere to strict maintenance rules. One such company is "Denso thermal system," an internationally renowned automotive company that has recognized the need to comply with safety standards proposed in America (OSHA).

This thesis project aims to support the Health, Safety, and Environment (HSE) department in the implementation and application of lock-out/tag-out (LOTO) procedures. My task specifically involved developing the most suitable procedure for each equipment or system in the facility to ensure safe maintenance interventions, selecting appropriate locking devices from those vailable on the market, and identifying and addressing any critical conditions for all individuals involved in the workstations, their integrity, and their full functionality."

3 Introduction to LOTO methodology

LOTO stands for "Lockout-Tagout," and it refers to a safety procedure used in industry and research to ensure that hazardous machinery is properly shut down and cannot be restarted before completion of maintenance or repair work. This procedure requires isolating and deactivating hazardous energy sources before commencing work on the equipment in question.

Figure 7. General warning label

The isolated power sources are then locked using a specific padlock (lockout procedure), onto which a tag is attached, identifying the worker who placed it and the reasons for the lockout (tag-out procedure). The operator keeps the key to the padlock, ensuring that only they can remove the lock and start the machine. This prevents the accidental startup of a machine while it is in a dangerous state or while a worker is in direct contact with it. This procedure has been implemented at the DENSO plant in Turin, after being studied and adapted to the company's needs by the maintenance and safety department. The area where I implemented this safety-focused methodology is the Nocolok area, where radiators, condensers, and related cooling system components are manufactured.

A lockout/tag-out system is necessary whenever maintenance work is performed near a machine that could cause injuries due to sudden equipment startup or the release of stored energy. It becomes essential when, for valid reasons, a safeguard or safety device is removed or bypassed, or when a body part needs to be inserted into a point where it could become trapped by a moving machine. It is useful, for example, when repairing electrical circuits, cleaning or lubricating machines with moving parts, or unlocking jammed mechanisms.

To correctly implement LOTO techniques, the following eight points are necessary:

- **Procedures**: They explain how to safely secure each piece of machinery, ensuring it is in a zero-energy state, with no activated or stored energy.

- **Training**: Personnel must be trained in the procedures and how to apply them through internal company training courses.

- **Administration**: Establishing guidelines for activating and implementing the procedures.

- **Devices**: Devices specifically designed for lockout and labelling of various switches and valves are necessary for procedure implementation.

- **Review**: Regularly check the entire procedure to improve the level of safety provided by the LOTO procedure. Considering all personnel working within the facility, it is necessary to identify three groups with different awareness need:

1. ***Authorized personnel***: They perform lockout/tag-out on machines or equipment for repair and maintenance, identifying equipment with potentially hazardous energy sources. They require more in-depth training in LOTO procedures.

2. ***Affected personnel***: Their tasks involve using a machine or equipment on which repair or maintenance work is being carried out after the LOTO procedure has been applied, or their tasks involve working in the affected area. They need to be informed about the LOTO procedure and should not attempt to remove lockout devices.

3. ***Other personnel***: The remaining personnel who may find themselves in situations where a lockout procedure has been implemented. They need to understand the meaning of the lockout procedure and should not interfere with its implementation.

To address all these precautions, the company decided to use a document that is easily understandable for anyone involved in maintenance work. A fundamental requirement is to eliminate any possibility of misinterpretation of the procedures. To ensure this, the Safety and Maintenance departments decided to use a "sheet" as a basis, which had been developed years ago and was already in use but had some significant shortcomings, such as the lack of energy localization and certain tested methods that were identified during my time there for the disconnection of various machines, as well as identifying the essential pneumatic diagrams to act while always being aware of what is being done and the risks involved.

During my experience, the goal was to thoroughly implement the sheet for each examined machine, striving for completeness in all aspects to leave nothing to chance and minimize risks during interventions.

The LOTO procedure requires that the machine be isolated and made safe by following a predefined sequence that prepares it for the application of isolation devices. However, the use of padlocks is only one part of the procedure. To be effective, it requires the support of several minimum requirements. A general strategy for the procedure must be defined, identifying which machines require its application and ensuring the availability of all necessary devices for its implementation.

As previously mentioned, Italian legislation does not require the use of this procedure. However, many requirements can be met by implementing LOTO for safety purposes. Within the company, it has been determined which interventions require the use of the procedure:

- Maintenance work performed with any body part exposed to a hazardous area, where an unintentional machine restart could cause serious harm to the operator.
- Interventions in systems that transport or contain hazardous fluids.

To correctly apply the LOTO procedure, seven fundamental steps have been defined to ensure a complete and secure shutdown of the machine. These steps are explained below:

1. *Preparation for shutdown*: Based on the type of intervention to be carried out on the machine, the operator identifies the energy sources to be controlled and prepares the necessary materials for the intervention.

2. *Notification*: All personnel involved are informed that the machine is ready for intervention, with the stoppage and application of devices.

3. *Equipment shutdown*: Performed following the standard shutdown procedure to simplify operations. This is usually done by pressing a stop button, opening a switch, or closing a valve.

4. *Isolation*: Actions are taken on power circuits to eliminate energy in the intervention area. A lockout/tagout device is used to ensure complete lockout throughout the entire duration of the intervention, preventing any possible reactivation of energy flow.

5. *Energy dissipation*: Once a machine is shut down, it may still contain residual energy. The discharge of capacitors, circuits, and hydraulic and pneumatic accumulators must be performed. Additionally, precautions must be taken to prevent lower dead movement and lock loads at heights.

6. *Verification of energy absence*: The person in charge of the safety measures checks for the absence of energy. Through testing, measurements, or try-out procedures, they ensure that the machinery designated for maintenance is in a "zero-energy" state. Once confirmed, the machine is considered safe.

7. *Documentation*: Essential for verifying that all steps have been completed.

Upon completion of the maintenance activity, operators must verify the safety measures and inform the affected personnel before reactivating the machine. The LOTO devices and warning signs are removed. Similarly, for reactivation, a series of standardized logical steps are followed.

3.1 Cataloging of 'residual' energies

All sources of energy present in a system must be identified and clearly labeled with signs so that they can be easily recognized and secured before any maintenance intervention is initiated. The validity of the method is based on evident facts: in fact, the maintenance worker could be exposed to hazardous conditions in the event of an incorrect instruction or unintentional action that would lead to an unexpected restart of the machine. With the use of LOTO devices, on the other hand, the various hazardous energy sources cannot be activated until each maintenance worker has completed their portion of work and removed their own locks from the various switches. Within the industrial facility, there are various sources of hazardous energy, and for many of these, the LOTO procedure is the ideal control:

- Electrical, in transmission lines, transformers, switches, motors;
- Mechanical, contained in springs or rotating components;
- Hydraulic, due to the movement of pressurized fluid;
- Pneumatic, due to the presence or movement of compressed air or other gases;
- Thermal, due to refrigeration systems, ovens, or heat generated by the operation of a machine;
- Chemical, due to specific reactions;
- Gravitational, present in machinery where vertical movement of large components is free.

The goal of LOTO is to ensure that machines are properly stopped and not restarted until the maintenance or servicing work has been completed. The most evident elements of the LOTO procedure are the safety devices that lock the energy sources in a position where they cannot be reactivated except by those who have secured them.

The method involves establishing criteria and work practices to identify hazardous energy sources, isolate and dissipate such energies, and proceed with the safe shutdown and restart of machinery.

During maintenance phases, one of these hazardous energy sources can bypass safety systems and trigger dangerous conditions for individuals who are in close proximity to the machinery at that particular moment. It is necessary, therefore, to identify all energy sources present in a system and label them with signs so that they can be easily recognized and brought under control before starting any repair or maintenance intervention. To this end, labels have been created and placed in specific locations where it is possible to deactivate the energy to minimize risks."

3.2 Lockout and Tagout Devices

Lockout devices and tags are essential elements within the procedure, and they are divided into three different categories:

• **General**: It is used for energy isolation devices during lockout procedures, such as a padlock for a switch or a lockable cover for a gate valve. It is not assigned to a specific maintenance operator, but the keys for opening it are specific to each

maintenance worker. Master keys are not available. It is not identified with a specific color but should be dedicated exclusively for LOTO procedures.
It is recommended, but not necessary, to associate a tag with this type of device, identifying it as a device used for maintenance.

Figure 8. Emergency push button lockout

• **Personnel**: It is assigned and used exclusively for the personal protection of maintenance personnel and is allowed for use during a single shift. It is typically red in color and also has a single key available.

Figure 9. Personal Lockout Device

• **Transitional**: used for machinery that is temporarily idle and does not have an ongoing maintenance intervention. They are accompanied by yellow and blue tags indicating the status of the machine. They can be used for multiple shifts, but exclusively for LOTO procedures.

Figure 10. Warning Identificative Tag

The photo depicts an example of a tag used in the procedure when multiple maintainers are working on the same machine or equipment: each one will use their personal padlock that only they can remove once the work is completed.

3.3 Preparation of the LOTO Card

To address the work performed on the systems, it is necessary to explain the preliminary study conducted to determine which measures would make the procedure more efficient within the production area. The idea of the procedure originated with the intention of creating an unequivocal document that could be attached to each machine, enabling any maintenance worker to perform interventions even without specific knowledge of the system. In industrial plants, operators, including maintenance personnel, are often assigned to specific departments, and this assignment remains relatively unchanged. As a result, maintenance workers become particularly familiar with the machinery in their respective departments and develop mechanisms that allow them to work more quickly and safely.

In this way, the maintenance worker is not solely reliant on their memory or experience to correctly isolate a machine or system. This significantly reduces the risk of human error. The following methods were chosen to improve the efficiency of the procedure in the company's case:

- **Procedure posted on the machine**: The necessary steps were directly displayed on the machine instead of being included in a manual stored in an archive, which would make it impractical to read.

- **Machine layout with isolation points indicated**: The machine layout was included as an attachment to the procedure, with each isolation point clearly marked with a specific label indicating the type of energy being isolated.

- **Photographic support**: To further clarify the procedure, an image was included for each isolation point, showing the switch or label indicating the type of isolation. These images were compared with those in the layout. This step is identified as "One Point Lesson" or OPL, which, according to Kaizen Coach International, is the development of a document in an essential format that gathers all the key points of a topic related to work, a workstation, or a work area. It collects all the highly important information and uses primarily visual methods to convey as much information as possible in the shortest possible time.

The role of the technologist, the chief operator in the department, was crucial during this phase due to their extensive knowledge of the machinery and experience in maintenance activities. This made it easier to identify isolation points in the machines, especially within the work cells, where it would not be possible to approach without temporarily stopping the cell.

Once the site inspection was completed and all necessary information was gathered, a preliminary draft of the document was prepared. Once approved, it was posted on the machine, outlining the procedure to be followed. Initially, a table summarizing the energies circulating in the machine and how to handle them was compiled. The following information was recorded in the table:

- Type of energy

- Identification label: Each energy had its own label located near the isolation point, allowing for easy recognition by referring to the table. Each energy was differentiated by color and label code.

- Method of isolation: In the case of electrical energy, the procedure indicated pressing a stop button or disconnecting a switch. If dealing with hydraulic or pneumatic energy, it also specified how to discharge any residual energy.

- Locking device: Each isolation point had its own locking device, and the specific device to be used was specified. The accessory required to render the device inoperable in case multiple operators were performing maintenance operations was also indicated.

The machine layout was attached to the table to facilitate the identification of energy isolation points. The layout provided an overhead view of the machine, with labels indicating the energies present and their respective isolation points. The points for disconnecting electrical and pneumatic energy were highlighted. The associated labels were placed at the corresponding points on the machine. The label for pneumatic energy was multi-coloured to indicate that, in addition to shutting off, the discharge of residual energy occurred automatically through a specific valve connected to the pneumatic isolation point.

The layout was included on the first page of the procedure to provide an immediate overview of the machine. Beneath it, the steps for stopping the machine using the LOTO procedure and restarting it were outlined. Once the document was completed, it underwent review by the Maintenance and Safety Office and then by the Workers' **Health and Safety Representative (RLS)**. The safety office reviewed the document, identifying any errors or inconsistencies, while the RLS ensured compliance with safety measures on behalf of the workers in the facility.

Once the document was approved by all relevant parties, the hazardous energy sources on the machine were marked. The presence of the department technologist or a maintenance worker was necessary for this task, as they were responsible for temporarily shutting down the machine to affix adhesive labels indicating the energy isolation points. Two labels were placed at each isolation point: one indicating the type of energy and the other indicating the sequence of disconnection. In the analysed department of the facility, the main energies consisted of three types: electrical, pneumatic, and fluid dynamics. Each had a specific label for identification.

Robots were used in the facility with large movement ranges, and to prevent accidental entry into their work areas, the work cells were enclosed with access allowed only through doors. These doors were equipped with interlocks, contact sensors that, when disconnected, would halt the entire work cell without completely shutting it down.

Activities could only be resumed once the doors were closed and the interlocks were reconnected. In maintenance interventions within the work cells, the first devices to be disconnected were the doors. Therefore, it was decided to include a specific label for the doors in the procedure to indicate their identification.

After marking the machine's isolation points, photographs were taken, showing the isolation device, the label indicating the type of energy, and the numerical label. These photos were attached to the procedure in numerical order to allow for additional verification by the maintenance worker, ensuring that the correct switch or valve was shut off. In collaboration with the technologist, the proper functioning of all safety devices was verified, and their numerical identification was marked.

This allowed for the creation of a list highlighting all the safety devices present on the machine, such as emergency stop buttons, safety interlocks, limit switches, photoelectric barriers, and main switches. The positions of these devices on the machine were indicated on the layout, following the chosen numbering system.

The marking of safety devices improved the efficiency of maintenance work because, in the event of a device signal, the location could be quickly identified, enabling the identification of the problem area in a matter of seconds. This is particularly useful in large-scale plants and can make a difference in preventing accidents.

For the proper preparation of procedures and to make them as closely aligned with the company's reality as possible, it was decided to verify the accuracy and, if necessary, the currency of all the information, data, and materials available to us. This was done because many of the equipment in the facility have undergone substantial modifications over the years to adapt to their purpose, enhance performance, and improve safety. This ensures that both the production and the safety/maintenance sides can benefit from the optimal efficiency of the production line.

Starting with the manuals provided by the manufacturers of the machinery on the production line, a targeted check was carried out, focusing particularly on the pneumatic and electrical schematics. This aspect was crucial as residual energy originates from these systems, and they are among the leading causes of workplace accidents, as mentioned in Chapter 1.

Based on this experience, it was also decided to search for any anomalies and deviations from the manufacturers' manuals. Naturally, this process involved referring to individual cases and documenting only the information relevant to the current conditions of all the examined machinery. As a final step, it was demonstrated how various entities have collaborated over the years to develop a clear methodology to align procedures as closely as possible with reality.

This work was also conducted to ensure that the company possesses the most updated versions of all the materials concerning the machines, which are essential for maintenance and the proper use of each component.

4 Company Procedure

As mentioned earlier, this thesis will focus on the development of the LOTO procedure in an industrial plant where it was partially implemented. Looking at the Nocolock area, the procedure needs to be implemented in a way that can adapt to the different types of machinery on the production line. In our case, we examined various types of assembly machines, including automatic, semi-automatic, and manual machines.

These will be examined in detail later, describing step-by-step the choices made for each case and the motivations behind those decisions. Before delving into the work carried out on the equipment, it is necessary to explain the preliminary study work conducted to determine which measures would make the procedure more efficient within the machine room. The idea behind the procedure was to create an unambiguous document that could be attached to each machine, enabling any maintenance personnel to intervene even without specific knowledge of the particular equipment.

In industrial plants, operators, including maintenance personnel, are often assigned to specific departments, and these assignments are rarely changed. This familiarity with the machinery in their respective departments allows maintenance personnel to work more quickly and safely, acquiring mechanisms specific to their assigned machines.

However, in some cases, such as the absence of the designated maintenance technician or a task requiring a specific qualification not possessed by the assigned technician, there may be a need for personnel to change departments for a particular job. In such cases, methods were studied to ensure that timing and safety levels remained consistent regardless of the assigned maintenance personnel. This way, the technician is not solely reliant on their memory or experience to correctly isolate a machine or system, significantly reducing the risk of human error.

A fundamental aspect is the site visit, one of the main and essential activities for drafting the document. During this phase, the energy sources present, primarily electrical, pneumatic, and hydraulic, were identified.

For the procedure to be applicable, energy insertion systems, such as selectors on electrical panels or valves on pneumatic systems, must have the possibility of being locked with a padlock and must be easily accessible. If this is not possible, a notification should be sent to the Maintenance and Safety Department, which will arrange for the modification of the isolator or its position.

During the site visit, the positions of the energy control devices need to be identified. These devices can be divided into two categories based on their function:

- **Isolation**: These are mechanical devices that prevent energy circulation within the system. Examples include general switches, isolating switches, or gate valves.
- **Control**: Devices installed on the machinery that measure the energy within the systems. They are essential for verifying the presence of residual energy. Examples include pressure gauges, ammeters, or thermometers.

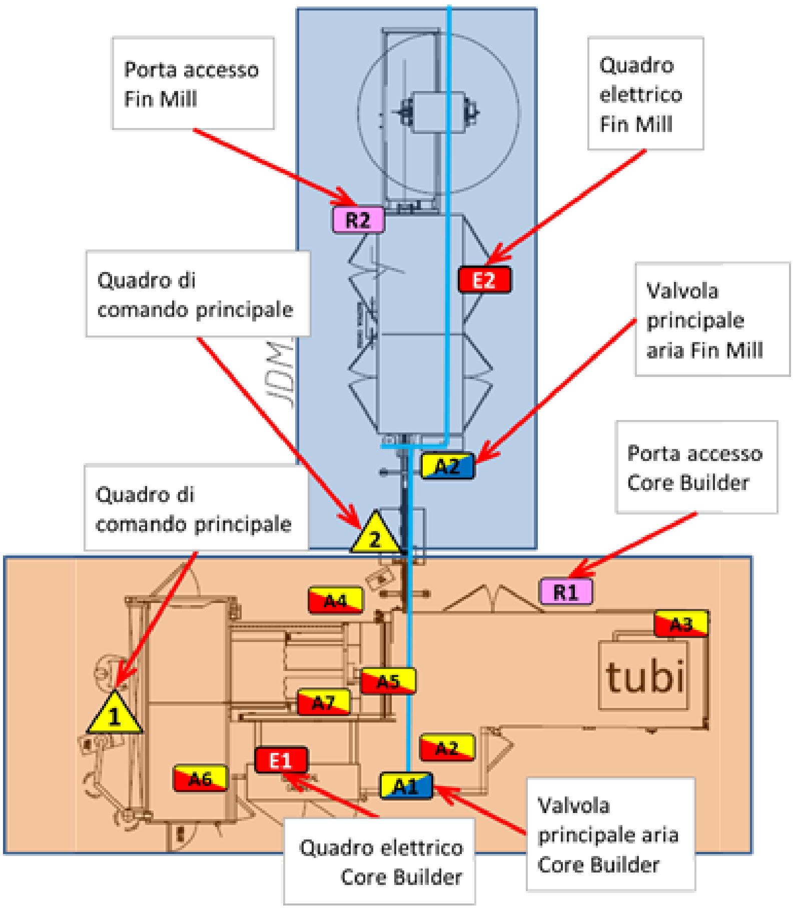
The role of the technologist, the chief operator in the department, is crucial during this phase due to their in-depth knowledge of the machinery and their experience in maintenance activities. Collaboration between the services and plant areas was important, as the services area provided the machine room layouts with highlighted connections for hydraulic, pneumatic, and electrical energy on each machine. This made it easier to identify the isolation points on the machinery, especially within the workstations or islands where access would not be possible without a temporary stoppage.

4.1 Applicative example

To provide an idea of how a specific card can express its usefulness and functionality, we decided to take one as an example and illustrate step by step the choices made and the reasons behind those decisions. Certainly, the underlying purpose of this work was to delve into the safety aspects of production lines. This was further supported by the fact that previous work was limited to cataloging the energy sources present on the machine, but the old procedures provided little information on how to proceed and, most importantly, what aspects required greater attention.

We started by giving the cards an identity that would make them recognizable and easily understood by everyone. As mentioned in the previous chapter, they were placed in a location accessible to operators to expedite the start of the procedure. Therefore, the first page serves as an introduction: on the left column, a text was created that includes all the main information related to equipment shutdown, lockout, tagout, and restart procedures. On the right side, the layout of the example machine, in this case a "JDM 15," is displayed.

The two different sections that make up the machine, namely the Fin Mill section dedicated to forming fins using aluminum sheet processing, were highlighted in different colors. The Fin Mill section is depicted in blue, where the aluminum sheet, preloaded from a coil upstream of the machine, is processed.

<table>
<tr><th>MODALITA' DI ARRESTO PER ESECUZIONE LOCK OUT TAG OUT</th><th>LAYOUT IMPIANTO "JDM15"</th></tr>
<tr><td>
- Capo UTE o Team Leader di produzione comunicano al capo squadra di manutenzione la richiesta di intervento e inseriscono la stessa sul sistema Prometeo.
- I manutentori incaricati dal capo squadra prendono visione del layout apposto sull'impianto di quali siano i punti di sezionamento e si muniscono dei dispositivi di blocco così come descritto nelle varie procedure.
- I manutentori applicano i dispositivi di blocco sulle parti indicate nella scheda riferita alla zona interessata dall'intervento, rispettando la sequenza delle operazioni riportata nelle tabelle delle procedure. (Fig. 1,2 e 3). Nel caso dei circuiti in pressione, provvedono a sfiatare le pressioni residue intrappolate nella linea facendo riferimento al "PACCO Ax VALVOLE" riportato sullo schema pneumatico fornito dal costruttore in allegato.
- Tutti coloro che partecipano all'esecuzione dell'intervento devono apporre il proprio lucchetto su ciascun dispositivo di blocco.
</td><td rowspan="3">


</td></tr>
<tr><td>MODALITA' DI RIAVVIO IMPIANTO</td></tr>
<tr><td>
- I manutentori rimuovono i sistemi di blocco in ordine inverso rispetto alla fase di sezionamento e riarmano tutti i dispositivi di sicurezza di protezione dell'impianto, ripristinandolo.
- Si intende ultimato il lavoro solo dopo aver verificato insieme al Team Leader di produzione che l'impianto funzioni correttamente.
- Il manutentore informa il proprio capo squadra di aver terminato l'intervento.
</td></tr>
</table>

Figure 11. LOTO card example

Figure 12. "JDM" Fin Mill side

In orange, the Core Builder section is depicted, which is the part of the machine where the previously formed fins are sent for final assembly. It involves the insertion of tubes by the operator who has a fixed workstation on this side. This distinction allowed us to delve even further into the details and discover the possibility of sectioning the machine and developing different procedures based on specific needs, a possibility that had not been considered in the past. Furthermore, all the isolation possibilities and their specific positions are listed so that they can be easily identified at the intervention site.

Figure 13. "JDM" Core builder side

Thanks to the support of the Tutor, the first procedures to be carried out when a problem arises have been documented, ensuring that all the relevant entities are aware of what has occurred. From here, the information is entered into the platform that keeps track of all ongoing, past, and scheduled maintenance interventions for each individual machine on the production line.

The platform in question is called "Prometeo," a dedicated software for the planning and management of plant maintenance. It provides a set of suitable tools to monitor and improve their operational performance. The machines can be organized into multiple hierarchical levels and grouped by cost center, location, area, and site. Each machine can be associated with one or more maintenance plans, each with its own type (electrical, mechanical, hydraulic, etc.) and frequency (time-based or meter-based). For each plan, it is also possible to define the following: the registry of maintainers (internal or external) who will carry out the intervention, the list of spare parts required for the intervention, and a checklist containing the sequence of operations that the maintainer must perform, including any measurements and calibration limits, if necessary.

4.2 Warning symbol

To ensure that interventions could be carried out without hesitation, there was a need to create a legend of symbols that, when placed in the appropriate locations on the layout, can immediately indicate the type of device and specifically where it is located. By doing so, with the layout in hand, it is possible to have a general overview of the situation and also be aware of the type of lockout (electrical, pneumatic, etc.) used at a specific point on the machine.

Labels have been created using different colors to provide a clear understanding of what will be addressed, without the need for interpretation. The legend also serves to eliminate any doubts, as everyone involved in the interventions is trained to recognize and identify the different signals to eliminate hazards associated with residual energy. Now, a brief description of the labels created and previously seen on the example layout.

Figure 14. Emergency button label

Undoubtedly the most recognizable due to the shape of the 'danger sign', it represents the emergency button, which is the primary shutdown device and undoubtedly the most numerous, as it can be found in different points of the machinery. It performs an instantaneous electrical interruption and serves as the main control panel, always within reach of the operators to intervene as quickly as possible.

Figure 15 - "Electric panel" label

Staying on the topic of electricity, the second label represents the possibility of isolation from the power supply. The electrical panel button is typically located on the cabins related to the machinery, where all the electrical connections are housed to ensure a 400V power supply. Therefore, having a switch of this type essential to eliminate any residual electrical current.

Figure 16. Access door label

An important aspect is undoubtedly the ability to interrupt the operation of a machine through the entry and exit from certain sensitive areas, namely highly dangerous zones that are, however, delimited for safety by strategically positioned light barriers. These barriers consist of an emitter and a receiver that manage the transmission of a stop signal when the barrier is crossed by any object, whether it be a tool or a maintenance worker's limb. The same label is used for the presence of doors equipped with safety limit switches that halt the operation if any of the doors are accidentally left open or improperly closed.

Figure 17. Principal Air valve label

By changing the type of energy, we start considering the hazardous nature of the high-pressure system to which the machine is connected. It ensures the proper execution of all operations related to pneumatic energy, which is primarily applied on the Core Builder side due to the presence of the press. Compressed air represents a potential source of energy, and precautions must be taken when working with pneumatic systems. With this label, isolation points can be easily identified through a quick disconnect valve that instantly interrupts the pneumatic network.

This is indeed the visual reference to what are known as "valve packs," which are the interception points of the entire pneumatic system. Its importance lies in the realization that it is possible to act on these valve packs to eliminate the danger of residual energies. Even after interrupting the high-pressure air, residual energies persist due to the type of valves used throughout the system. As these are closed-center valves, this double precaution is necessary to eliminate the risk of residual energies below the pneumatic point.

Figure 18. Valve island label

4.3 Applied procedure

As mentioned earlier, in the past, a comprehensive procedure had already been established for certain machines in the company. However, it had some aspects that had not been taken into consideration, such as different residual energies and the possibility of working separately on certain segmented parts of the machines in question. This immediately highlighted the limitations of the old procedures, making them unsafe. Therefore, it was decided to start from the examples found on the company network and the guidelines proposed by the company to carry out the implementation project of LOTO.

An attempt was made to maintain the same format used previously for the following reasons:

- The tables used are very clear and unequivocally indicate the sequence to be followed.
- Different colors are used to create different categories of energy and indicate the magnitude of the energy itself.
- The point of isolation, the type of device to be isolated, the action to be taken, and finally the photo of the specific safety device used are indicated. In this case, the personal safety device suitable for each type of lock present on the machine.
- Finally, the operations to be performed to step-by-step verify that each step of the sequence has led to the expected results for the type of intervention carried out.

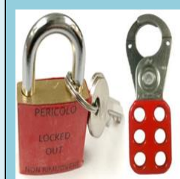
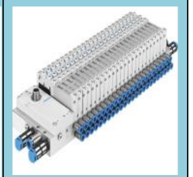
LOTO - BLOCCO IMPIANTO JDM15- PROCEDURA COMPLETA									
SEQUENZA	OPERAZIONE								
	1	2	3	4	5	6	7	8	9
Sezione									
	INTERRRUZIONE ENERGIA PRIMARIA								
Tipo di energia	-	-	Generale	Generale	Elettrica	Elettrica	Pneumatica	Pneumatica	Pneumatica
Entità energia	-	-	-	-	400 V	400 V	6 bar	6 bar	6 bar
Id. punto sez.	R1	R2	1	2	E1	E2	A1	A2	Ax
Punto di installazione dispositivo di isolamento	Porta accesso Core Builder	Porta accesso Fin Mill	Quadro di comando principale	Quadro di comando principale	Quadro elettrico Core Builder	Quadro elettrico Fin Mill	Rete alimentazione Core Builder	Rete alimentazione Fin Mill	Gruppo valvole per sfiato pressione residua
Dispositivo da isolare	Elettroserratura porta	Elettroserratura porta	Pulsante di emergenza	Pulsante di emergenza	Interruttore generale	Interruttore generale	Valvola di intercettazione per inserimento e scarico	Valvola di intercettazione per inserimento e scarico	Valvola di intercettazione
Azionamento da compiere	Richiedere accesso da pannello operatore	Richiedere accesso da pannello operatore	Premere in posizione mantenuta e bloccata	Premere in posizione mantenuta e bloccata	Portare su "0" o "off"	Portare su "0" o "off"	Ruotare in senso antiorario	Ruotare in senso antiorario	Staccare tubo
Dispositivo LOTO da utilizzare									
Verifiche da compiere a garanzia dell'isolamento	Caduta pressione, segnale apertura su quadri, dispositivo porta lucchetto inserito con lucchetto chiuso	Caduta pressione, segnale apertura su quadri, dispositivo porta lucchetto inserito con lucchetto chiuso	Caduta pressione, segnale rosso emergenza su quadri, pulsante bloccato con coperchio, porta lucchetto e lucchetto	Caduta pressione, segnale rosso emergenza su quadri, pulsante bloccato con coperchio, porta lucchetto e lucchetto	Impianto spento, quadri, video non più attivi, dispositivo porta lucchetti inserito con lucchetto chiuso	Impianto spento, quadri, video non più attivi, dispositivo porta lucchetti inserito con lucchetto chiuso	Verificare che il dispositivo installato sia correttamente posizionato e volantino o saracinesca risultino inamovibili	Verificare che il dispositivo installato sia correttamente posizionato e volantino o saracinesca risultino inamovibili	Verificare che il dispositivo installato sia correttamente sezionato e che non ci siano pressioni residue
IN CASO DI DUBBI/ANOMALIE FERMARSI E CHIAMARE IL PROPRIO RESPONSABILE									

Figure 19. LOTO complete procedure

Of course, having a written procedure emphasizes that if any step does not produce the desired effects, the procedure must be immediately halted. It is possible that an isolation device may not function correctly, which is why there is a need for confirmation every time a maneuver is performed. Otherwise, the procedure must be interrupted, and the responsible person must be informed, as indicated by the bold text at the end of the table.

From a training perspective, the true revolution lies in having multiple paths to follow, having more chances to act, and having a broader view of the reality of the machinery in the production line compared to the past. This is why the opportunity to see the machine not as a single entity but as a collection of multiple parts that can be separated, isolated, or even left in operation while maintenance work is being carried out on another side has been recognized. This not only allows for a different perspective on the different systems but also enables better management of both routine and extraordinary maintenance interventions, reducing time and optimizing the necessary work windows for certain operations.

Beyond the positive aspects, one must also consider the fact that dealing with a large number of procedures could be seen as a negative in terms of time. However, in reality, it is not, as the procedures are implemented to reduce intervention times and focus on the objective, thus avoiding time waste and production stoppages.
Let's examine specifically: taking the same machine, JDM15, the different procedures are provided for both sides, namely Core Builder and Fin Mill, in order.

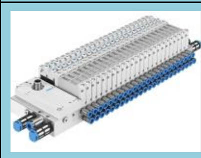
LOTO - BLOCCO IMPIANTO JDM15- PROCEDURA LATO CORE BUILDER					
SEQUENZA	OPERAZIONE				
	1	2	3	4	5
Sezione					
	INTERRRUZIONE ENERGIA PRIMARIA				
Tipo di energia	-	Generale	Elettrica	Pneumatica	Pneumatica
Entità energia	-	-	400 V	6 bar	6 bar
Id. punto sez.	R1	1	E1	A1	Ax
Punto di installazione dispositivo di isolamento	Porta accesso Core Builder	Quadro di comando principale	Quadro elettrico Core Builder	Rete alimentazione Core Builder	Gruppo valvole per sfiato pressione residua
Dispositivo da isolare	Elettroserratura porta	Pulsante di emergenza	Interruttore generale	Valvola di intercettazione per inserimento e scarico	Valvola di intercettazione
Azionamento da compiere	Richiedere accesso da pannello operatore	Premere in posizione mantenuta e bloccata	Portare su "0" o "off"	Ruotare in senso antiorario	Staccare tubo
Dispositivo LOTO da utilizzare					
Verifiche da compiere a garanzia dell'isolamento	Caduta pressione, segnale apertura su quadri, dispositivo porta lucchetto inserito con lucchetto chiuso	Caduta pressione, segnale rosso emergenza su quadri, pulsante bloccato con coperchio, porta lucchetto e lucchetto	Impianto spento, quadri, video non più attivi, dispositivo porta lucchetti inserito con lucchetto chiuso	Verificare che il dispositivo installato sia correttamente posizionato e volantino o saracinesca risultino inamovibili	Verificare che il dispositivo installato sia correttamente sezionato e che non ci siano pressioni residue
IN CASO DI DUBBI/ANOMALIE FERMARSI E CHIAMARE IL PROPRIO RESPONSABILE					

Figure 160. Core Builder side procedure

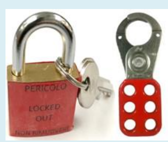
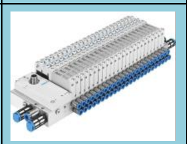
LOTO - BLOCCO IMPIANTO JDM15- PROCEDURA LATO FIN MILL						
SEQUENZA	OPERAZIONE					
	1	2	3	4	5	6
Sezione						
	INTERRRUZIONE ENERGIA PRIMARIA					
Tipo di energia	-	Generale	Elettrica	Elettrica	Pneumatica	Pneumatica
Entità energia	-	-	400 V	400V	6 bar	6 bar
Id. punto sez.	R2	2	E1	E2	A2	Ax
Punto di installazione dispositivo di isolamento	Porta accesso Fin Mill	Quadro di comando principale	Quadro elettrico Core Builder	Quadro elettrico Fin Mill	Rete alimentazione Fin Mill	Gruppo valvole per sfiato pressione residua
Dispositivo da isolare	Elettroserratura porta	Pulsante di emergenza	Interruttore generale	Interruttore generale	Valvola di intercettazione per inserimento e scarico	Valvola di intercettazione
Azionamento da compiere	Richiedere accesso da pannello operatore	Premere in posizione mantenuta e bloccata	Portare su "0" o "off"	Portare su "0" o "off"	Ruotare in senso antiorario	Staccare tubo
Dispositivo LOTO da utilizzare						
Verifiche da compiere a garanzia dell'isolamento	Caduta pressione, segnale apertura su quadri, dispositivo porta lucchetto inserito con lucchetto chiuso	Caduta pressione, segnale apertura su quadri, dispositivo porta lucchetto inserito con lucchetto chiuso	Impianto spento, quadri, video non più attivi, dispositivo porta lucchetti inserito con lucchetto chiuso	Impianto spento, quadri, video non più attivi, dispositivo porta lucchetti inserito con lucchetto chiuso	Verificare che il dispositivo installato sia correttamente posizionato e volantino o saracinesca risultino inamovibili	Verificare che il dispositivo installato sia correttamente sezionato e che non ci siano pressioni residue
IN CASO DI DUBBI/ANOMALIE FERMARSI E CHIAMARE IL PROPRIO RESPONSABILE						

Figure 171. Fin Mill side procedure

Although they are very similar, they represent substantial differences that make them unique. The smaller size of the sequence is obviously due to the fact that there are fewer devices to be checked when segmenting the machine. It should be noted that the convention of using '1' for the Core Builder side and '2' for the Fin Mill side has been chosen to simplify matters compared to the complete procedure, which naturally has more elements but is not necessarily more difficult to implement.

One substantial difference that immediately stands out is the presence of a dual intervention in the Fin Mill side procedure, indicated by the presence of two electrical panels. In fact, despite the possibility of segmenting the machine into two individual parts, there are some elements that serve a dual purpose. This brings to mind the fact that even though they can be divided, the two parts must still be able to communicate with each other and send signals that convey what is happening elsewhere, which energies have been isolated, what issues there are, which of the two parts is ready for restart, etc.

In this regard, the important work performed by the PLC deserves mention. Thanks to the PLC, it is possible to manage all the adjustable parameters and obtain a wealth of information, such as:

- Parameters related to the geometry for fin forming.
- Parameters related to the assembly side and movement.
- Stoppage, restoration, and production startup.
- Historical records of anomalies detected over time.

A significant aspect of the PLC, beyond its numerous uses, is its ability to disconnect the machine from the power supply without causing bugs in the PLC itself. The shutdown/restart phase is crucial for this component. Since it holds a wealth of information, it is important to handle it properly to avoid losing all the pre-set data with each restart. As evident from the Fin Mill side procedure, by following the sequence in reverse, we can identify both electrical panels, in descending order and in separate positions '4' and '5'. From this, it can be deduced that the PLC on the Core Builder side is subordinate to the one on the Fin Mill side, which has control and takes precedence, thus needing to be activated first.

This brings us back to the issue of communication between the two parts. By performing the correct maneuvers, the technical downtime during the production restart on the machine in question can be reduced when the PLCs synchronize.

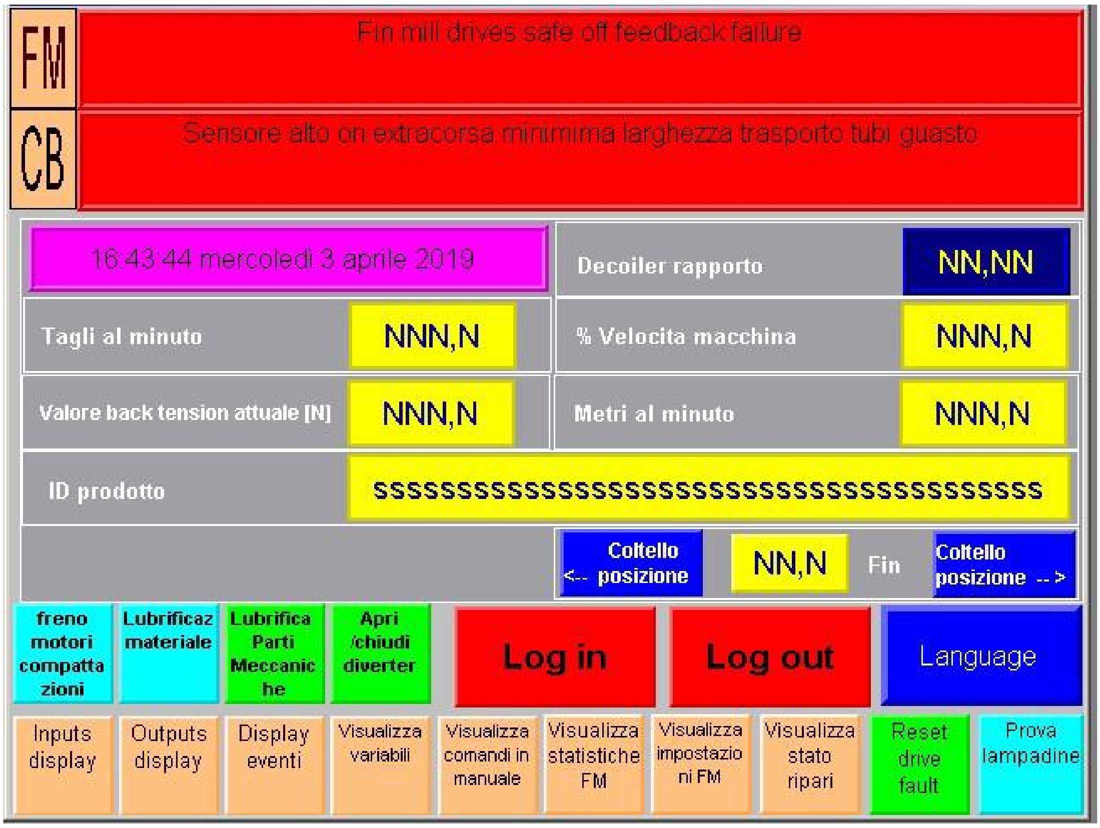


Figure 182. PLC screen example for parameters setup

4.4 Development against residual energy

There are many positive aspects to the decision to implement the LOTO procedure by a significant and large company like Denso S.p.A., but undoubtedly one of the most important is related to residual energies present on the production line.

We have already discussed in 3.1 the magnitude, categories, and how to approach this type of energy. However, the fundamental aspect is to establish a methodology that can keep all operators participating in a maintenance intervention safe from risks.

To this end, it was decided to expand the scope of the LOTO card by adding instructions on how to deal with this issue. However, one of the main challenges, also due to the complexity of the machinery, is to understand where these energies are generated and how they can be released, leading to injuries of various degrees.

Such work cannot be based solely on experience due to the dangers that this approach could pose. Therefore, a different and certainly safer approach was chosen. The strategy chosen was to inspect each individual machine from every perspective. With the help of technicians, all panels, control panels, and access points relevant to maintenance interventions were examined. This initial part of the work allowed me to become aware of the most important aspects of different types of machinery. It was interesting but undoubtedly very useful, as the knowledge gained during these activities provides a more comprehensive understanding of what is being studied and also offers insights into the underlying design and construction philosophy of the machine.

In addition to this in-depth visual study, the manuals provided by the respective manufacturers of the machinery were also examined during the inspections. These documents are essential both for their legal and bureaucratic significance and for the wealth of important information they provide.

The content of these manuals is technical in nature. They meticulously detail the electrical and pneumatic schematics of each individual machine, along with design drawings for the components and all relevant information regarding recommended routine/preventive maintenance interventions by the manufacturer, as well as default production and maintenance data for the machine over the years.

Based on these considerations, the work proceeded with the identification and documentation of key steps in the interventions that raised greater concern. The following is a key example that gives an idea of how far we went in the search for potential hazards.

The following figure shows a schematic representation of a "VALVE PACK". As the name implies, it is a grouping of 5/2 closed-center valves arranged in this configuration to create a fixed point where interventions can be carried out with a complete view of the task at hand. The issue with closed-center valves is their ability to maintain pneumatic pressure within the circuits even when disconnected from the pneumatic supply.

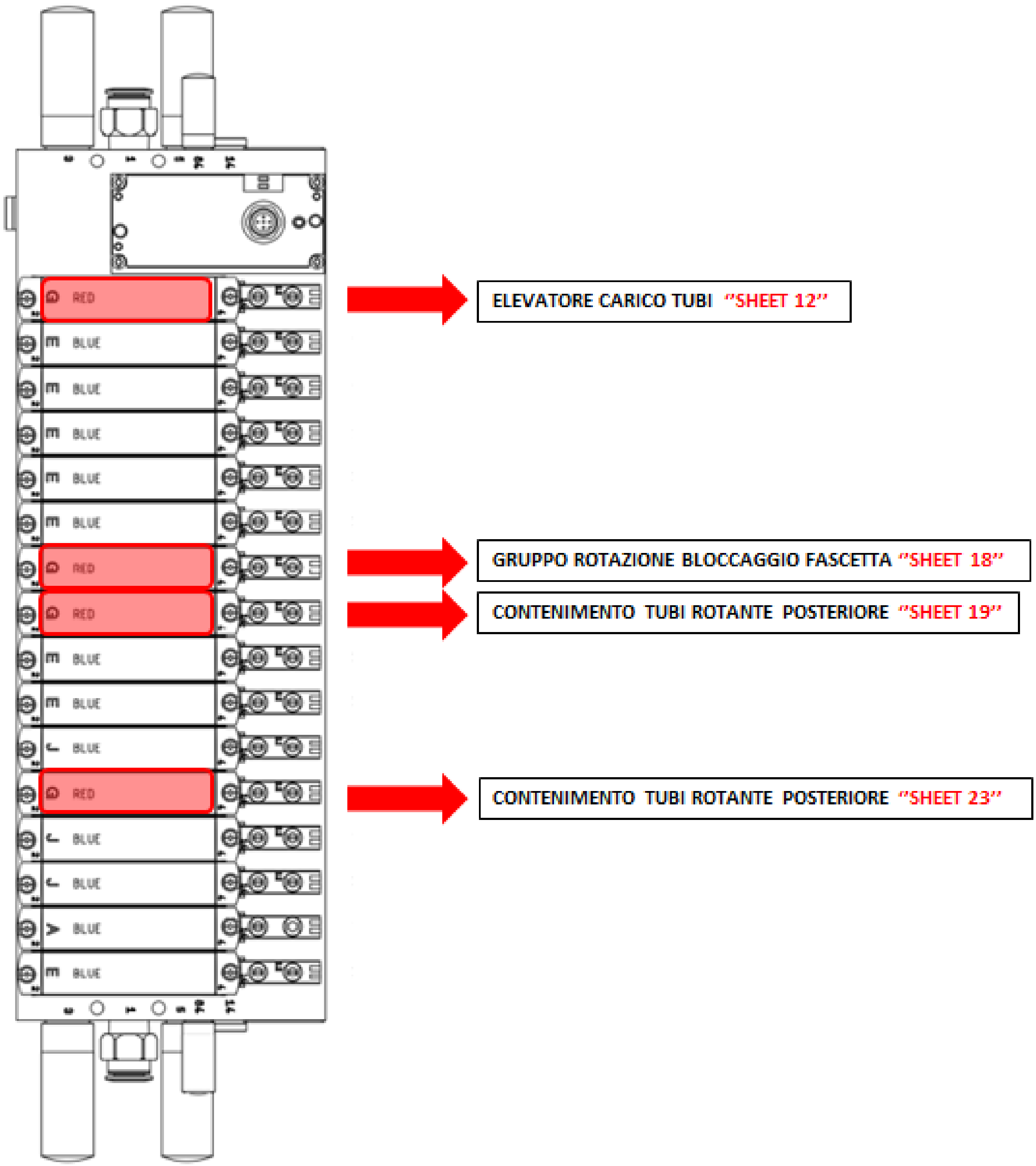


Figure 23. Valve island schematiozation

The most evident distinction is not limited to the color aspect alone. In fact, the interception valves highlighted in red are associated with those circuit segments where residual pressures remain trapped and can become hazardous to anyone in the vicinity. Therefore, action must be taken to manually release the pressure from these tubes or by using a tool as suggested by the manufacturer. Finally, to ensure the unambiguous use of these schematics, sheets with the corresponding page numbers of the complete diagrams have been added. The maintenance technician now has all the elements available in the card to operate while being aware of all the hazards present at the intervention site, thus enabling them to work in complete safety.

Here is a real example of a pneumatic diagram: specifically, this one from page 51 or 'SHEET 51' relates to the pneumatically operated comb lift on the Core Builder side.

As can be seen from the image, this diagram illustrates the connections between the elements involved. In this specific case, we can observe a 5/2 electronically controlled valve that simultaneously acts on two actuators, namely two double-acting cylinders, managed and regulated by flow regulators and one-way valves for immediate interruption if necessary.

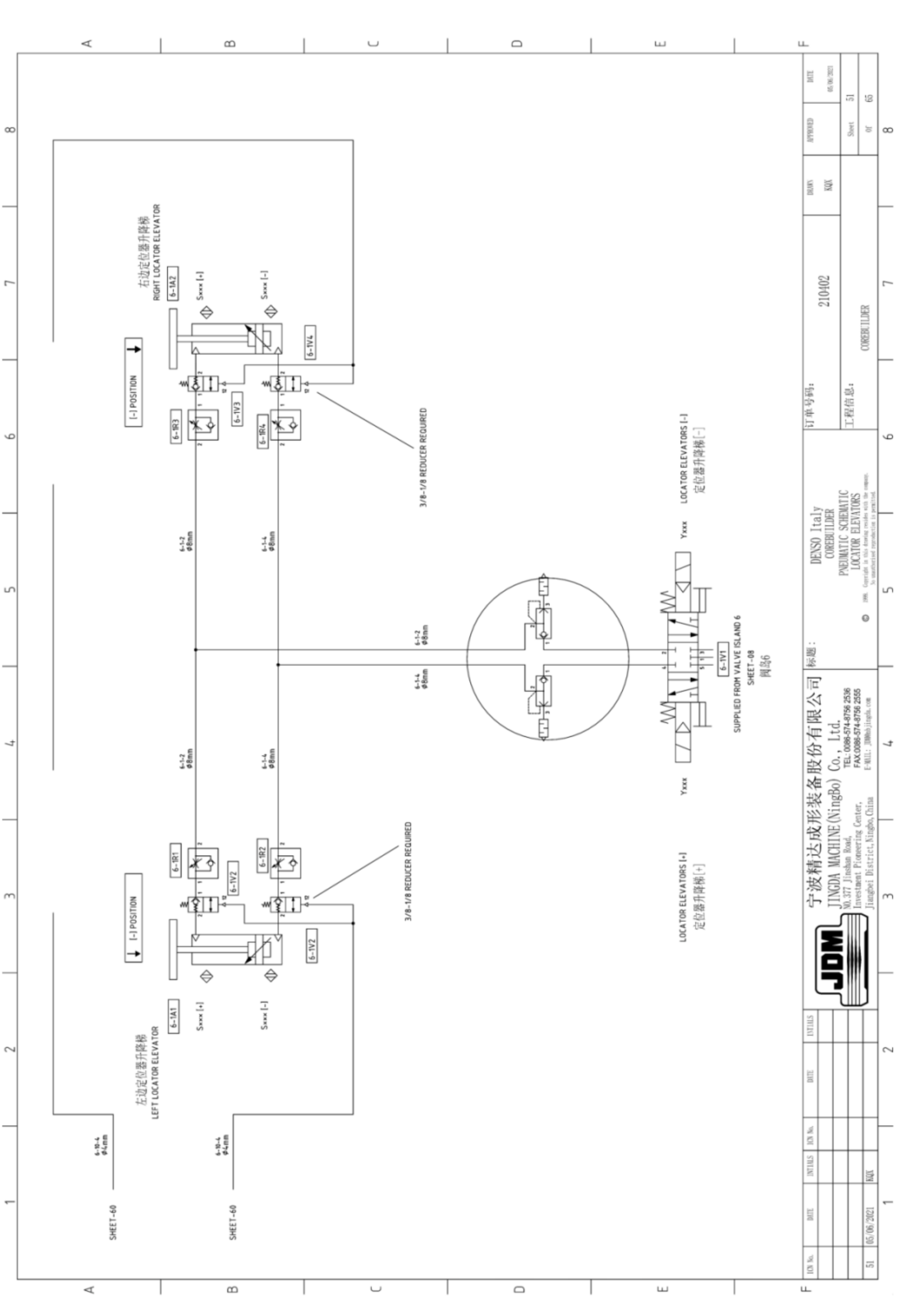


Figure 24. Pneumatic scheme of a single valve

5 Conclusion

The approach described in Chapter 4 is a brief summary of the work carried out on a single machine, but the same methodology was applied to all types of machinery on the production line. This highlighted differences and similarities, critical aspects, and strengths for each of the approximately 30 machines examined. In addition to these, work was also done on the entire transportation and storage system provided by a leading company in industrial automation solutions.

The volume of work completed during my experience, although yielding excellent results and serving as a foundation for safety developments in other areas of the company, is not everything. If not coupled with appropriate company policies and procedures, it would be rendered ineffective.

On the other hand, the creation of all the LOTO cards is not enough to achieve the intended goal of the company. There are certain aspects that can hinder the successful outcome of a project. Some of these include:

• Environmental factors: Some machines, especially older ones, present problems or difficulties in applying locking devices because the machine's design did not account for such adaptations. There are also cases where the procedures are applicable, but the actuators and switches are not easily accessible.

• Organizational factors: In an industrial facility, shutting down a machine for repairs may be perceived as a loss of time and, consequently, a decrease in profits due to production pressures. Similarly, the lack of well-established guidelines, written procedures, or an insufficient number of LOTO devices may be seen by maintenance personnel as a lack of management's attention to safety and methodology.

• Experiential factors: Individuals involved often tend to underestimate pre-established procedures, considering the tasks to be performed as risk-free, despite the various types and magnitudes of energies involved. This can lead personnel to rely solely on their experience accumulated over the years.

To overcome these issues, management must not only define an action plan to incorporate the LOTO program within the company and assign it the appropriate importance but also consider all crucial management measures to ensure the success and continuity of the project in the future. The relevant entities must emphasize the importance of the methodology through support, involvement, and setting a good example. It is crucial to define in advance the necessary resources, both in terms of financial resources for acquiring equipment such as labels, padlocks, and personal safety devices.

The responsibilities for implementing the program must be clear and well-defined, and staff should be encouraged to fulfill their tasks. Managers should oversee the entire implementation process to ensure that each step is carried out correctly. The active involvement of personnel is perhaps the most important aspect of the process, although it can be the most challenging to achieve. Staff participation leads to better results as it enhances their understanding of the procedures. Furthermore, different backgrounds and experiences can be a source of new ideas. By listening to the suggestions of those who have been performing certain tasks for many years, deficiencies in the LOTO program can be identified, and opportunities for improvement can be recognized. Conversely, the lack of involvement of employees in decisions that concern them can be considered a serious mistake to be avoided at all costs.

Another fundamental aspect for the success of the LOTO program is continuous and effective communication. Information related to LOTO operations must be shared among all stakeholders, including not only the workers directly involved in the maintenance intervention but also those who may be affected or working in close proximity. The performance of the LOTO safety program should be continually evaluated and improved through audits, inspections, risk assessments, incident analysis, investigations of near-misses, and feedback from workers.

5.1 Economical aspects

It should be considered that the implementation of LOTO policies in the company results in a modification of the risk profile associated with maintenance personnel, with an increase in the average level of safety for individual employees. However, establishing and maintaining a hazardous energy control system requires a certain amount of resources in terms of finances, personnel, and time.

Through analysis, the following types of costs have been identified:

- Staff training: Conducting training courses, learning assessments, practical demonstrations of procedure application, and field verifications are necessary.
- Planning and implementation: This involves the preliminary work required for implementing the method, including startup and maintenance phases.
- Equipment modifications to enable LOTO application.
- Purchase of materials: Lockout devices, padlocks, tags, and others.
- Validation: An external company will be responsible for validating the effectiveness and usefulness of the cards, ensuring compliance with relevant regulations.

While LOTO may entail increased costs for risk reduction, it is associated with a decrease in workplace injuries, which in turn leads to a reduction in the total number of lost workdays and the associated costs. Before implementing the method, a feasibility analysis should be conducted to minimize the total safety management costs.

5.2 Future improvements

As for Denso S.p.A, possible future developments related to the control of hazardous energies through Lockout-Tagout may involve the application of the method to corrective maintenance activities, i.e., those performed whenever a machine breakdown occurs. Another potential development is the repositioning of isolation and try-out devices in more easily identifiable and accessible locations, with the aim of reducing the time required to apply the method.

Given the positive results achieved at the Poirino plant, it could be considered to implement the same safety procedure at other facilities worldwide, in order to have a much broader case study that can further enhance the protection provided by the method. LO.TO procedures, in fact, are part of the plans for all Denso facilities. This initiative, proposed by safety organizations years ago, has undoubtedly made progress but still requires further improvements. This thesis work has brought even greater awareness of the issue, to the extent that some guidelines can be proposed in other plants to provide useful material for the implementation of the method.

Currently, in Italy, there is not much discussion about the risk associated with the re-energization of hazardous energy sources. The widespread adoption of the LOTO method, following the example of the American model, could lead to benefits in terms of reducing workplace incidents and improving health and safety levels not only for maintenance personnel but for the entire plant staff.

Unfortunately, workplace incidents are a reality that no company can overlook. Denso has embraced this line of thinking, considering that over the years, there have been incidents of various natures and varying degrees of severity on the production lines. Given the complexity of the examined departments, it is challenging to completely eliminate the problem, but efforts can be made to contain and minimize it.

Figure 25. Plant sensibilization

Although we are not discussing specific numbers (which, by the way, are not disclosed) due to the sensitivity with which safety is treated at the company level, the plans are very clear. Following the philosophy of 'Kaizen' extensively discussed in Chapter 1.2.1, the objective is to minimize risks and strive towards zero workplace incidents/deaths.

Unfortunately, in recent years, there have been incidents where someone has been seriously injured or, in the worst cases, lost their life. These incidents bring great sorrow to a work environment like the one I have encountered in this facility. That is why the commitment put into this work by myself and the supporting organization receives full support from all those who recognize the importance of the work conducted for this thesis.

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