Increasing Operational Efficiency and Quality in an Automotive Industry Supplier

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Resumo

Esta dissertação documenta um programa de melhoria contínua, orientado para a excelência, conduzido pelo Kaizen Institute em colaboração com a Empresa X, uma empresa de tranformação metálica no setor automóvel. Diante do aumento dos custos de qualidade, das paragens recorrentes do equipamento e das exigências estritas de entrega, o projeto focou-se em dois pilares de produção fundamentais: manutenção e controlo de qualidade.

O objetivo consistiu em aumentar a eficácia global do equipamento, ao mesmo tempo que se procedia à mitigação das perdas de qualidade internas. As dificuldades enfrentadas pela empresa foram agravadas pelo contexto de atuação num setor altamente competitivo e exigente, onde os atrasos e defeitos dos produtos podiam ter consequências significativas.

Os objetivos foram estabelecidos com o intuito de alcançar um aumento de 20% na eficiência operacional e uma redução de 50% nos custos internos de qualidade (ou seja, material rejeitado). A primeira etapa da metodologia consistiu na execução de uma Análise de Fluxo de Valor, um processo que permitiu a identificação de problemas e a subsequente formulação de soluções. Posteriormente, deu-se início à implementação das soluções desenhadas.

As soluções direcionadas para a eficiência identificaram a disponibilidade como o componente com o valor mais baixo de Overall Equipment Effectiveness (OEE). Foi também determinado que a causa desta falta de disponibilidade eram paragens devido a falhas, derivado de manutenção insuficiente.

No caso específico das prensas, a meta será alcançada por meio de uma investigação aprofundada sobre o procedimento de manutenção da ferramenta, sendo o principal objetivo reduzir o tempo perdido para paragens não programadas causadas pelo estado da ferramenta. A abordagem seguida, consiste em enfatizar a importância da prevenção de falhas face à sua correção. Relativamente às máquinas de soldadura, o ênfase será colocado na alteração das normas atuais de manutenção, a introdução de tarefas de manutenção autónoma a serem realizadas a nível do operador e a eliminação de constrangimentos existentes no processo de manutenção, como a acessibilidade a peças sobresselentes. Máquinas equipadas com braço robótico vão ser alvo de uma atenção especial devido à sua complexidade e necessidade de rendimento superior. As alterações compreenderam modificações ao chão de fábrica, à periodicidade da manutenção e ao redesenho das respetivas operações de manutenção. Estas alterações foram fundamentadas pela padronização do trabalho, garantindo, deste modo, a sustentabilidade do projeto.

No que diz respeito à auditoria de qualidade, foi imperativo proceder à reestruturação de vários dos atuais procedimentos de qualidade. Adicionalmente, foi necessário implementar um processo que garantisse a geração de dados confiáveis, que pudessem ser utilizados pela equipa de qualidade. Posteriormente, a informação foi organizada e foi implementado um padrão para a sua análise. Esta metodologia resultou na identificação de problemas passíveis de resolução, que foram posteriormente alvo de intervenção.

Após a conclusão do projeto, ficou claro que as soluções implementadas se tinham revelado eficazes. A mentalidade predominante na empresa sofreu uma transformação significativa,

evoluindo para uma equipa mais proativa e em busca de melhorias, em comparação com a atitude inicial.

A eficácia das filosofias Kaizen foi demonstrada, e a empresa X ficou com um processo estruturado para seguir, de modo a manter os ganhos e procurar melhorias adicionais.

Abstract

This dissertation chronicles a Kaizen-led improvement programme conducted by the Kaizen Institute in partnership with Company X, a metal working company from the automotive sector. Faced with mounting quality costs, recurrent equipment stoppages, and stringent delivery demands, the project focused on two pivotal production pillars: maintenance and quality control.

The objective was to enhance overall equipment effectiveness while concurrently mitigating internal quality losses. The challenges faced by the company were further compounded by the context of operating within a highly competitive and exacting industry, where product delays and defects could result in significant repercussions.

The objectives were established with the aim of achieving a 20% increase in operational efficiency and a 50% reduction in quality internal costs (i.e. scrap). The initial step in the methodology entailed the execution of a VSA (Value Stream Analysis), a process that facilitated the identification of issues and the formulation of solutions. Subsequently, the implementation of the aforementioned solutions was initiated.

The efficiency-related solutions targeted maintenance because, of all the components of Overall Equipment Effectiveness (OEE), it was the one with the lowest values. It was also determined that the cause of the stoppages was breakdowns.

In the specific case of stamps, the goal will be achieved through an in-depth investigation of the tool's maintenance procedure, with the main objective being to reduce the time lost to unscheduled downtime caused by the condition of the tool. The approach taken is to emphasize the importance of preventing breakdowns rather than correcting them. For welding machines, the emphasis will be on changing current maintenance standards, introducing autonomous maintenance tasks to be carried out at operator level and removing existing constraints in the maintenance process, such as accessibility to spare parts. Machines equipped with robotic arms will receive special attention due to their complexity and need for higher performance.

The alterations encompassed modifications to the layout, the frequency of maintenance and reconstruction of the maintenance procedures. These changes were underpinned by the standardisation of work, thereby ensuring the sustainability of the project.

In terms of quality auditing systems, it was necessary to restructure a number of the existing quality audit procedures. Furthermore, a process was required to ensure the generation of reliable data that could be utilised by the quality team.

Subsequently, the data was organised and a standard was implemented for its analysis. This resulted in the identification of actionable problems that were then targeted. Upon the culmination of the project, it was evident that the implemented solutions had proven to be effective. The prevailing mentality within the company has undergone a marked transformation, evolving into a more proactive and improvement-seeking team than was initially apparent.

In summary, the following points should be noted: the strategic methodology addressed in the analysis and structuring

The efficacy of the Kaizen philosophies was demonstrated, and the company was provided with a structured process to adhere to in order to maintain momentum and pursue additional enhancements.

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UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework to achieve a better and more sustainable future for all. The 17 goals address the world's most pressing challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice.

This dissertation contributes to specific SDGs by promoting sustainable industrial practices, enhancing operational efficiency, and empowering employees to actively engage in continuous improvement processes. The project focuses particularly on improving production processes through Lean methodologies, reducing waste, and fostering decent work conditions.

The Sustainable Development Goals directly related to this work are:

SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

SDG 12 Ensure sustainable consumption and production patterns.

SDG	Target	Contribution	Performance Indicators and Metrics
8	8.2	Increasing the efficiency of production processes through maintenance optimization and employee engagement in autonomous maintenance, contributing to productivity growth.	OEE improvement; Reduction in MTTR and increase in MTBF; Employee participation levels.
	8.5	Empowering operators through training and involvement in continuous improvement initiatives, promoting decent work conditions and skill development.	Number of trained operators; Implementation of autonomous maintenance practices.
12	12.2	Reducing material waste by minimizing scrap rates through quality control improvements and preventive maintenance.	Scrap volume reduction; Nonconformities rate; Internal quality costs.
	12.6	Implementing sustainable production strategies such as Kaizen and TQM to optimize resource use and promote operational excellence.	Progress in Lean initiatives; Number of improvement actions implemented; Quality system maturity levels.

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"If you can't explain it simply, you don't understand it well enough."

Albert Einstein

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Acronyms and Symbols

KPI	Key Performance Indicator
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
NOK	“Non-OK” – non-conforming part
OEE	Overall Equipment Effectiveness
PPM	Parts Per Million (defect rate)
TPS	Toyota Production System
TPM	Total Productive Maintenance
TQM	Total Quality Management
VSA	Value Stream Analysis

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Chapter 1

Introduction

1.1 Framing the problem

The dissertation project was carried out within the scope of the Kaizen Institute, an international consultancy, with the aim of providing Lean solutions and implementing Kaizen methodologies. This approach aims to achieve sustainable competitive advantages.

This project is a partnership between the Kaizen Institute and Company X, a metalworking company that supplies industries such as the automotive and thermo-domestic sectors.

Due to the competitiveness of the sector in which it operates, the need to increase the operational excellence and efficiency of its operations has arisen.

The project in question tackled various aspects of production with the aim of increasing operational efficiency. This dissertation focuses on solutions aimed at maintenance and quality control.

In terms of maintenance, the aim was to ensure greater availability of stamps and welding machines during production as a result of fewer unplanned interruptions.

With regard to quality, the aim was to reduce the number of non-conforming parts and the need for quality inspections at the end of the production process.

It is projected that these initiatives, together with the others included in the project, will lead to a considerable increase in the operational efficiency of company X, allowing it to respond as efficiently as possible to production orders and remain within the quality requirements imposed by customers.

1.2 The Kaizen Institute

The Kaizen Institute is an international consulting company founded in 1985 in Switzerland by Masaaki Imai, a professor at the University of Tokyo and a leading figure in the field of continuous improvement. The theme of Continuous Improvement is at the heart of the Kaizen Institute, starting with the company's name. Kaizen is a Japanese word derived from the words "Kai" and "Zen", translated, respectively, as "Change" and "Better", resulting in "Continuous Improvement".

According to the company's values, this improvement must take place in all areas, all people, and every day (Kaizen Institute, 2025b).

The Kaizen Institute is currently present on five continents and in more than sixty countries and provides consultancy services in various sectors such as banking, hospitals, and industry. The Kaizen Institute was responsible for bringing knowledge of the TPS (Toyota Production System) to the West, with a focus on Pull systems, integrating concepts related to Lean (Kaizen Institute, 2025a).

Today, the company's focus remains the same as ever, guaranteeing solutions that enable clients to improve and sustain their performance at the lowest possible cost.

1.3 Automotive Sector

Company X belongs to a group of companies producing metalworking assemblies and sub-assemblies for the automotive industry, supplying some of the most important producers in Europe, and therefore subject to high quality standards and volumes of demand.

Founded in 1982, Company X focuses on the production of metal parts for the automotive and domestic heating industries.

In the automotive industry, which is one of the most competitive, there is constant pressure to remain competitive, and reducing operating costs is one of the main differentiating factors between producers in the sector and serves as a bridge to innovation and sustainability. In this sector, the application of Lean and Kaizen principles is one of the main drivers for reducing operating costs and increasing productivity.

As Stellantis represents approximately 90% of Company X's total sales, it holds a position of critical strategic importance. Being one of the world's largest automotive groups, Stellantis imposes stringent requirements in terms of quality, delivery performance, and continuous improvement. As a result, the need to meet tight deadlines and ensure flawless product quality becomes imperative. These two dimensions — quality and timely delivery — are therefore placed at the core of the project.

The Portuguese car industry is in a downward spiral as a result of disruption during the pandemic, difficulties in the transition to electric cars and increased competition from China. Portugal has a strong presence in the automotive parts supply industry, with an estimated 98% of cars on the road in Europe containing at least one part manufactured in Portugal (Euronews, 2024). Environmental factors and a very demanding regulatory matrix also put companies based in Europe at a disadvantage compared to suppliers from America or China, contributing to the aggravation of these factors. Due to all these factors, it is necessary to innovate in terms of production methodologies in order to be able to compete with the pace of production, quality and prices practiced by companies in the same environment (Euronews, 2024).

Company X essentially uses two production processes: welding and stamping. Stamping is divided into progressive stamping and conventional stamping. Conventional stamping requires

manual feeding of the roll, unlike progressive stamping, where the roll is fed automatically and the deformations are applied consecutively.

Although progressive stamping is more efficient because of shorter cycle times due to less manual intervention, the elements required for this production are more complex and conventional stamps are still present in company X's production process.

In terms of stamp size, company X has three different ranges:

- Conventional stamps - smaller stamps with one single operation.
- Progressive stamps - capacity up to 250 tons.
- Heavy stamps - capacity over 250 tons.

Welding is also divided into two strands, conventional welding and robotic welding (carried out by a mechanical arm). Although both require human intervention, the use of a mechanical arm considerably increases the speed of the process and constant quality levels with less waste.

1.4 Objectives

The aim of the project is to improve the company's production process without investing too much in resources. To this end, the focus is on increasing the use of currently available resources by applying more efficient methodologies. After analyzing the current process and comparing it with reference values, established the following quantitative targets:

- Increase in OEE, which includes availability, performance and quality, by 20%;
- Increase of die MTBF by 22,5%, and welding machines MTBF by 75% ;
- Descrease MTTR for dies by 58% and for welding machines by 73%;
- Reduction of non-conformities (volume of scrap) by 50%;

In order to achieve these goals, the focus will be on improving the current maintenance process, aiming for a longer time between failures and reduction in downtime caused by failures, contributing to a substantial increase in equipment availability. Within the scope of quality control, reducing unnecessary quality inspections and reducing the production of non-conforming parts.

1.5 Scope and method

The initial phase consisted on performing a Value Stream Analysis (VSA), with the aim of carrying out a diagnosis and identifying the main opportunities for improvement. After this phase, the implementation phase takes place, consisting of a set of initiatives with expected durations of between 3 and 12 months. Each of these initiatives follows the 9-step A3 methodology, with the aim of gaining an in-depth understanding of the problem in question, as well as the actions needed to correct them. This methodology is divided into the following steps:

1. Define Challenge – Establish the project scope and objectives.
2. Check Current Situation – Visit the Gemba to collect data on the current state.
3. Define Target – Set a SMART goal with timeframe, metric, and target value.
4. Identify Root Causes – Use tools like the Ishikawa Diagram and 5 Whys.
5. Design Solutions – Develop and classify solutions by impact vs. effort (e.g., Quick Wins, Key Projects).
6. Test Solutions – Pilot selected improvements on-site.
7. Update Action Plan – Assign responsibilities and deadlines to each action.
8. Confirm Results and Set Standards – Assess improvements and establish standards; if needed, revisit step 2.
9. Consolidate and Improve – Review lessons learned and improve future project phases.

1.6 Dissertation Structure

The dissertation is divided as follows:

- Chapter 1- Introduction (current)- contextualization of the project, presentation of the company and the sector in which the project is inserted.
- Chapter 2- Theoretical Framework - literature review and theoretical presentation of the methodologies and tools used throughout the project.
- Chapter 3- Current Situation - description of the problem faced and explanation of its critical points.
- Chapter 4 - Proposed Model and Action Plan - presentation of the proposed problem-solving model and the implementation of the main resolution actions.
- Chapter 5 - Results and Analysis - A presentation of the results obtained as a result of the project and a comparison with the initial situation.
- Chapter 6 - Conclusion and future work - Conclusion of the dissertation, detailed analysis of the impact of the project, obstacles faced, and the proposal for future work, in order to guarantee the continuity of the proposed solutions

Chapter 2

State of the Art

2.1 Kaizen Methodology

The Toyota Production System (TPS), a manufacturing technique created in Japan in the years following World War II, serves as the basis for the Kaizen methodology. Taiichi Ohno had a significant role in this development. His quote, "All we are doing is looking at the timeline, from the moment the customer gives us an order to the point when we collect the cash", summed up his methodology. The goal should be to cut down the timescale by eliminating the non value-added operations (Kaizen Institute, 2018).

Ohno was inspired by Henry Ford's production strategy, which allowed raw resources like iron ore to be turned into a completed car in a matter of days. However, Ohno went one step ahead, improving this idea by significantly cutting changeover times from days and hours to minutes and seconds (Kaizen Institute, 2018). By eliminating strict job classifications, he also promoted greater workforce flexibility and created a dynamic workplace where employees could react quickly to changing demands (Kaizen Institute, 2018).

Masaki Imai, the creator of the Kaizen concept, and later brought the Toyota mindset into the western world, had the chance to observe American industrial methods while he was employed at the Japan Productivity Center in the United States. Later, while Toyota was experiencing severe financial difficulties, he worked with Soichiro Toyoda, the head of Toyota Motor Corporation. During a period in Toyota where a large number of cars were sitting idle in the store because the corporation had collected excess inventory, Imai and Toyoda set out on a study tour of American car makers out of fear of going bankrupt, hoping to pick up and apply effective techniques back home (Imai, 1986).

They soon discovered, that although American plants prioritized mass manufacturing in large quantities, this strategy frequently resulted in overproduction, increased waste, more mistakes, and deteriorating quality. Toyota started moving toward a demand-driven flow production system, challenging this paradigm. They adjusted manufacturing to meet current market demand by concentrating on smaller lots rather than making big quantities of similar cars. More flexibility and responsiveness are possible while waste is reduced (Kaizen Institute, 2018).

The Toyota Production System, which is based on three main pillars—quality, waste reduction, and continuous improvement—was formed out of this idea. The pull-based strategy, which was implemented using kanban cards, was a significant advance in TPS. These visual cues made it possible to quickly start manufacturing in response to consumer demand, which reduced inventory and avoided overproduction (Kaizen Institute, 2018).

TPS also introduced a cultural shift in workforce practices. Japanese workers were required to actively monitor quality, stop the line if problems emerged, and contribute to continuous improvements, in contrast to the American approach, where workers frequently passively monitored machinery. This respect for people served as the cornerstone of Kaizen and set TPS apart from its western rivals (Imai, 1986; Kaizen Institute, 2018).

These ideas were put to the test in the actual world during the 1973 oil crisis. Although many multinational manufacturers faced difficulties, Toyota was able to maintain its flexibility and profitability due to its lean approach, which produced impressive financial returns in the years that followed. The global adoption of lean manufacturing and the formalization of *Kaizen*, a concept of continuous incremental improvement involving all members of the organization, were made possible by this success, which attracted attention to what Toyota was doing differently on a global scale (Imai, 1986).

The basis of TPS were the pillars on which many of the Kaizen Principles were funded, Kaizen has 5 main principles:

- Creating Value for the Client- The client is only willing to pay for value added activities, therefore these should be the core of the process, and the non-value added activities should be reduced and eliminated. By alligning processes with the client needs' and expectations', a competitive advantage is created.

- Eliminating Waste(Muda) - There are seven different types of waste: wait of people, wait of material, movement of people, movement of material, overproduction and over processing. These practices are systematically targeted and eliminated.

- Visual Management - Just like Toyota did, making processes visual and transparent, so that everyone can understand them clearly with no effort, promotes good communication and versatility of people.

- Go to Gemba - Gemba is the place where value is added. And one of the Kaizen Principles is that managers should be going to Gemba to observe and understand problems at the source.

- Active Involvement of Everyone - Kaizen promotes the continuous improvement of all the processes, by everyone and everywhere. It fosters a team and active leadership culture and leaves behind practices such as mistake blaming.

2.2 TPM

The development of equipment maintenance in an industrial setting is embodied in the idea of Total Productive Maintenance (TPM) (Nakajima, 1988). Originating from American imports, TPM was modified and refined in Japan to suit its industrial culture and customs. By incorporating every employee in increasing equipment effectiveness and preventing losses, it goes beyond typical maintenance (Ireland and Dale, 2001).

The 1950s saw the adoption of American preventive maintenance techniques into Japanese manufacturing, which is known as the Preventive Maintenance Period. The key objective was to use planned maintenance to decrease unplanned malfunctions (Nakajima, 1988).

The 1960s marked the beginning of the Japanese industry's integration of concepts like reliability engineering, maintenance prevention and productive maintenance. From the design stage onward, there was an increasing emphasis on the equipment's dependability and economic efficiency (Nakajima, 1988).

The 1970s saw the official creation and application of TPM. A Toyota affiliate, Nippondenso Co., introduced a program in 1969 that was referred to as "productive maintenance with total employee participation." This marked one of the first official implementations of TPM in Japanese industry. Two years later, the company won the Distinguished Plant Prize as a result of their success (Nakajima, 1988; Japan Institute of Plant Maintenance (JIPM), 2019).

Between 1976 and 1979, the percentage of Japanese plants implementing TPM rose significantly—from 10.65% to 22.8%, reflecting its growing adoption and effectiveness (Sharma and Bhardwaj, 2012).

In contrast to conventional American methods, which clearly distinguish between operators and maintenance staff, TPM in Japan promotes complete employee involvement. One fundamental idea is that everyone, including operators, must be involved in equipment improvement. Basic maintenance and the ability to spot any problems before they become breakdowns are demanded of operators(Nakajima, 1988).

TPM's importance in top-tier manufacturing systems was further cemented in the 1980s when it was extensively used in Japan and significantly aided the Toyota Production System (Nakajima, 1988). The goal of TPM is to make maintenance a corporate-wide endeavor. Its five pillars are:

- Increase the efficiency of the equipment.
- Create a profitable maintenance program that covers the full life cycle of the equipment.
- Participate in TPM implementation from all departments that plan, design, use, or maintain equipment.
- Engage every worker, from the shop floor to management.
- Encourage ownership and dedication while promoting TPM through motivation management.

TPM often requires a high initial cost, primarily to restore equipment to its original optimal condition. However, these upfront investments are balanced by reducing downtime, speed and defect losses (Nakajima, 1988).

- Downtime losses (Breakdowns, setups or adjustments)
- Speed losses (Idling and minor stoppages)
- Defect losses (Defects in process and rework)

In order to measure the impact of this implementation, indicators such as MTBF (Mean Time Between Failure), MTTR (Mean Time to Repair), and OEE (Overall Equipment Effectiveness) are used. With respect to OEE, it is expected that good maintenance will greatly impact the availability of equipment and also influence their performance by minimizing performance losses (Nakajima, 1988).

2.2.1 Kobetsu Kaizen

Kobetsu Kaizen means "focused improvement" in Japanese. It is a structured problem-solving methodology that targets specific issues, identifies their root causes, and implements solutions. It emphasizes incremental improvements across all processes within the scope of action and requires the involvement of all relevant stakeholders (Kaizen Institute, 2018).

This methodology can be broken down into the following 9 steps:

1. Problem description
   The first step involves selecting and clearly defining the problem that is negatively affecting the process. This creates a focused objective for the improvement initiative.

2. Initial state observation
   To better grasp the current situation, simple diagnostic tools such as the 5W2H method can be used. This approach structures the initial analysis by addressing key questions: what the specific problem is, when it occurs, where it takes place, who is involved or affected, which factors contribute to it, how much it impacts the process, and how the issue unfolds in practice.

3. Set the target
   Establish clear objectives using the SMART criteria to guide the improvement efforts:

   - Specific – The goal should be well-defined and unambiguous.
   - Measurable – It must be possible to quantify progress and outcomes.
   - Assignable – Someone should be clearly responsible for each objective.
   - Realistic – Targets must be achievable given the available resources.
   - Time-constrained – There should be a deadline or defined timeframe.

4. Identify root causes
   Investigate the origin of the problem using structured tools like the 5 Whys technique or the Ishikawa (Fishbone) diagram. These methods help clarify the underlying issues rather than just the symptoms.

5. Design solutions
   Develop and propose ideas that directly tackle the root causes. Focus on practical, feasible measures that can bring measurable improvements.

6. Test the solutions
   Before full-scale implementation, trial the proposed actions in a limited scope to assess their effectiveness in real conditions.

7. Define the action plan
   Create a structured implementation plan, outlining each task, responsible persons, timelines, required resources, and any risk management measures.

8. Analyse results and standardise
   Review the outcomes after implementation. If the solutions prove effective, formalise the new practices to ensure they are maintained over time.

9. Capture lessons learned
   Reflect on what was successful and what could have been done differently. Use these insights to inform future initiatives or extend improvements to other areas.

2.2.2 Measuring efficiency

In order to measure efficiency in a industrial context, the OEE is frequently used. This metric considers three different arguments considered core and encompass the essential of the efficiency in a industrial setting.

$$\text{OEE} = \text{Performance} \times \text{Availability} \times \text{Quality}$$

- Quality: The quality argument is given by the ratio of good units per the total production units. It reflects how many of the produced units meet the required quality standards.

- Performance: The performance is given by the ratio of real cadence per the theoretical cadence, which indicates how quickly the machine is operating compared to its designed speed.

- Availability: The availability is given by the ratio of productive time per the total planned time. Planned time is the duration of a shift minus the planned stoppages, which include mandatory breaks and non-production activities required at the start and end of shifts.

2.2.3 Autonomous Maintenance

A key pillar of Total Productive Maintenance (TPM) is the idea of merging functions — eliminating the traditional divide between those who operate machines and those who maintain them. This principle gives rise to autonomous maintenance (Jishu Hozen), which empowers operators to take responsibility for the basic upkeep of their own equipment (Nakajima, 1988).

Rather than depending entirely on maintenance staff, operators are trained to perform routine tasks such as cleaning, lubrication, inspection, and early detection of potential issues. This shift in mindset is often one of the most significant challenges organizations face when adopting TPM — but it's also one of the most impactful.

Autonomous maintenance is built upon the 5S methodology, which represents five Japanese principles of workplace organization and cleanliness — the foundation of efficient and safe working environments (Sharma and Singh, 2015). The 5S five key principles are, Seiri (Sort), which focuses on eliminating unnecessary items from the work area; Seiton (Set in order), which ensures tools and materials are properly arranged for easy access; Seiso (Shine), which emphasizes cleanliness of the workplace and equipment; Seiketsu (Standardize), which involves creating consistent practices and procedures; and Shitsuke (Sustain), which encourages maintaining and continuously improving these standards.

The 5S principles are operationalized through the seven steps of autonomous maintenance, which form a progressive roadmap for operators to gradually take more ownership of their equipment (Nakajima, 1988):

1. Initial cleaning – Clean the equipment thoroughly and inspect for abnormalities.
2. Eliminate sources of contamination – Identify and address root causes of dirt, leaks, or misalignments.
3. Establish cleaning and lubrication standards – Define clear and sustainable routines for ongoing care.
4. General inspection training – Train operators to detect wear, misalignment, or performance deterioration.
5. Autonomous inspection – Enable operators to independently perform inspections and minor maintenance.
6. Standardize work and improve organization – Organize tools, materials, and procedures to support autonomy.
7. Full autonomous maintenance – Operators fully manage basic maintenance, early detection, and prevention of equipment issues.

Autonomous maintenance maturity also develops through four progressive levels (Kaizen Institute, 2018):

Autonomous maintenance can be structured in four progressive levels. Level 1 focuses on awareness, where operators understand the importance of cleaning and inspecting their equipment. At Level 2, they become more proactive, identifying early signs of failure and performing basic preventive tasks. In Level 3, operators demonstrate ownership by taking full responsibility for routine maintenance and suggesting improvements. Finally, Level 4 involves leadership, where experienced operators coach colleagues, lead improvement initiatives, and collaborate with maintenance teams on continuous improvement efforts.

When implemented effectively, autonomous maintenance significantly reduces the need for corrective maintenance. Operators become more engaged and skilled, and small problems are identified before they escalate into major breakdowns. It not only improves equipment reliability but also fosters a culture of responsibility, pride, and continuous improvement on the shop floor.

2.2.4 Planned Maintenance

Preventive maintenance involves periodic inspections aimed at detecting and correcting conditions that could lead to breakdowns, stoppages, or performance loss. It is comprised of two main activities (Raj, 2018):

- Periodic inspections
- Restoration based on inspection results

A fundamental step in planned maintenance is the development of standardized operations to address potential problems before they occur — ideally when the equipment is not in use or not required for production. These standards ensure that every person performs maintenance tasks consistently and effectively.

Maintenance techniques can be complex and difficult to master. Relying solely on a few experienced individuals is not sustainable. Standardized procedures enable broader participation while maintaining quality and consistency.

Maintenance is inherently non-repetitive and often demands lengthy preparation. Thus, the use of standards becomes essential for operational efficiency (Nakajima, 1988).

Maintenance standards cover a broad range of topics, from how equipment should be operated and designed, to procurement guidelines for materials and testing procedures. The main types include:

- Inspection standards: Define techniques for measuring equipment deterioration. These should include visual aids such as photos and illustrations and specify the frequency of inspections.
- Servicing standards: Describe routine maintenance tasks using hand tools, such as cleaning, lubrication, adjustments, and part replacements.
- Repair standards: Outline the methods for conducting repairs and detail available working hours or resource allocations.

- Maintenance work standards: Used to measure the efficiency of the maintenance team and the effectiveness of their interventions.

Maintenance activities must be planned in alignment with available resources, equipment condition, and performance data. Plans should be regularly reviewed and updated, especially for equipment with high rates of unexpected failures.

2.2.5 Layout Design

The redesign of a shop-floor layout, particularly in space-constrained industrial settings, necessitates more than merely integrating additional equipment into a fixed footprint; it demands a configuration that is in harmony with both the production flow and the operator's needs. Suhardi et al. (Suhardi et al., 2019) demonstrate that the process should commence with a thorough audit of spatial requirements and constraints, subsequently followed by the elimination of all non-value-adding elements. Following the streamlining process, the reallocation of functional zones should be conducted to ensure the efficient movement of materials, information and personnel. The framework under discussion couples spatial optimisation with an ergonomic assessment, ensuring that each square metre recovered translates into safer, more comfortable working conditions. The logic of lean design principles – namely, mobility, standardisation, and built-in adaptability – is further extended in this manner. An effective layout must support rapid repurposing of workstations, remove physical barriers to parallel activities, and reserve space for proactive maintenance long before unplanned breakdowns occur.

2.2.6 Employee Training

The success of Total Productive Maintenance (TPM) relies heavily on a skilled and engaged workforce. Operators must possess a solid understanding of the equipment they handle, as they are expected to lead and support daily maintenance activities. This includes carrying out basic tasks such as cleaning, lubrication, simple repairs, tightening bolts, and performing routine inspections. While maintenance personnel remain essential for more complex interventions, the goal is to empower operators to take ownership of the first line of equipment care (Nakajima, 1988; Hong Kong Society for Quality, 2016).

Operators are typically responsible for four key functions:

1. Monitoring oil levels, power current, and unusual vibrations.
2. Checking temperature and operating speed during production.
3. Observing control panels for any abnormal values.
4. Lubricating equipment according to schedule.

In instances where the operators' capabilities are exceeded, the maintenance teams are called in to assist. These professionals rely on equipment records to identify recurring problems and to

anticipate the necessary manpower and spare parts for efficient resolution. In addition to direct machine interventions, maintenance teams are also responsible for the following:

- Estimating optimal replacement part stock levels.
- Selecting appropriate lubricants and materials.
- Correcting equipment design weaknesses.
- Providing technical education and training across the organization.

In his 1989 book on TPM development, Seiichi Nakajima outlined a structured training programme for maintenance personnel. The curriculum is divided into four technical modules: bolts and nuts, keys and bearings, power transmission and hydraulics, and pneumatics. Each module incorporates classroom-based and hands-on shop-floor training, with a typical duration of three days. The programme maintains a 7:3 ratio of practical to theoretical lessons over a period of four months, thereby cultivating a culture of experiential learning.(Nakajima, 1988).

For equipment operators, the Japan Institute of Plant Maintenance (JIPM) recommends a structured course beginning with one week of basic training at the company's facility. This is followed by ongoing one-on-one instruction provided by experienced maintenance staff. Topics include bolts and nuts, shafts, bearings, gears, sealing systems, lubricants, and power devices (Japan Institute of Plant Maintenance (JIPM), 2019).

In addition to technical training, instructor development is also emphasized. Maintenance personnel who complete the technical program are encouraged to participate in a course designed to build teaching capabilities. They are challenged to prepare and deliver portions of the curriculum themselves, developing the communication and leadership skills necessary to train future employees (Nakajima, 1988).

2.3 TQM

The pursuit of quality in industrial production has evolved through various theoretical and practical contributions. In his 1951 Quality Control Handbook, Joseph Juran introduced the concept of quality-related costs, dividing them into avoidable and unavoidable. Avoidable costs include rework, repairs, and complaint handling, while unavoidable costs encompass inspection, sampling, and quality control procedures. Juran estimated that quality improvements could reduce avoidable costs by up to $1,000 per operator annually (Juran, 1951).

Building on this, Armand Feigenbaum proposed Total Quality Control in 1956, advocating for quality as a cross-departmental responsibility. His methodology emphasized statistical tools such as control charts and sampling procedures to ensure product consistency (Feigenbaum, 1956).

To manage quality effectively, it must be broken down into measurable components. David A. Garvin proposed eight dimensions of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality (Garvin, 1987).

From these foundational ideas emerged total quality management (TQM), a holistic approach that gained traction in Japan and later spread to the U.S. in the 1970s, as American companies struggled to match Japanese manufacturing standards (Feigenbaum, 1956).

TQM is built on several core principles:

- Customer focus: Aligning company efforts with what the customer values as quality.
- Employee involvement: Training and empowering all workers to take responsibility for quality at every production stage.
- Process orientation: Embedding quality into each process step, as defects become costlier the later they are detected.
- Integrated systems: Leveraging all organizational resources to support quality.
- Strategic, systematic approach: Embedding quality within overall business strategy.
- Data-driven decision-making: Using controlled processes to collect data that guides actions.
- Effective communication: Eliminating silo thinking to foster collaboration.

TQM maturity can be viewed across five levels (Kaizen Institute, 2018):

- Level 0: Evaluate the cost of quality – this is the baseline situation, and the first step is to map the costs of defect detection at the final client.
- Level 1: Contain defects from reaching customer – the control is only made at the end of the process, avoiding reaching the client.
- Level 2: Reduce defects by adjusting processes – Tools such as 3C and Kobetsu Kaizen are used in order to lower the amount of defects.
- Level 3: Isolate the root causes of defects – control defect detection across the entire process, using standards, Poka Yoke, Jidoka.
- Level 4: Achieve zero defects – using Six Sigma methodology to achieve a no defect stage.

The quality standards in the automotive industry are extremely high, as any product defect can critically affect user safety. Consequently, Company X places exceptional emphasis on quality, ensuring that potential defects are detected and addressed promptly.

Automotive industry standards are primarily defined by IATF 16949, a comprehensive set of guidelines designed to help companies align their processes with industry expectations. This certification covers areas such as continuous improvement, defect prevention, waste reduction, product safety, risk management, contingency planning, embedded software management, supplier management, and warranty management.

In this sector, if a product defect forces a client to stop their production line, the manufacturer responsible for the defect must cover the associated production loss costs, as well as any sorting activities performed at the client's site (Kaizen Institute, 2025a).

To maintain compliance with these rigorous requirements, several quality control tools are employed:

- Checking Fixture: A physical tool where the operator places the final product to quickly verify the absence of defects.
- Visual Inspections: Performed during production, following specific guidelines or detailed work instructions.
- Destructive Testing: Involves intentionally breaking the component to understand its limits and behavior under stress.

Given the stringent quality demands, companies operating in the automotive sector must invest heavily in qualified personnel and specialized equipment. Moreover, an undersized quality team can create a bottleneck in production, as the manufacturing process cannot proceed without the completion of mandatory tests(Kaizen Institute, 2025a).

IIn *Total Quality Management as Competitive Advantage* (1995), Thomas Powell presents an empirical study highlighting that organizations implementing TQM achieve superior performance, including higher quality outputs, improved customer satisfaction, and greater operational efficiency. He emphasizes that the success of TQM depends more on intangible factors—such as leadership commitment, organizational culture, and employee involvement—than on tools and techniques alone. Companies that do not adopt TQM practices often struggle with inconsistent quality and reduced competitiveness. Powell also notes that TQM is most effective in organizations that are culturally prepared for change and have leadership that actively promotes continuous improvement. TQM is especially beneficial in highly competitive, innovation-driven industries like manufacturing and services, where maintaining high quality is critical (Powell, 1995).

The impact of TQM initiatives can be accurately measured by its impact on OEE, mostly due to its relation with the quality rate. However, good quality practices can also be displayed in the availability, due to the lack of need to stop production caused by defect detection. The amount of quality-related overprocessment and number of non-acceptable parts produced are also relevant indicators to measure the success of such initiatives (Kaizen Institute, 2018).

2.3.1 Auto-Quality Matrix

In any production environment, the cost of correcting a defect increases significantly the later it is detected. This fundamental principle underpins the importance of implementing effective quality control measures throughout the manufacturing process. Auto quality measures are designed to minimize both the number of defects and the time between their creation and detection, ensuring faster response and lower remediation costs.

One of the most effective tools for visualizing and improving these efforts is the auto quality matrix. This matrix provides a structured view of when and where defects are generated and detected within the production flow, helping teams identify weak points in quality control and prioritize corrective actions.

To build this matrix, every critical step in the process must be identified. Each defect is then mapped based on the stage in which it was *created*, and the stage in which it was *detected*. This allows for clear analysis of gaps in quality response (Sütőová and Grzincic, 2013).

As illustrated in Appendix A, the upper half of the matrix is shaded to reflect the impossibility of detecting a defect before it has occurred.

The matrix highlights where quality control measures should be strengthened to reduce the cost of late detection. The ideal scenario is one in which defects are detected at the very stage they are created—ensuring minimal impact on downstream processes and overall efficiency.

2.3.2 Auto-Quality Tools

Auto quality measures aim to prevent defects from advancing through the production chain. By stopping a defect at the end of the stage where it is created—rather than allowing it to proceed to the next—errors can be addressed earlier, when the cost of correction is at its minimum.

The operator plays a key role in this process and can intervene at two levels. At level 1, the operator separates defective items from defect-free products, allowing only conforming units to move to the next stage. At level 2, the operator stops the entire production line upon detecting a defect and follows the predefined standards to address the issue.

To support this effort and reduce reliance on operator skill alone, several tools are employed to make defects visible and easily detectable. Two such tools are Poka Yoke and Jidoka (Kaizen Institute, 2018).

Poka Yoke, from the Japanese words *poka* (error) and *yoke* (proof), refers to mechanisms that make errors impossible to advance unnoticed in the production flow. These are low-investment systems that can be directly implemented on the production line to block products that do not meet size, position, or orientation standards (Kaizen Institute, 2018). Some visual examples of this mechanism can be found on the Appendix B.

Jidoka is associated with the second level of auto quality. It describes the ability of a machine to stop automatically when a defect is detected, allowing the process to resume only once the problem is resolved. This prevents the continued production of defective parts and avoids unnecessary waste of resources.

Jidoka can also be manual, triggered by the operator instead of the machine. In either case, an Andon system—usually a light or sound signal—is activated to alert the team that an issue has occurred and immediate action is required.

These auto quality tools contrast with more traditional, manual quality control methods, such as standard comparison. In such practices, the operator compares the produced item against a reference standard — typically defined by specific measurements and acceptable tolerances.

While this method is capable of detecting defects, it has several limitations. It demands time and attention from the operator, introduces variability due to human judgment, and is generally less dependable. As a result, it increases the risk of defects escaping detection or being identified too late in the process (Kaizen Institute, 2018).

Auto quality tools, by contrast, aim to autonomous, low operator intervention detection, therefore reduce dependence on operator skill, and enable more consistent, scalable quality control. They support a proactive approach to quality that minimizes waste, rework, and costs.

Chapter 3

Current situation

In this chapter, all actions taken to improve the aforementioned indicators will be discussed. As mentioned earlier, Company X operates as a supplier in the automotive industry, where quality standards are exceptionally high. Currently, meeting these standards demands significant effort, with a considerable amount of rework required to achieve the desired quality levels. According to Kaizen principles, rework is classified as one of the key types of waste, highlighting the need for process improvement.

Additionally, the pace of production and the ability to meet demand represent vulnerable areas for Company X, since delayed deliveries can result in substantial costs.

This chapter is divided into three distinct sections. The first two focus on productivity, analyzing breakdowns and their causes in the stamping and welding processes. The third section addresses quality control throughout the entire production process.

After identifying the main issues in the current state using TPM and TQM methodologies, these problems will be addressed in a subsequent stage.

3.1 Stamping

Stamping is a fundamental manufacturing process in the automotive industry, particularly among suppliers involved in producing metal components for vehicles. It involves shaping flat metal sheets into specific forms using dies and high-pressure stamping stamps. In the highly competitive and quality-driven automotive sector, stamping must deliver precision, repeatability, and durability, aligning with strict industry standards. The integration of advanced stamping techniques and machinery ensures high productivity, minimal waste, and consistent quality—key factors for maintaining efficiency and competitiveness in the supply chain. Using historical data from 2024, a detailed evaluation of stamping and welding performance was conducted, focusing on equipment availability, maintenance-related stoppages, and overall equipment effectiveness (OEE). The goal of this assessment was to identify the root causes of downtime and evaluate whether the lack of correct maintenance practices contributed to recurrent equipment failures.

The OEE across both stamping and welding processes revealed performance limitations largely due to availability and performance issues, indicating that machines would work less than expected and at a slower pace. In a first instance, the OEE was broken down and analyzed to understand which areas were impacted the most, and how this metric had evolved from mid 2024 until the start of the initiative. To determine which components required the most attention, the Overall Equipment Effectiveness (OEE) was broken down in its three constituent elements and calculated individually, providing a more detailed insight into the primary issues.

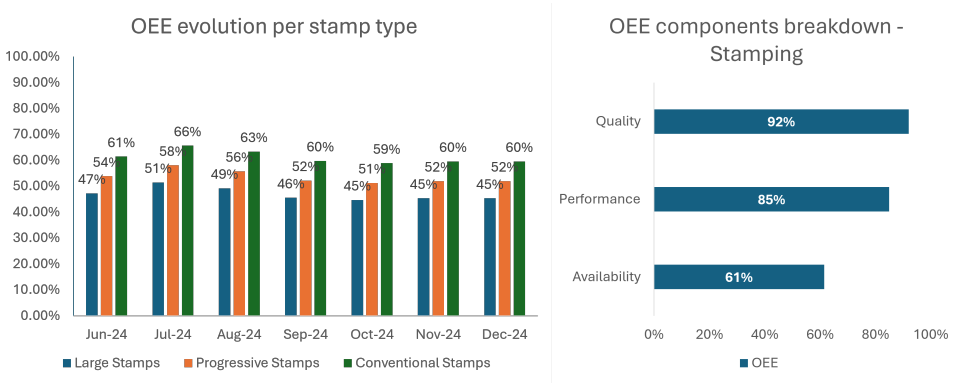


Figure 3.1: OEE Breakdown - Stamping

After analyzing the historic evolution of OEE and its components, it was concluded that the availability and performance of machines were the main causes for low OEE values. Along the previous months to the project the OEE was steadily decreasing when compared to the earlier months. This was an indication that measures were needed in order to fight this downward trend.

After analysing if the stamping process had any correlation with the OEE value, it was concluded that heavy stamps had a considerably worse performance, which was expected due to having more complex components involved.

Two main conclusions were drawn: availability was the largest factor contributing to overall underperformance; the heavy stamping sector was the most affected segment. The first step into understanding why the availability was so low, was to develop an Ishikawa Diagram, with the purpose to make the main issues clearer.

The resulting diagram is presented in the following figure.

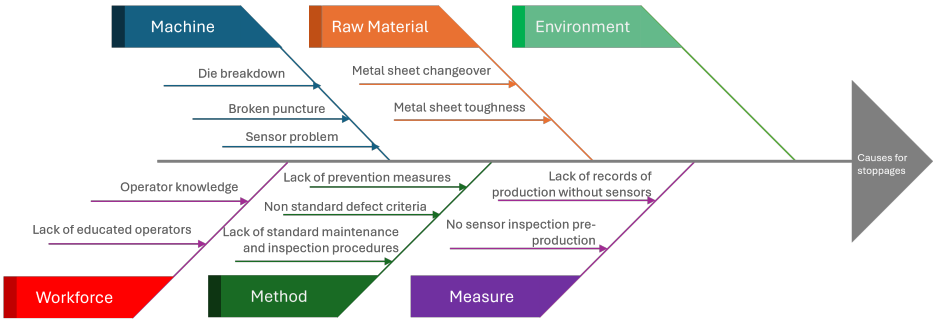


Figure 3.2: Ishikawa Diagram - Stamping

This diagram's purpose is to enlighten which problems are separating the current state from the desired state, and it will be used during the solution design phase, developed in the next chapter. Given that the primary focus was increasing availability by reducing stoppages, the next step in the analysis was to identify the most frequent causes of machine stoppages within each of the three stamping segments.

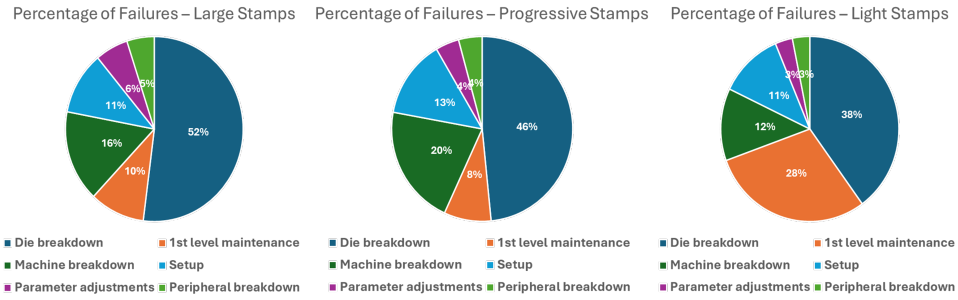


Figure 3.3: Causes of Stoppages

Given the critical impact of die-related failures on productivity, a more detailed analysis was carried out to identify the underlying causes of tool stoppages during stamping operations. In stamping, the die is a core component responsible for shaping and cutting materials with high precision under significant mechanical stress. Over time, dies are subject to a range of issues such as punch and die wear, misalignment, cracking, chipping, or accumulation of scrap material in clearance gaps. These problems can lead to dimensional inaccuracies, burrs, or catastrophic failure, ultimately causing unplanned downtime and compromised part quality.

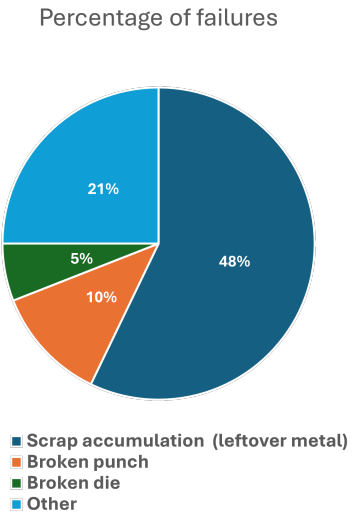


Figure 3.4: Causes for Die Breakdown

The results reveal that scrap accumulation was the predominant cause of tool stoppages, accounting for nearly half of the observed failures. This suggests that end-of-cycle cleaning procedures and preventive maintenance protocols may be insufficient or inconsistently applied. While

broken punches and dies also contributed to downtime, their lower incidence further emphasizes how operational discipline—rather than catastrophic tool damage—is often at the root of performance losses. These findings underline the importance of reinforcing standardized maintenance routines and process audits to mitigate avoidable disruptions.

To address the maintenance issues identified, a structured analysis of historical data was conducted through the following steps:

1. Identify the tools critical to production;
2. Map the resources required to maintain all critical tools at an adequate rate;
3. List the most frequent issues leading to production stoppages;
4. Analyze whether the current maintenance procedures addressed all identified problems.

To determine which tools were critical to production, usage records from the past six months were reviewed. Tools with the highest amount of maintenance procedures done were classified as critical.

The table on Appendix C presents data on die usage and the maintenance actions applied. The "Usage Frequency" column indicates the number of times each die was used in production. The "Preventive", "Corrective", and "Cleaning" columns reflect the number of instances each die underwent the respective procedures. Lastly, the "Area" column represents the total space required for die maintenance, calculated as twice the surface area of the die. The area was considered because the space needed for maintenance was also identified as a problem that be explained in detail in further chapters.

The die F-1127 was selected as the pilot for the maintenance initiatives, due to being one of the most used dies in production, while also being the die were more maintenance procedures were made.

The next step involved first-hand observation of maintenance procedures to identify the most common causes of die breakdowns. This approach aimed to uncover weaknesses in current practices and inform targeted improvements. The following table outlines the most frequent issues encountered during these shadowing sessions and the corresponding maintenance procedure.

Table 3.1: Maintenance Tracking – Tool F-1127

Occurrence	**Cause**	**Procedure**
Broken punches	Improper tool use	Cleaning; Straighten pad; New punch; Weld die; Replace die.
Cleaning	Dirt	Cleaning.
Sensors	Dirt; Faulty LED	Cleaning; LED replaced and sensors serviced by DMEI.

The analysis revealed that many stoppages were due to inadequate cleaning or component failures, as it was backed by the initial tool stoppages causes in Figure3.2. This suggested that

a significant amount of downtime could be prevented if checks were performed before tools entered production and if cleaning procedures were conducted more frequently. When combined with the previously analyzed corrective and predictive maintenance data, these findings clearly indicated that the existing preventive maintenance procedures were inadequate. The robustness of the procedures themselves proved insufficient to prevent recurring issues effectively.

To assess whether the frequency of preventive measures was appropriately set, a cross-comparison was conducted between production activity and maintenance interventions, including both preventive and corrective procedures.

The following Gantt Chart shows the cross comparison made between maintenance interventions and production from the start of the year until mid February for the die F-1127.

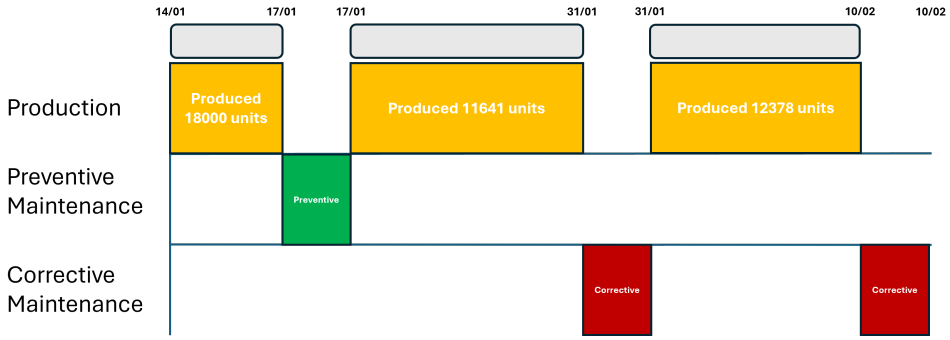


Figure 3.5: Production and Maintenance Gantt Chart

For this specific die, the production increment between two preventive maintenance actions was set at 17.600 units—meaning that after producing this quantity, a preventive maintenance procedure would be triggered the next time the tool exited production. However, as the data shows, the tool often had to be removed from production before reaching this threshold due to the need for corrective maintenance, indicating that the set interval was too long to prevent unplanned stoppages. Following the production-to-maintenance analysis, a comparison between preventive and corrective maintenance was conducted using the historical data from the previous 6 months. The goal was to identify which tools required more frequent preventive interventions and which ones could potentially have their preventive measures reduced without compromising performance. This analysis aimed to optimize maintenance efforts by aligning them more closely with actual die behaviour and needs.

Table 3.2: Corrective and Preventive Maintenance Overview by Equipment

Die	Corrective	Corrective Hours	Preventive	Preventive Hours	Evaluation
F-1759	14	32,32	1	2,03	Under Dimensioned
F-1760	21	44,23	3	6,83	Under Dimensioned
F-1425	14	35,31	1	1,64	Under Dimensioned
F-1127	25	52,3	5	9,65	Under Dimensioned
F-1544	1	2,89	11	32,3	Over Dimensioned

The valuation was done by comparison with the other dies, since their behaviour is very similar. If the prevention time invested on the die was higher than 5 times the corrective time, the prevention frequency was considered over dimensioned, for the cases where the corrective time was equal or higher than the time spent on prevention the opposite evaluation would be made. The comparison between preventive and corrective maintenance confirmed that, in most cases, preventive actions were under-dimensioned and needed to occur more frequently—an expected outcome. However, there were instances where the opposite was observed, a lot of time was invested into preventive measures with little signs of breakdowns (corrective measures). In these cases, increasing the interval between preventive actions could lead to time gains without compromising tool reliability, this was always something to carefully evaluate, since it is preferable to invest into prevention rather than correction, nevertheless is an option that is left open to consideration.

The indication that additional preventive measures were necessary introduced a new challenge: the layout of the maintenance area. The space was already constrained for the existing workload, and increasing the frequency of preventive maintenance—while potentially reducing the volume of simultaneous corrective interventions—highlighted a clear need for expanded capacity. Accommodating more personnel and maintenance procedures within the same area would require a reassessment of spatial organization and resource allocation.

3.2 Welding

Welding is a core joining process in automotive manufacturing, essential for assembling body structures, subframes, and numerous metallic components. It involves the fusion of materials—typically steel or aluminum—using heat, pressure, or both, to form strong, permanent joints. In the context of automotive production, welding must ensure high structural integrity, dimensional accuracy, and resistance to fatigue and vibration. Maintaining consistent performance of modern welding lines, which are complex and automated, requires precise control, regular calibration, and effective integration of robotic systems.

As with the stamping process, the first step in assessing welding performance involved analysing the evolution of Overall Equipment Effectiveness (OEE) over the previous seven months, along with a detailed breakdown of its core components: availability, performance and quality.

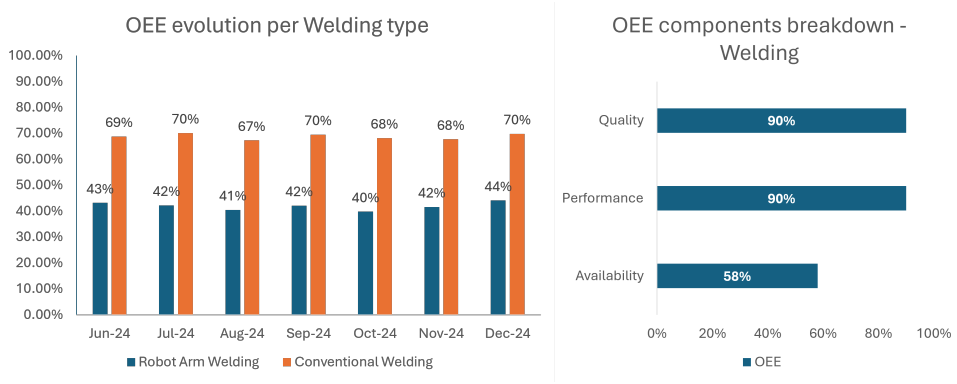


Figure 3.6: OEE Breakdown - Welding

The conclusions drawn from the OEE analysis of welding were largely similar to those observed in stamping. Availability once again emerged as the primary limiting factor, indicating a consistent pattern of equipment-related stoppages in both processes. This reinforced the hypothesis that maintenance practices and intervention strategies play a decisive role in overall production efficiency. Understandably, the robot arm welding presented much more worrying results, since it is the more complex procedure.

While the primary issue was availability, the causes of reduced availability differed between welding and stamping. In stamping, the die was the component most affected, frequently breaking down due to the high mechanical stress it endures. In contrast, welding encountered more issues with the machine itself. These differences align with the nature of each process: stamping is a highly mechanical operation in which components such as the die experience constant force and wear, whereas welding involves numerous electrical components and exposure to corrosive elements, which makes the equipment more susceptible to electrical failures and degradation. The majority of welding stoppages could be grouped into one of the following five categories:

- Machine Breakdown: Occurs when the welding machine stops functioning properly due to mechanical failure or electrical issues, which interrupts production and may require repairs or replacement of parts.

- Cleaning: Refers to the removal of contaminants like rust, grease, or weld spatter from the workpieces or welding equipment to ensure a clean welding surface, improving weld quality and preventing defects.

- Quality Control: The process of inspecting and testing welds to ensure they meet specified standards, ensuring consistency, strength, and safety of the welded parts, and preventing defects that could lead to failures.

- Die Breakdown: In the context of welding, it refers to the failure or wear of dies used in certain welding processes, leading to production delays or defects in the welded parts due to improper fit or pressure.

- 1st Level Maintenance: Basic maintenance tasks performed by operators to prevent machine breakdowns, such as lubricating moving parts, cleaning components, and checking for wear, to ensure smooth operation and reduce downtime.

An analysis on the distribution of these stoppages for each type of welding for the same six-month period, resulted in the following graph.

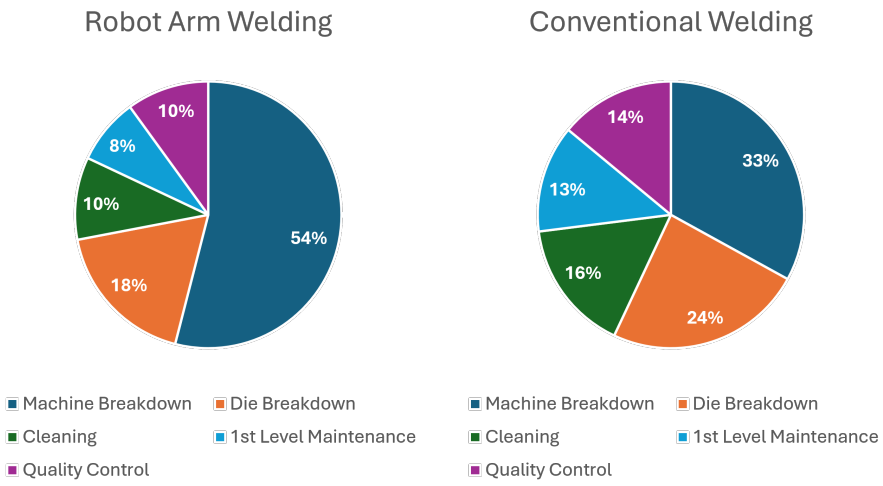


Figure 3.7: Welding Issues (June-December)

After analyzing the OEE of both conventional welding and robot arm welding, along with the causes of their stoppages, attention was directed toward understanding the reasons behind robot arm welding downtime. This focus was justified not only because robot arm welding had the lowest OEE and the greatest impact on overall welding performance, but also because these machines represent a significantly higher investment. Their output should reflect that value in both efficiency and reliability.

In the welding process, the following step was to analyse robot arm welding machines individually to understand which brought the most stoppage time.

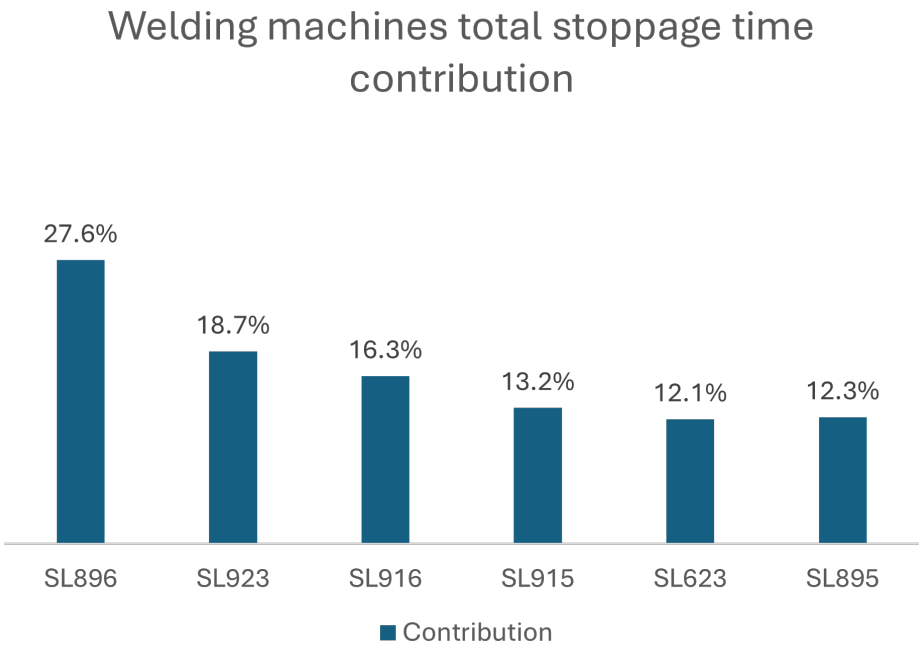


Figure 3.8: Welding machines - stoppages

Equipment SL896 was chosen, as it accounted for 27.6% of all robot arm welding-related stoppages, making it the most representative case. From now on this equipment will be referred as 'Robot X'.

The selection was followed by an intensive analysis to the machine, conducting a root cause analysis, which is illustrated through the following Ishikawa diagram.

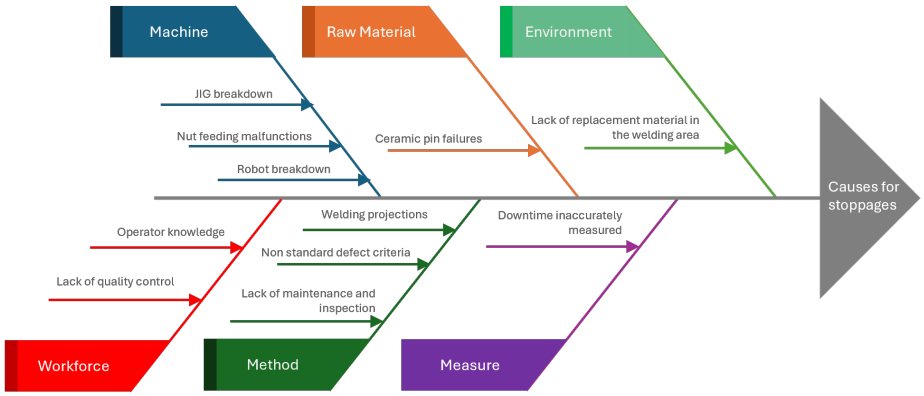


Figure 3.9: Ishikawa Diagram - Robot X

From the Ishikawa Diagram created, the most time consuming problems identified were the following:

- Robot arm issues - often stem from joint wear, cable fatigue, and sensor or control failures. These problems lead to loss of precision, misalignment, and unplanned downtime.

- Ceramic pin failures: Ceramic pins insulate and protect components during welding; when they fail, they compromise the precision and integrity of the weld.

- JIG breakdowns: JIGs are essential for holding components in place during welding. Malfunctions here result in misalignment and poor-quality joints.

- Nut feeder malfunctions: Automatic nut feeders support efficiency in nut welding processes. Failures in this system cause interruptions and manual rework.

- Welding projections: Inconsistent or damaged projections (small raised areas on parts meant to localize the weld) lead to weak or incomplete welds.

The follow-up performed on the machine confirmed the main problems identified during the general assessment. However, it also uncovered smaller, underlying issues that contributed to the more significant failures. Factors such as an inexperienced workforce, lack of proper maintenance, and insufficient inspection—although not evident in the previously analyzed data— these minor causes were clearly contributing to the poor condition of the robots and tools.

Following this assessment, a Pareto analysis was conducted on the robot breakdown issues using the previous 6 months of data. The objective was to identify the root causes behind the robot breakdown in order to address these failures through targeted maintenance practices.

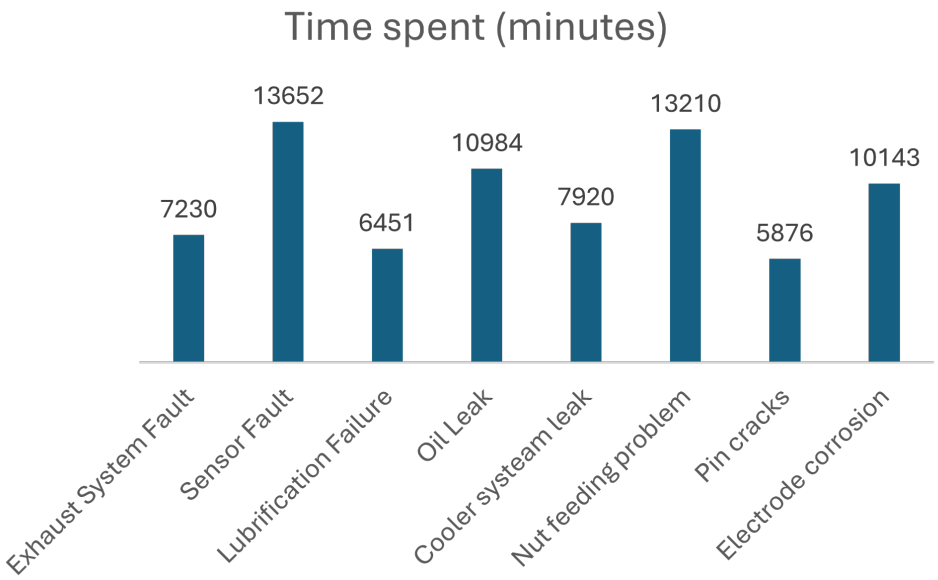


Figure 3.10: Pareto Analysis Welding

Having identified the most impactful problems and their root causes, sufficient information was gathered to define the correct maintenance procedures. These procedures were followed during the solution implementation and will be detailed in the solution Chapter.

3.3 Quality systems

Company X, as a supplier in the automotive industry, operates under extremely high quality standards due to the critical nature of its products. A key priority for the company is ensuring that no defects reach the final client. When defects do reach the client, two types of penalties may be imposed: formal warnings or significant fines. These fines are particularly burdensome for Company X, as its clients are significantly larger in scale.

The primary focus, therefore, is to eliminate defects reaching the client. However, also a priority is to reduce the volume of internal rework caused by quality control, which also incurs substantial cost and time inefficiencies.

To identify gaps and improvement opportunities in the current quality management system, a material flow exercise was conducted. This involved tracing the entire lifecycle of a component throughout the production process, from initial manufacturing stages to final delivery, in order to better understand where defects may occur and how they can be systematically prevented.

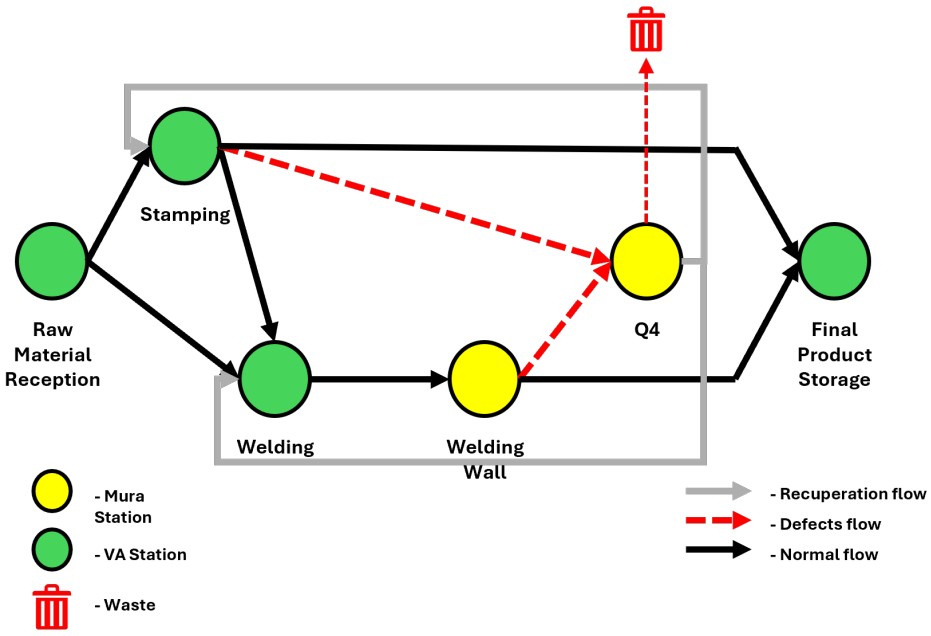


Figure 3.11: Material Flow

The first stage is Raw Material Reception, where materials from suppliers are delivered and sorted. This is followed by Stamping and Welding, which are the core stages of production. In some cases, products flow directly from the stamping stage to the welding stage. After production, approved products are transferred to final product storage, where they await shipment. These four areas are essential to the company's operations and would be retained even in an optimised, ideal scenario.

However, there are also two additional workstations known as 'Mura Stations'. These are considered non-value-adding steps in the process and are primarily dedicated to quality rework. Ideally, their workload would be significantly reduced, or these stations might not exist at all.

One of these is the Welding Wall, which is a dedicated area within the welding section. Its main function is to inspect all welded products before they are moved to Final Product Storage. If any defects are found, the items are redirected to Q4.

Q4 is located on a floor below the welding area. It receives materials from all stages of the production line and serves as a central hub for inspecting and recovering defective items. This process involves a considerable amount of rework, making Q4 a key area for potential improvement.

Quality control was found to be frequent and consistent throughout the process. The control processes followed a different approach depending on the stage at which they were implemented.

Before describing the quality control tools found at each stage of the production process, the procedures will first be explained.

- Visual Inspections: Conducted at several stages to identify surface defects, deformations, or other visible anomalies. These inspections followed a strict control plan, which served as a guideline for how the checks should be performed, these are an industry standard in the automotive industry.
- Use of JIGs: Jigs were used for dimensional and geometric verification of components, ensuring conformity to reference standards.
- Destructive Testing: Functional tests were applied to confirm that parts operated correctly under specified conditions.
- Automated Welding Control: At robotic welding stations, the system automatically stopped production when a defect was detected. This allowed immediate intervention, preventing the manufacture of further defective parts.

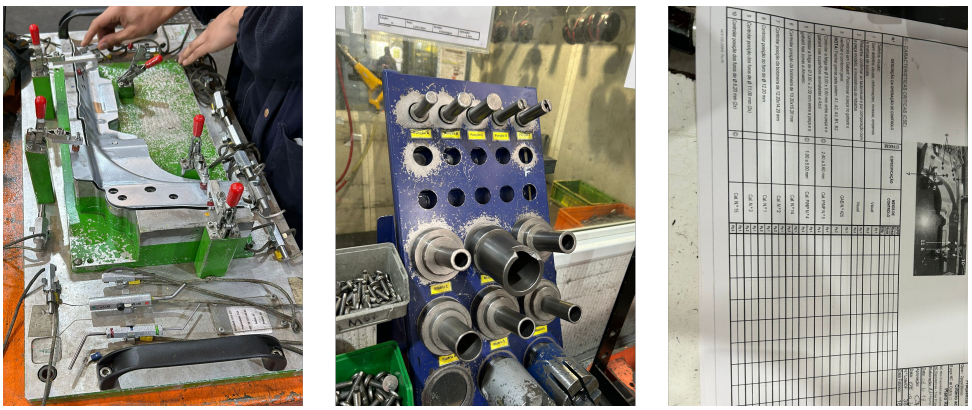


Figure 3.12: Quality control tools (JIG, Destructive Testing station, Control Plan)

Regarding the control done at each stage, this was as follows, raw material inspection served as the first quality checkpoint in the entire production process. It involved inspecting the metal sheets supplied by vendors, using the skip lot method—a quality control strategy aimed at reducing the frequency of inspections without compromising product quality.

Under this method, not every batch or lot is inspected. Instead, selected lots are inspected based on a predefined schedule or criteria, while skipped lots are accepted without verification. For suppliers with a strong quality record and compliant initial deliveries, subsequent lots would typically bypass inspection.

However, despite the theoretical existence of the skip lot system, the assessment revealed that its practical application did not materialise, despite its registration. Consequently, there was a risk that non-conforming materials were being incorporated into the production process without adequate detection, which could potentially compromise downstream quality.

At the start of each production run, the initial two units are isolated and subjected to inspection by the quality control team prior to the initiation of production. Nevertheless, this procedure frequently resulted in delays and diminished production efficiency, as the quality team was often inundated with an excess of inspection requests, particularly during start-ups. Consequently, operators frequently experienced delays of 20 minutes or more during the inspection process, resulting in idle time and inefficiencies within the manufacturing environment.

Whenever there was a production stop or an operator change, the initial inspection would be repeated, causing additional stoppages during the day, some of which, such as the ones due to operator changes, could potentially be skipped.

These initial inspections were conducted according to pre-established control plans, in line with automotive industry standards, and utilized JIGs for precise dimensional measurements. During ongoing production, periodic checks were carried out by the operators themselves to ensure continued compliance with quality requirements.

At the end of the production run, the last two units were stored by the quality team to serve as reference samples for the next production cycle.

In welding, visual inspection and JIG usage, were also applied. However, some new procedures were introduced. Since the robot arm can automatically detect defects and stop production (Jidoka), one of the initial operator checks before starting production was to place a known NOK (non-conforming) piece on the robot to verify that it reacted properly (anti-error testing). This validation was repeated after any production stoppages.

Additionally, an hourly destructive test was performed to assess the weld resistance. This test was conducted on all products currently in production, providing a robust verification of structural integrity.

Destructive testing is a quality control method where a sample product is intentionally damaged or broken to evaluate its mechanical properties, such as strength, durability, or weld integrity. This type of test provides direct insight into how the product will perform under real-world stresses but renders the tested sample unusable afterward.

The Welding Wall was the place every part that underwent welding had to be inspected on. Where both visual and JIG inspections were performed. If any defect was detected, the entire batch was sent to Q4. As mentioned earlier, this area was considered a ‘Mura Station’ since it was dedicated solely to inspect end product and in case of defect detection at this stage, the correction would already be expensive.

Q4 was the ultimate barrier preventing defective products from reaching the client. Inspections were carried out on any product from a lot where a defect had been detected, involving a significant amount of rework. A decision was then made whether the product could still be recovered within accepted tolerance limits or if it should be discarded. This waste represented one of the company's largest losses.

A major issue identified during the analysis of Q4 was the lack of standardized defect classification. Many defects were not properly categorized, and tracing their origin was often difficult because mistakes were not adequately documented or indicated.

Finally, in the Final Product Storage, units could undergo one last inspection prior to shipment. If a defect was detected at this stage, no clear escalation process was defined on the approach to the situation.

Following the previous material flow exercise, it became evident that there was a significant excess of quality-related rework within Company X.

However, reducing this rework indiscriminately posed a considerable risk: an increased likelihood of defects reaching the final client, which would have severe consequences both reputational and financial.

Some of the existing quality control mechanisms relied heavily on rework or late-stage defect detection, which, although effective at preventing defective units from being shipped, contributed to inefficiencies and high costs.

Another evident issue was the lack of standardized escalation procedures when defects were detected, which caused slower response times.

In addition to these problems, the time between defect creation and detection proved to be too long. In many cases, defects were only identified at one of the two previously mentioned Mura Stations.

The difficulty in tracing defects complicated efforts to develop effective solutions, as it obscured which defects deserved priority and which processes were more problematic. Consequently, establishing proper defect classification and traceability became a mandatory goal for the future to enable effective defect control.

Given the overall analysis of quality control throughout the company, it was evident that the system was operating at Level 1 of Total Quality Management (TQM). As described in the previous chapter, companies at this level are capable of evaluating quality costs, which aligned with the current capabilities of the company. However, there was a clear focus on end-of-process quality control aimed at preventing defects from reaching the client, consistent with the characteristics of Level 1 TQM.

3.4 Objectives

In response to the identified issues—namely frequent breakdowns, excessive corrective interventions, and inconsistent preventive routines—improvement goals were established to enhance equipment reliability and reduce downtime.

Stamping

For stamping dies, the objective is to increase the average MTBF from 15,5 to 19 hours (22,5%improvement) . Additionally, by improving maintenance practices, the MTTR is expected to decrease from 2,85 to 1,2 hours (average time for a maintenance procedure). The improvement rates for these goals and the welding ones mentioned further, were obtained by using benchmarks from projects in similar industries and the assessment of Company X capacity for improvement.

Welding

In welding, where high stoppage frequency and poor problem classification were observed, the target is to increase the average MTBF from 32 to 56 hours (a value considered from machine benchmark from the industry), reduce the MTTR from 0.9 to 0.25 hours.

Quality

During the diagnosis part of the project the costs related to quality from the previous years were calculated the following way.

Table 3.3: Quality Related Costs

Costs	**2023**	**2024**	**% Increase**
Internal Costs	346.591 €	311.549 €	-10%

Table 3.4: Quality Wall

Quality Wall	**2023**	**2024**	**% Increase**
Units verified	11.057.317	11.076.967	+0,2%
Nº defects	45.776	43.292	-5,5%
Total (ppm)	4.140 ppm	3.908 ppm	**-6%**

It is projected a reduction of internal PPMs from 3.908 to 3.480. Furthermore, the total value of waste was set to be cut in half, with a goal of reducing it from €311.549 to €155.000. These measures reflect a shift from reactive quality control to a more proactive and source-focused quality management approach.

The conjunction of all these improvements was expected to result in a 20% OEE increase.

Chapter 4

Solution

4.1 Stamping

Stamping is one of the core production processes within Company X, playing a critical role in supplying the automotive sector with high-precision metal components. Given the complexity of this process and the demanding quality standards imposed by the industry, any inefficiency or downtime in stamping directly affects the company's ability to meet client requirements.

The current state analysis revealed that stamping performance, particularly in terms of equipment availability, required significant improvement. Increasing machine availability is essential to mitigate production stoppages, improve operational flow, and ensure product conformity from the earliest stages of the process.

This section presents the initiatives designed to optimize stamping operations, focusing on enhancing maintenance practices and eliminating process inefficiencies. These actions are fundamental to improving equipment reliability, minimizing unplanned stoppages, and contributing to overall production stability.

4.1.1 TPM Stamping

4.1.1.1 Kobetsu Kaizen

As mentioned in the previous chapter, the existing maintenance practices were inadequate to meet the demands of production. This led to prolonged downtimes of stamping dies, which remained out of service longer than acceptable. Furthermore, once reintroduced into production, dies frequently failed prematurely, causing unplanned stoppages of the machines. These breakdowns not only disrupted the production flow but also resulted in significant productivity and financial losses due to the idle time of high-value equipment. As mentioned previously, the objective for die maintenance was to increase the Mean

Time Between Failures (MTBF) from 15.5 hours to 19 hours, while reducing the Mean Time To Repair (MTTR) from 4.8 hours to 1.5 hours.

The first step was to assess which problems contributed most significantly to the gap between the current state and the desired future state. This was done in the previous chapter and the problems identified in the Ishikawa diagram presented in the Ishikawa Diagram - Stamping, Figure 3.2, the following set of solutions was identified.

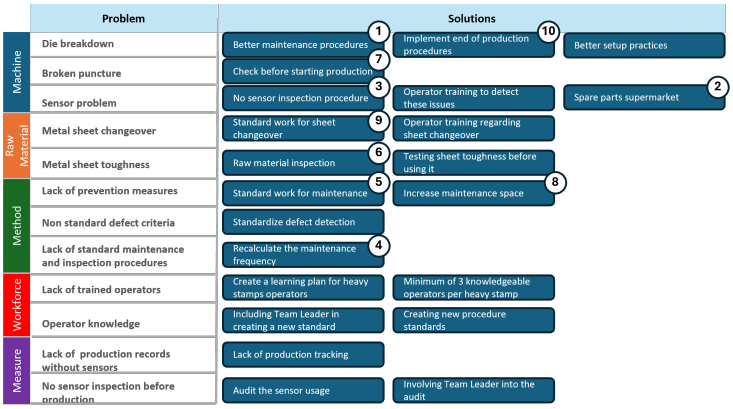


Figure 4.1: Solutions - Stamping

The solutions presented in Figure 4.2 were developed through work sessions with Company X personnel and field analysis. The next step was to evaluate which of these solutions were most viable, organizing them in an Impact/Effort matrix to determine which should be implemented and which could be discarded or postponed. This matrix was created in collaboration with Company X personnel, whose input was essential, particularly in estimating the effort required for each solution. After an initial selection where low-impact solutions were discarded, the following Impact/Effort matrix was created for the remaining solutions.

The selected solutions were evaluated the following way:

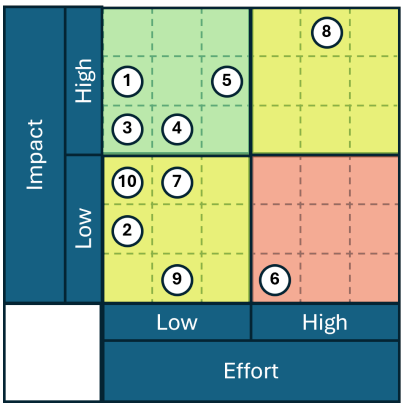


Figure 4.2: Impact/ Effort Matrix - Stamping

After analysing the previous solutions, the most relevant ones were selected to implement and move forward with. The Impact/Effort Matrix is a decision-making tool used to prioritize solutions based on their potential impact on a project and the effort required to implement them. It divides tasks into four quadrants: High Impact, Low Effort (Quick Wins), which offer significant benefits with minimal effort; High Impact, High Effort (Major Projects), which require substantial resources but deliver long-term value; Low Impact, Low Effort (Fill-ins), which are low-priority tasks that can be completed when resources allow; and Low Impact, High Effort (Time Sinks), which are costly in terms of resources and time but provide little value, and should generally be avoided unless necessary. This matrix helps teams focus on high-return tasks first and avoid efforts that provide minimal benefit.

All the solutions from the matrix aside from 6 (Time Sink) and 2, 9 (Fill-ins) were implemented as explained in the next section. These 3 solutions were left aside as its implementation was not as effective as the remaining.

4.1.1.2 Preventive Maintenance

In this section, all the solutions implemented regarding preventive maintenance will be explained. Many of the identified solutions were directly related to maintenance procedures, making this the primary focus of the designed solutions.

The first two problems addressed were the lack of puncture checks and sensor inspections (solutions 3 and 7). Both of these procedures were incorporated into a new preventive standard to be followed moving forward, ensuring that dies would undergo frequent checks on these two components, preventing them from reaching production with any faulty parts.

To address the absence of a solid maintenance procedure (solutions 1 and 5), an analysis was conducted on all available maintenance documentation from the company and its suppliers.

The company had four different levels of maintenance procedures, each to be applied depending on the units produced by the die and the time elapsed since the last maintenance. It was found that the lower three levels were insufficient, and the amount of production required to trigger the fourth level of maintenance was often excessively high. This meant the die would remain under inadequate maintenance until it reached a point of no return. Consequently, the maintenance procedure was restructured into a single level for each die, with the procedures varying based on the type of die and its mechanical complexity.

Four groups of maintenance dies were defined to optimize the use of maintenance resources. This classification aimed to prevent unnecessary complexity in the maintenance

of simpler dies while ensuring that mechanically complex dies received the required attention.

Group A: Dies working in a non-progressive system, mechanically not complex, with no movement apart from the one induced by the stamp.

Group B: Dies working in a non-progressive system, mechanically not complex, however with some movement induced by springs or hidraulic systems.

Group C: Dies working in a progressive system, mechanically simple.

Group D: Dies working in a progressive system, mechanically complex.

With the maintenance levels restructured, the next step was to develop four standard procedures to ensure dies remained in good condition. The level 4 maintenance from the previous structure was considered the baseline, as it was the most intensive procedure under the current system. This procedure was then enhanced by adding the sensor-checking process and intensifying the puncture-checking procedure to ensure all punctures in the die were manually inspected.

Finally, the die manufacturer was involved in certifying that the procedure aligned with the original design specifications during production.

The following solution to be implemented was redefining the frequency of the preventive maintenance (solution 4), as was concluded from the previous chapter, it was frequent for dies to breakdown before reaching the production needed to trigger a preventive measure. A critical step was to recalculate this frequency, and to do so the previous values were very lightly considered since many of them were extremely outdated, and none of the current employees on the company knew the reason behind the current numbers. In order to recalibrate these values a simple excel file was used, considering simply the historical production records and maintenance records. The process to define a new increment is easily explained by the following image.

Die	Previous Increment	Average Production between interventions	Average lot size	New Increment
Die-X	17600	6874	3000	6000
Die-Y	4000	11027	3000	9000
Die-Z	11000	8025	9000	8000

Figure 4.3: Increment Calculation - Stamping

The preventive maintenance is triggered when the production total surpasses the increment. Therefore, this value should ideally be surpassed near the end of the production order to avoid a significant deviation from the total production. For instance, if the increment of 6000 units is surpassed but 10000 units are still left on the active production order, the die would reach maintenance with a total of 16000 units produced, which increases the likelihood of requiring corrective maintenance.

To prevent this situation, the new increment is adapted to the lot size, ensuring that the preventive maintenance is triggered towards the end of the production orders and not at their start. This alignment helps to avoid triggering unnecessary corrective actions.

For cases such as Die-X, where the previous increment was 4000 units but the average production between preventive maintenance actions is 11000 units, and the lot size is 3000, the new increment is calculated as 9000 units, corresponding to three production orders between maintenance procedures. This ensures that the preventive maintenance will occur at the right time, minimizing production disruptions and the need for corrective actions.

In the rare cases (Die-Y as an example) where the average lot size exceeds the average production between preventive interventions, the lot size is adapted (in this case it would be lowered to 8000 units) so that the new increment remains lower or equal to the breakout production value. This adjustment ensures that the preventive maintenance continues to be timely and effective.

The new increment approach was compared to the previous using the F-1127 data in the same period of 2025 previously analyzed.

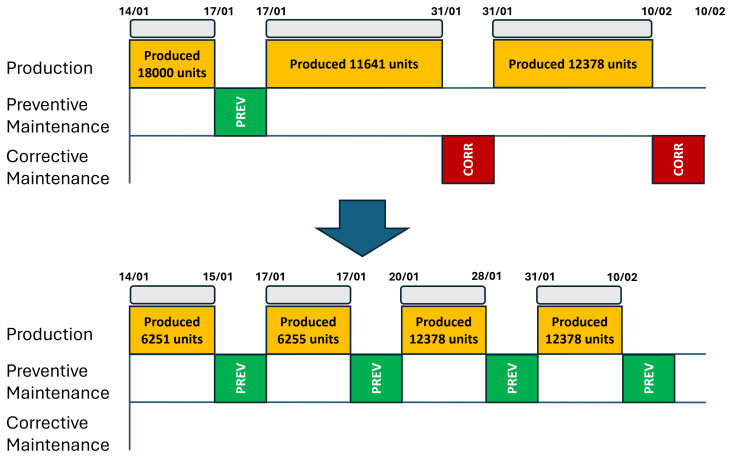


Figure 4.4: New Increment comparison - Stamping

The approach being proposed emphasizes the shift from corrective to preventive maintenance by increasing the frequency of interventions to prevent breakdowns, thereby avoiding production stoppages. By implementing preventive measures more frequently, such as reducing the increment to 6000 units, maintenance interventions occur before the die reaches a critical point where failure could happen. In the case of the F-1127 die, reducing the increment to 6000 units, which is below the average production between interventions (6800 units), ensures that the die can be serviced regularly without interrupting production.

In this scenario, the lot size considered is 3000 units, which fits within the expected

production capacity per intervention. This results in the die returning to production without requiring further corrective measures, as no intervention would be necessary until the preventive maintenance threshold is reached. By preventing failures before they happen, production is not halted, leading to smoother operations.

Additionally, the total number of interventions increases slightly, from 3 to 4, but the maintenance time required is reduced because the preventive interventions take less time (2 hours) compared to corrective actions, which could take up to 6 hours. Therefore, the proposed preventive maintenance strategy leads to improved efficiency and a reduction in production downtime, as well as maintenance time savings, while making the maintenance work load more predictable and easier to manage.

This analysis demonstrates the benefits of preventive over corrective maintenance, not only in reducing interruptions but also in optimizing the maintenance process to be more time-efficient. The conclusions were clear, the lower increment would come with significant maintenance benefits, the amount of productions stoppages would go down considerably, and the amount of maintenance work invested could even go down, however there was the need for space in the maintenance area, as the preventive maintenance required to be done in the maintenance dedicated area, whereas the corrective measures would occasionally occur outside of it.

4.1.1.3 Autonomous Maintenance

Autonomous maintenance is a proactive approach where operators take responsibility for routine maintenance tasks on their own equipment, such as cleaning, lubrication, and simple inspections. The goal is to improve equipment reliability, reduce downtime, and empower operators to maintain their machines, allowing maintenance teams to focus on more complex issues.

One of the implemented solutions aimed to ensure that autonomous maintenance was also being carried out, helping to prevent die issues. This was achieved by revamping the end-of-production procedures (solution 10).

Some of the issues causing die breakdowns could be prevented if the dies were stored in better conditions. Often, dies would accumulate scrap, oil, and dirt during production, and in some cases, they would re-enter production with these issues still present.

To address these concerns, the stamps production team was trained by the maintenance team on topics such as die lubrication, ensuring that production would end without excess oil on the dies. Additionally, a simple cleaning checklists was implemented and performed at the end of production. This checklist included cleaning scrap, removing excess oil, and cleaning the die surfaces.

4.1.1.4 Layout Redesign

In order to understand how much space was needed (solution 8), a first analysis was done to dies, the amount of time each would require for a preventive action, and the amount of time a corrective action would take on average.

Dies were separated into two distinct groups: critical dies, where the new increment and new procedures had to be implemented right away, and non-critical dies, where the new increment and procedures would be implemented once the critical dies had reached an equilibrium. This was done to not overload the maintenance team with preventive measures on every die, since many of them rarely gave problems wither because their production volume was not sufficient or the current measures were enough.

This critical classification was established by identifying the dies with a high ratio of corrective maintenance relative to their usage frequency, and combining them with all dies associated with heavy stamping operations, as these exhibited the lowest Overall Equipment Effectiveness (OEE) and accounted for the highest productivity losses due to idle time.

As shown by the calculations in Appendix D, it was concluded that there was the need for 7 maintenance operators working simultaneously, something that at the time, was deemed impossible, as at most 3 people could be working at once due to space limitations. The current maintenance area had more than 50 square meters, but the actual working space was much smaller due to the area being extremely disorganized and cluttered with peripheral equipment.

As shown in the picture below, there were approximately 105m² of working space (blue area). The red area includes stock, a computer for managing daily tasks, a desk, and support machines for the maintenance of specific pieces. However, no die work was carried out in this area.

To achieve the desired free space, two different solutions were implemented, reorganizing the current layout to eliminate non-value-added objects and expanding the working space into the surrounding area, occupied by non-value-added objects.

The second approach proved to be the most impactful, offering a significant space gain without affecting the convenience of storage. This was the first step taken. The transformation is shown in the following picture. The transformation can be seen in the following picture.

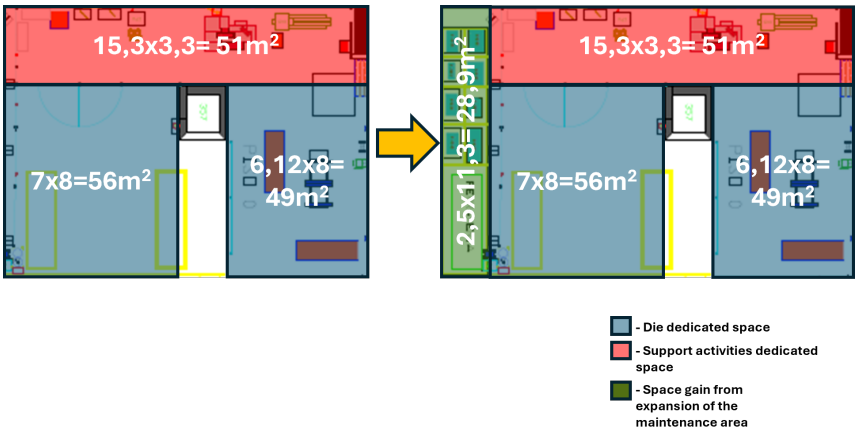


Figure 4.5: Expansion Layout - Stamping

This solution had no resistance from the maintenance team, as none of their working equipment was displaced, and it resulted in a nearly 30m² space gain, this space was previously used as storage for dies and obsolete machines, these were transferred to a less valuable area. The total space available was split into die dedicated space and support activities dedicated space, the difference between then was whether the support bridge, used to move dies around, was able to access the space. As shown in the Figure 4.5 there is a decent amount of space that can't be used for die maintenance for this reason alone.

Having increased the available space, the next approach consisted of moving all the necessary static peripherals to the new area, and transforming some of the static peripherals into movable ones while removing the unnecessary ones. Some of the equipment choices made were as follows:

- Transforming all individual utility closets into moving closets, allowing workers to have 'dynamic tables', while also being able to store them in a convenient space whenever not needed.

- The main storage closet was transferred from the central position to the new area on the left, allowing for more central maintenance space.

- Two large tables were removed, and another was cut in half in order to reduce unused 'working' space.

- Two different closets with substitution pieces for maintenance were removed from the maintenance area and placed into a nearby storage room.

After the cabinet sorting the space gain was clear as it can be explained in the following figure.

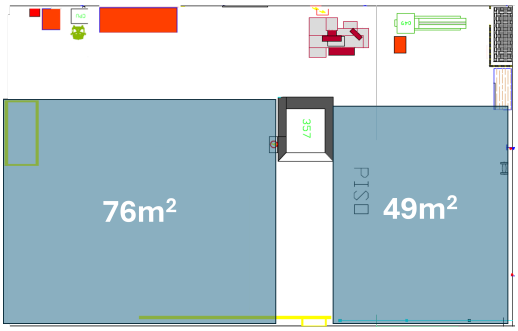


Figure 4.6: New Layout - Stamping

With this redesign, the maintenance team gained nearly 32 m^2 of working space, 20 m^2 were gained from the expansion and 12 m^2 were gained from removing cabinets, closets and tables from the die dedicated area, providing the capacity to carry out all required preventive interventions.

4.1.1.5 Operator Training

Operators were thoroughly trained to ensure the sustainability of the improvements made previously. This training included the use of tool, such as standard work for maintenance procedures and end-of-shift processes, ensuring sustainability of solutions.

New practices introduced during the reshaping of the layout—such as ensuring that only the necessary tools and equipment for work were present in the workstation—will be sustained through audits and monitoring performed by the production supervisor.

Furthermore, to continuously improve and refine the system, weekly meetings were implemented. These meetings aim to analyze the data collected from the work floor, focusing on key areas like increments that may need updating, reallocation of dies to different groups if their status changes, and identifying areas where the layout may need further adjustments.

4.2 Welding

4.2.1 TPM Welding

4.2.1.1 Kobetsu Kaizen

As mentioned in the previous section, the existing maintenance practices for the welding process were inadequate, leading to high stoppage frequency and poor problem classification, particularly with robot arm welders, such as Robot X. These machines often remained out of service for longer than acceptable, and once reintroduced into production,

they frequently failed prematurely, causing unplanned stoppages. These breakdowns disrupted the production flow and resulted in significant productivity losses and financial impacts due to the idle time of high-value equipment.

The objective for robot arm welding maintenance is to increase the Mean Time Between Failures (MTBF) from 32 hours to 120 hours, reduce the Mean Time To Repair (MTTR) from 0.9 hours to 0.25 hours, and lower daily stoppage time from 1515 minutes to 1061 minutes (a 30% improvement).

In order to achieve these results, it was needed to assess which problems contributed most significantly to the gap between the current state and the desired future state. To support this analysis, an Ishikawa diagram (Ishikawa Diagram - Robot X, Figure 3.8) was developed. This tool helped identify and categorize the root causes of downtime, such as robot arm issues, cable fatigue, sensor malfunctions, and failures in related components like ceramic pins and JIGs.

After reanalysing the forementioned Ishikawa Diagram, the following solutions were proposed.

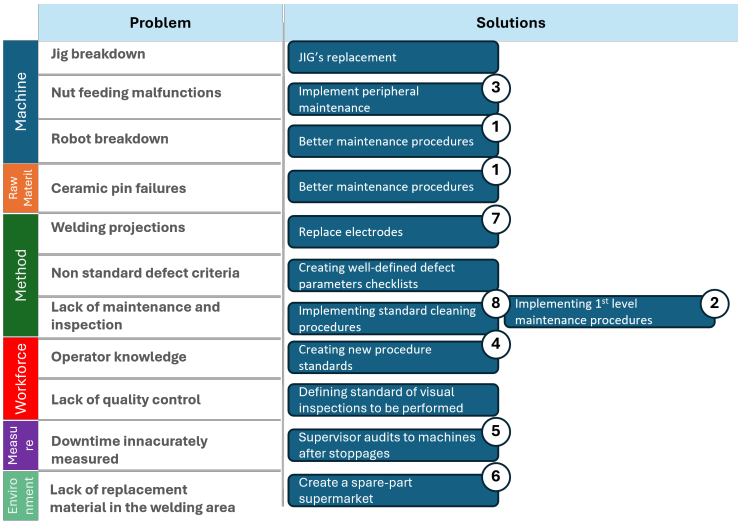


Figure 4.7: Welding Solutions - Welding

As it was done in stamping the next step was placing them in the effort impact matrix to figure out which of them would be implemented and which would be prioritized.

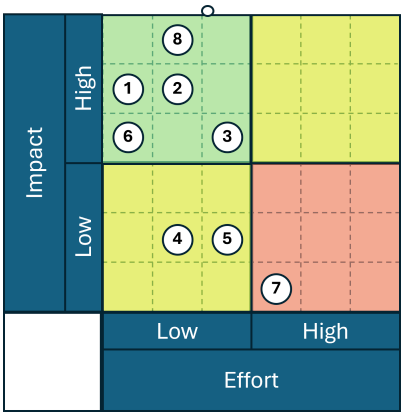


Figure 4.8: Welding - Matrix

After analysing all the available solutions, solution 7 was left out since the investment did not achieve the impact needed to be justifiable, as the replacement of electrodes would have to be extremely frequent due to the current maintenance procedures.

4.2.1.2 Planned Maintenance

Preventive maintenance on welding was quite different from the situation in stamping. The maintenance was done on the machine itself, and this was done periodically and it did not rely on the amount of pieces produced in between maintenances. Doing maintenance on a welding machine is much more complex than on a stamping die, these machines include many peripherals and very complex components like the welding arm. One problem from the multitude of peripherals and 'independent' components was that not all of them had the same periodicity of maintenance. In order to understand and implement the right procedures all the machine supplier documentation was analysed and all the maintenance suggestions were compiled into a list. Some key additions found that heavily impacted machine performance were the following :

- Lubrication with greases such as Shell Albida RL2 or Alvania RL3 is recommended for robotic joints and gear, taken from PSE manual (Production Engineering Department, 2021).
- Joint greasing instructions for the robot's base, shoulder, and wrist are also detailed in the same manual (Production Engineering Department, 2021).
- Cooling fans for drive units and amplifiers must be periodically cleaned to avoid thermal faults, taken from CHARNIERE welding cell manual (Production and Maintenance Department, 2022).
- Maintenance procedures for nut feeders and welding clamps, including sensor calibration, are provided in the CHARNIERE technical manual (Industrial Engineering Department, 2022).

- Maintenance of the air treatment unit, including use of ISO VG 32 oil and proper drip rate settings, taken from Automatic Press EE manual (Special Equipment Engineering Department, 2018).

Apart from implementing new procedures, the maintenance frequency was also restructured, as some tasks required to be done more often. A yearly preventive maintenance plan was introduced for all welding equipment, including both conventional machines and robotic arms. Additionally, it was specified that an external provider should perform a full grease replacement on the M20iA robot arms every three years. To further improve efficiency, a spare-part supermarket was implemented directly in the welding area, ensuring immediate access to regularly used maintenance items. Previously stored in the stamping building's shared maintenance room, these parts were harder to access and poorly organized—especially sensitive components like sensors This room was inaccessible during the night shifts, making it impossible to perform maintenance on welding if any component was required. The new supermarket improved material control and reduced downtime, making maintenance more efficient adn accessible.

4.2.1.3 Autonomous Maintenance

One of the main problems identified in the welding area was the lack of maintenance performed by machine operators and the lack of attention to early indicators of malfunction, often resulting in high repair costs or complete machine breakdown. To address this issue, two of the most impactful and easy-to-implement solutions were developed, focusing specifically on preventive actions carried out by the operators themselves.

To determine what should be cleaned or addressed during First Level Maintenance, a dual approach was used. First, the most frequent causes of machine stoppages were analyzed, and second, the components most often affected by these failures were selected as priority targets for routine maintenance actions. This ensured that operator tasks were directly aligned with the areas of highest failure risk.

First Level Maintenance (also referred to as Autonomous Maintenance or Operator Maintenance) involves basic upkeep activities performed by machine operators rather than specialized technicians. The primary objectives are to maintain equipment in optimal working condition, detect early signs of malfunction, and prevent avoidable failures.

In addition to the core welding equipment, several peripheral systems—such as emergency safety devices and the milling machine—were also included in the First Level Maintenance scope. As with planned maintenance, the proper procedures for each task were defined using manufacturer documentation and equipment manuals to ensure correctness and compliance.

The following are some of the most relevant First Level Maintenance practices that were implemented:

- Test emergency stop buttons, interlocks, and safety sensors at the start of each shift. Ensure they respond instantly and stop the machine. If any device fails, stop the operation and report it.
- Operators must regularly inspect electrodes for wear, deformation, or misalignment.
- Air pressure regulator should be checked to ensure the system is operating within the correct range.
- Operators should periodically tighten visible bolts and fasteners on clamps, holders, or brackets.

New cleaning procedures were also implemented, forcing operators to help preserve equipment performance through regular upkeep. These include:

- Clean markers: Clean marker heads and housings to ensure print quality and avoid material smudging or obstruction.
- Verify and clean nut feeder hose: Check the nut feeder hose for clogs or wear, and clean it to ensure uninterrupted part delivery to the welding gun.
- Clean robot arm surfaces: Remove dust and oil from the robot arm, especially near joints and sensor mounts.
- Clean cooling and electrical components: Use dry air or cloths to clean fans, cooling vents, and electrical housings, preventing overheating or malfunction.
- Verify milling machine detectors: Confirm that all detectors are functioning properly to avoid misalignment or unsafe operations.

All these tasks are low-risk and low-complexity, making them suitable to be performed by machine operators. Although the responsibility for carrying out First Level Maintenance lies with the operator, it is expected that the shift supervisor remains present on the shop floor during the first 15 minutes of each shift—the designated maintenance period—to ensure that procedures are being followed correctly and consistently according to the established standard.

4.2.1.4 Operator Training

To support the rollout of First Level Maintenance in the welding area, a focused training program was delivered to the production team. The maintenance points were explained using a highly visual standard, designed with clear images and minimal text, allowing operators to quickly identify what needed to be cleaned, checked, or verified.

Alongside the training, new maintenance standards were developed for both First Level Maintenance (performed by operators) and planned maintenance (performed by the maintenance team). While the First Level standards were deliberately simple and image-driven, the planned maintenance standards were more detailed and technical, as they were intended for skilled maintenance personnel already familiar with complex systems.

Additionally, the role of the shift supervisor became fundamental in responding to every machine stoppage. Their presence ensured that failures were properly recorded at the source, which was critical to generating reliable KPIs. The data recorded was analyzed weekly in order to identify new targets for maintenance or improvement opportunities.

4.3 Quality Systems

4.3.1 Defect Catalogue

One of the main issues previously identified in the company was the lack of defect tracking. As shown earlier, there were two main origins for defects: either in the welding process or in stamping. However, once a defective part reached Q4 or the Welding Wall, it became very difficult to determine where the defect had originated. This lack of traceability made meaningful data analysis impossible and hindered targeted improvements in specific parts of the production process.

The first step in addressing this problem was the development of a defect catalogue.

Proper identification of a defect is crucial in order to understand how to prevent it and to identify which component or stage of the process is responsible for its occurrence.

The defect catalogue should include the following elements, defect number, description and visual representation of the defect, detection method, probable causes, and corrective actions.

To properly classify the different types of defect, the company's internal quality documentation and the standards in use were reviewed. Based on this analysis, the defects were organised into seven main categories, with similar characteristics or causes grouped together.

1. Defects of shape and dimension: deviations from the intended geometry, such as incorrect size, misalignment or warping. These are often caused by tool wear, poor setup, or inaccurate fixturing.

2. Surface defects: imperfections on the exterior of the part, such as scratches or roughness. In stamping, this includes burrs and visible contamination (e.g. oil or dust).

3. Discontinuities and cracks: structural interruptions, such as cracks or separations, which are often caused by stress concentrations or poor process control.

4. Cavities and gas-related defects: voids caused by trapped gases or shrinkage during cooling that reduce material integrity.

5. Material flow and deformation defects: result from improper deformation, such as wrinkling or folding, typically caused by friction, die design, or pressure issues.

6. Microstructural and metallurgical defects: internal structural issues, such as grain growth, inclusions, or phase imbalance, often linked to overheating or contamination.

7. Physical resistance defects: reduce mechanical strength or durability due to porosity, poor bonding, or residual stresses.

As mentioned, the catalogue has important visual aid, making the process fairly easy. After validating the defect catalogue in collaboration with the Quality Department, the first key issue in revamping the quality system was addressed: the identification of defects was now based on a unified standard, with consistent terminology adopted across the entire organization. This eliminated previous discrepancies in how defects were classified and reported, enabling clearer communication between operators, quality technicians, and management. The next step was the implementation of the catalogue on the shop floor. This was carefully structured — physical copies were placed at all stations where quality inspection was performed. An example of the physical version implemented is in the Figure 4.9. This version was much simpler than the handbook present in Appendix E since the catalogue just contains images of the defect and a brief description. It was organized by defect category to allow quick navigation.

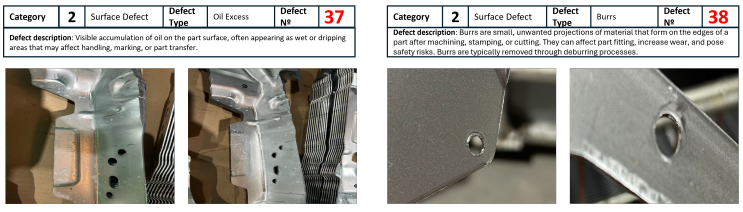


Figure – Oil Excess Figure – Burrs

Figure 4.9: Defect Catalogue - Operator version

To support its effective use, a simple standard procedure was created and deployed alongside the catalogue, ensuring that operators could follow a consistent method when consulting it and recording a defect. This tool quickly proved to be a valuable aid during quality control, significantly improving the accuracy and speed of defect identification on the production line. It also provided clear benefits for employee training: for less experienced operators, the visual and straightforward nature of the catalogue accelerated learning and improved their ability to detect and correctly classify nonconformities.

4.3.1.1 Auto-Quality Matrix

The implementation of the auto-quality matrix was initially impossible due to the lack of defect detection station data associated with defect records. During the rollout of the defect catalogue, as mentioned in the previous section, this limitation was addressed. The updated procedure required operators to not only register the defect after consulting the catalogue, but also to indicate the station where the defect was detected.

This step proved critical, as the majority of defective units that reached Q4 previously had no traceability regarding their origin. Although the defect label used in Company X already included a field to record this information, it was largely ignored by operators — a reflection of the high turnover and lack of standardized training, a new standard was implemented for filling this label, ensuring that the traceability of defect detection was always ensured. .

Once these improvements were implemented and defect records became more complete and consistent, the auto-quality matrix could finally be created. The required data inputs were now reliable:

- **Defect label** – With the new catalogue, defects were registered under standardized names, preventing confusion or wrong labelling across operators.
- **Defect detection** – The detection station was now consistently recorded at the time of defect identification.
- **Defect origin** – For parts processed only in stamping or welding, determining the origin was straightforward. For parts processed through both, the type of defect usually indicated the source, as most defects are process-specific (e.g., porosity typically originates in welding, while burrs are frequent in stamping).

The first version of the auto-quality matrix was built only after sufficient clean data had been gathered — made possible by full adherence to the catalogue and updated defect registration process. The final version of the quality matrix is presented in Appendix F.

After the preparation of the auto-quality matrix, a new routine was implemented: a structured weekly meeting where the matrix and other performance-related indicators were analysed. One of the most relevant metrics introduced was the detection ratio, which evaluates the proportion of defects detected at a given station compared to the total number of defects created at that same station. A detection ratio of 100% indicates a perfect auto-quality scenario, where all defects are caught at the station where they were generated, preventing them from reaching downstream processes.

Stations with the lowest detection ratios were selected for further analysis. This involved reviewing the auto-quality tools available at those stations and investigating the reasons why certain defects were not detected earlier in the process.

Another important metric evaluated was the total number of defects generated per station, which provided insight into the effectiveness of each station in preventing defect occurrence. Any abnormal increase in this value triggered a process review and corrective action.

The screenshot available in Appendix G, illustrates the dashboard used to track key maintenance indicators. These implementations were all in use in the improvements made in the quality systems, being key to understanding problems and how to tackle them. One example of it was the following:

- After analysing the dashboard, it was noticed that a large number of dimensional welding defects were occurring, most of which were only detected further along the value chain.
- A 3C methodology analysis was then conducted. The 3C methodology was chosen to address the issue due to its concise and action-oriented structure, which is particularly effective for frontline quality problems. It enables rapid identification of concerns, root-cause analysis, and practical countermeasures without requiring complex tools or prolonged analysis. The concern was the abnormal number of undetected defects at the welding station. The cause was identified as a malfunction in the Jidoka mechanism of the welding robots, which failed to detect errors when a defective unit was placed in the JIG.
- As a countermeasure, the existing anti-error test process was audited and subsequently standardized. This ensures that the Jidoka function is operating correctly and that the robot's defect-detection system is reliable before production begins.

This served as a very important example of an improvement that would have not been possible without the tracking done through the auto-quality matrix.

A structured meeting and the corresponding analysis were scheduled weekly and are now carried out by the designated quality team of the factory with the goal of identifying new opportunities or correct problems.

As a result of these improvements, the factory can now be positioned at level 3 of the Total Quality Management (TQM) scale, representing a significant advancement from its original classification at level 1. Level 3 is characterized by proactive defect prevention, standardized procedures, and systematic use of quality data to drive continuous improvement.

Chapter 5

Results

In this chapter, we evaluate the results and compare them with the project's baseline and intended goals. The discussion is divided into two parts. First, we review the stamping and welding outcomes—initiatives aimed at raising OEE by reducing MTTR and increasing MTBF. Second, we examine the quality-focused actions, where success is gauged primarily by reductions in total waste and in the internal poor quality metric.

As detailed in Appendix H, the initial assessment of stamping and welding quality defined baseline indicators and targets.

Every stamping and welding intervention was designed to move at least one of these metrics, and the results over the period confirm their effectiveness: performance improved markedly and, in most cases, exceeded the original targets.

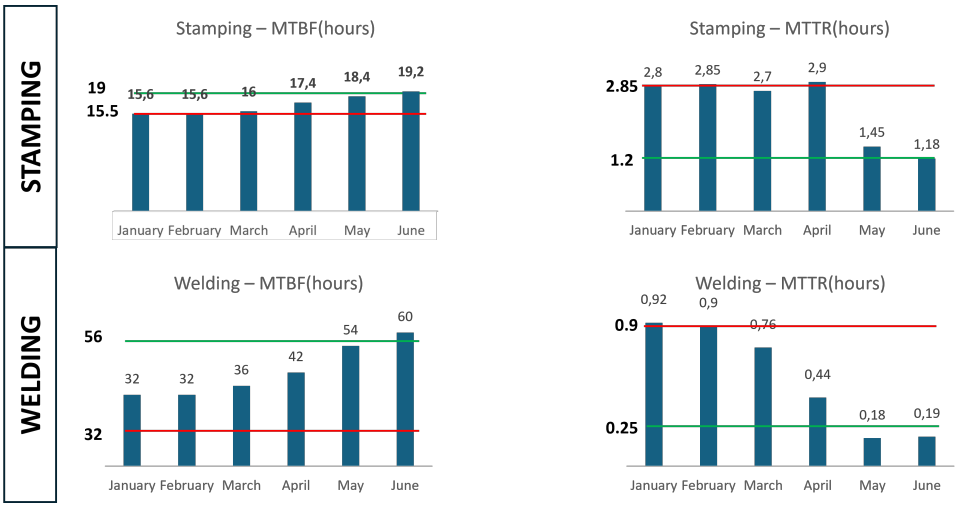


Figure 5.1: Stamping & Welding - Results

All individual initiative targets were surpassed. April's rise in stamping MTTR—an expected outcome while new preventive-maintenance procedures were bedding in and

operators spent longer on certain dies—every metric improved month over month. Importantly, that same April delivered the biggest jump in stamping MTBF of the entire period, underscoring the trade-off.

By May, MTTR fell sharply as the redesigned maintenance layout went live, giving the team far greater capacity to tackle breakdowns promptly. The remaining indicators advanced steadily, reflecting the cumulative impact of continuous-improvement work throughout the review window. Overall Equipment Effectiveness (OEE), the flagship KPI on the maintenance side, evolved as summarised below.

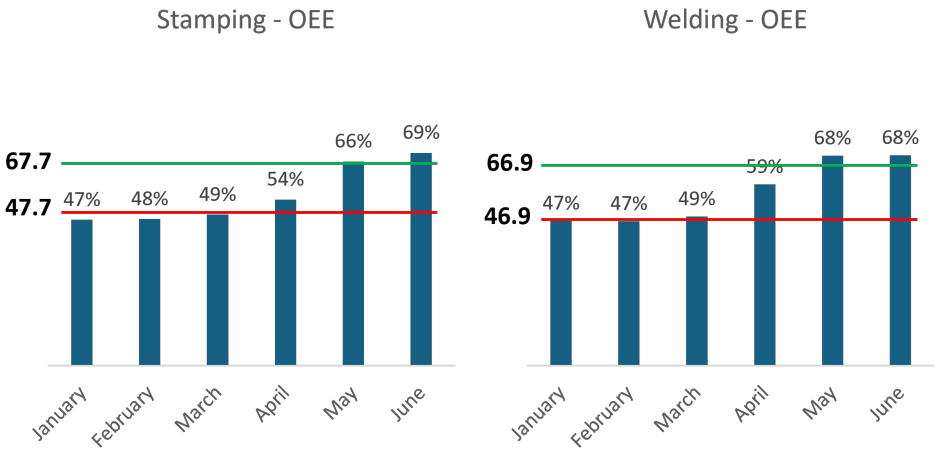


Figure 5.2: OEE Evolution

As anticipated, the consolidated OEE mirrored the individual trends of the stamping and welding lines, since it is calculated as their average. The overall target was achieved in May, and a further uptick in June—driven by process standardisation—underscores the maintenance initiatives' success.

Quality performance was evaluated by comparing the values obtained for the implementation period and half of the previous year.

Table 5.1: Quality Related Costs

Costs	**2024 (6 months)**	**2025**	**% Increase**
Internal Costs	150.834 €	74.245 €	-52%

Table 5.2: Quality Wall

Quality Wall	**2024 (6 months)**	**2025**	**% Increase**
Units verified	5.538.484	5.022.983	-9%
Nº defects	21.646	16.474	-24%
Total (ppm)	3.908 ppm	3.280 ppm	**-16%**

The evolution across the project duration and the projection for the remained of the year of the quality 2 internal main indicators, Quality Wall ppm and internal costs is showed in the Figure 5.3.

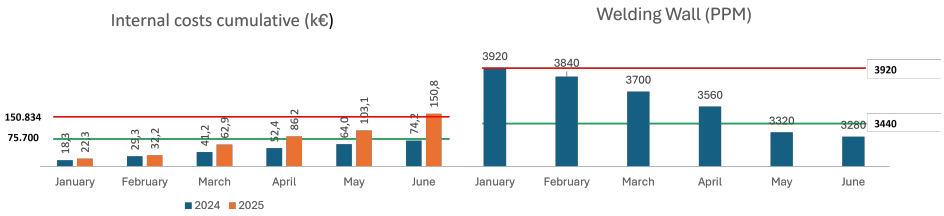


Figure 5.3: Internal Quality Indicators

In the year-over-year comparison, it is clear that the PPM objective was significantly surpassed, representing one of the project's greatest achievements — especially considering that this is a critical issue for companies operating in the automotive industry.

All goals, although ambitious, were successfully met — some even before the June deadline, and others exceeded, delivering even greater value than initially estimated.

The overall OEE increased by 22%, slightly above the 20% target set at the project's outset.

On the quality side, the number of fines decreased by six compared to the same period last year, supporting the projection that a total reduction of ten fines over the full year is likely to be achieved.

Regarding the welding wall PPM and internal costs, internal costs were reduced by 52%, again slightly exceeding expectations, while PPM decreased by 16%, a substantially better outcome than the initial 11% target.

Chapter 6

Conclusion

The implementation of the improvement initiatives presented throughout this dissertation demonstrated the significant positive impact that Kaizen methodologies can have on an organization. Through the combined application of TPM, TQM, and other Lean tools, Company X managed to surpass the ambitious targets established at the project's inception.

In particular, the maintenance processes for both stamping and welding were optimized, resulting in improved equipment availability, performance, and reliability. The standardization of procedures and the investment in preventive maintenance proved crucial to these results. The creation of autonomous maintenance routines and operator involvement further supported these improvements, fostering a proactive and ownership-driven workforce.

The quality system also underwent a substantial transformation. The development of reliable data collection mechanisms, supported by Auto-Quality tools such as Poka Yoke and Jidoka, ensured that defects were detected and addressed earlier in the process. The standardization of analysis and the establishment of a structured problem-solving approach allowed the quality team to tackle root causes effectively.

As a result, the project successfully achieved the targeted increase in Overall Equipment Effectiveness (OEE) and a significant reduction in internal quality costs.

Beyond the numerical results, the cultural change within Company X should be highlighted. The workforce became more engaged and improvement-oriented, which is fundamental to sustaining the gains made and ensuring future progress.

Looking ahead, it is imperative that the following next steps be taken to maintain and build upon the results achieved:

- Periodic audits must be performed across all production and quality areas to ensure that standards are being upheld and to identify any deviations that require corrective action.

- The maintenance space should remain clean, organized, and properly equipped, to facilitate efficient maintenance operations and minimize downtime.
- The quality team must continue to conduct weekly meetings and data analysis sessions, allowing for ongoing identification of improvement opportunities and the prompt implementation of effective solutions.

By following these steps, Company X will be well-positioned to sustain its operational excellence and pursue continuous improvement, ensuring long-term competitiveness in the demanding automotive sector.

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Appendix A

Auto-Quality Matrix

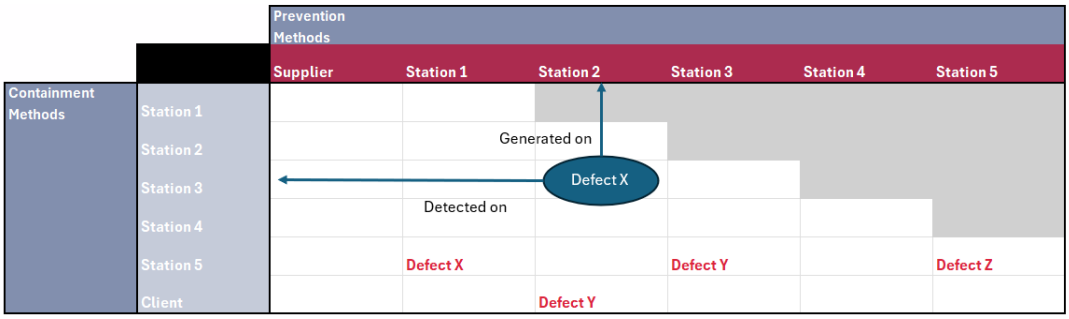


Figure A.1: Auto-Quality Matrix

Appendix B

Poke Yoke Example

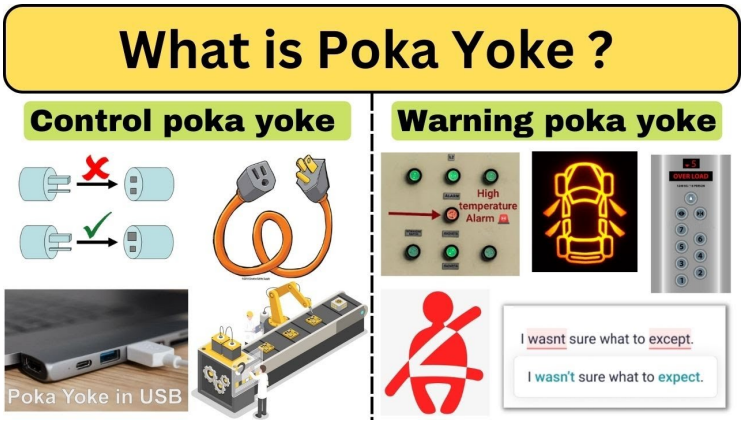


Figure B.1: Poka Yoke examples

Appendix C

Die Maintenances Interventions

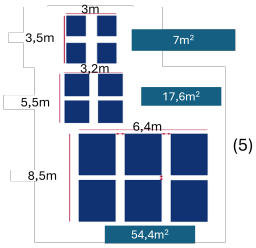
Table C.1: Top Die Stoppages and Maintenance Interventions

Die	Usage Frequency	Preventive	Corrective	Cleaning	Area (m^2)
F-1127	77	5	25	0	5,35
F-1544	51	11	1	0	4,22
F-1759	48	1	14	0	1,89
F-1760	44	3	21	0	1,35
F-1424	43	2	15	2	3,98
F-1764	42	0	12	0	4,27
F-1436	41	0	14	0	3,18
F-1601	41	4	15	0	6,21
F-1612	36	1	9	2	2,00
F-1605	33	0	8	1	4,58
F-1425	33	1	14	0	1,43
F-1503	32	0	9	0	2,00
F-1150	30	2	3	0	4,14

Appendix D

Space Calculation

	Non-Critical Dies	Critical Dies
Nº of interventions expected per day	-	10,8
Nº of hours per intervention	-	2
Total of hours (daily load)	13 (1)	21,6 (4)
Total of hours (daily load)	34,6	
Nº of needed workers	7 (6,92) (2)	
Area needed	79m² (3)	



(5)

Assumptions:

1-The total amount of hours for non-critical dies was assumed as the sum of daily historical work for those tools since the procedure would remain the same for now;

2-Assuming each worker would be able to do 5 hours of direct maintenance work, excluding machine related and other interventions;

3- Assuming the distribution shown of the picture on the right 2 small, 2 medium and 3 heavy);

4- The total of hours required for critical dies was calculated by the product of expected dies worked per day (10,8) by the expected duration of the new preventive maintenance (2 hours)
The total hours for non-critical dies and the nº of daily interventions for critical dies was obtained through the historical records of dies.

5- The space required was calculated for 2 dies (small and progressive stamps), each die requires to be opened so it needs double the área of the surface. For the large dies, the required space it is 3 times the surface since it might need to be rotated, requiring extra área for the procedure.
Die size : Small < 1,5m² Progressive <4,4m²

Figure D.1: Space calculation - Stamping

Appendix E

Defect Handbook

Category	2	Surface Defect	Defect Type	Oil Excess	Defect Nº	37
Defect description: Visible accumulation of oil on the part surface, often appearing as wet or dripping areas that may affect handling, marking, or part transfer.						
Typical causes: – Over-application of lubricant during stamping – Faulty or misadjusted oil spray system – Lack of cleaning before inspection or transfer						
Detection Method: Adjust lubrication system to apply the minimum required amount – Perform regular maintenance and calibration of the spray unit – Wipe or blow off excess oil from parts after stamping if needed						
Corrective/ Preventive action: – Adjust lubrication system to apply the minimum required amount – Maintenance and calibration of the spray unit – Wipe or blow off excess oil						

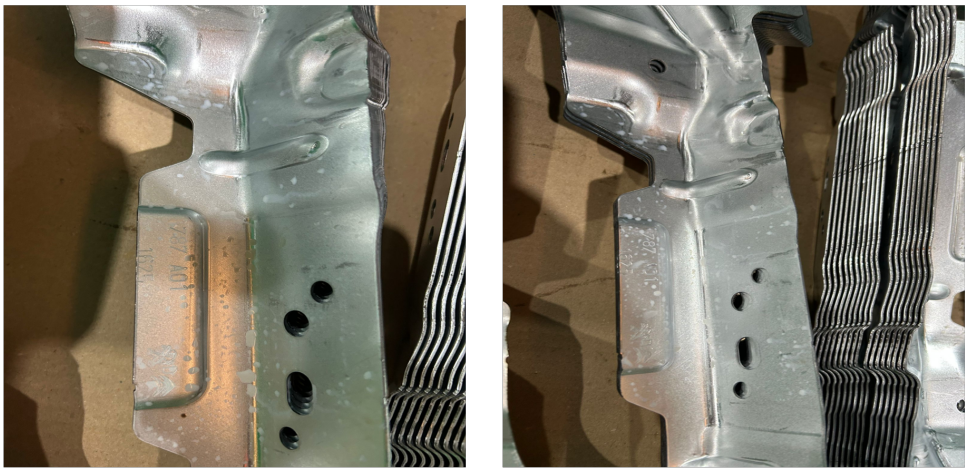


Figure 1 – Oil Excess

Figure E.1: Defect Handbook - Oil Excess

Appendix F

Quality Matrix Overview

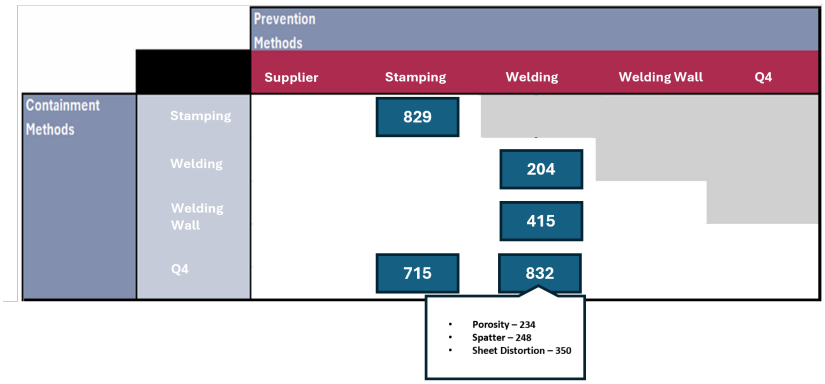


Figure F.1: Quality Matrix – Draft

Appendix G

Quality indicators dashboard

This analysis was made using the dashboard, showing the average value for the metrics and the evolution of the indicator across the previous 6 weeks.

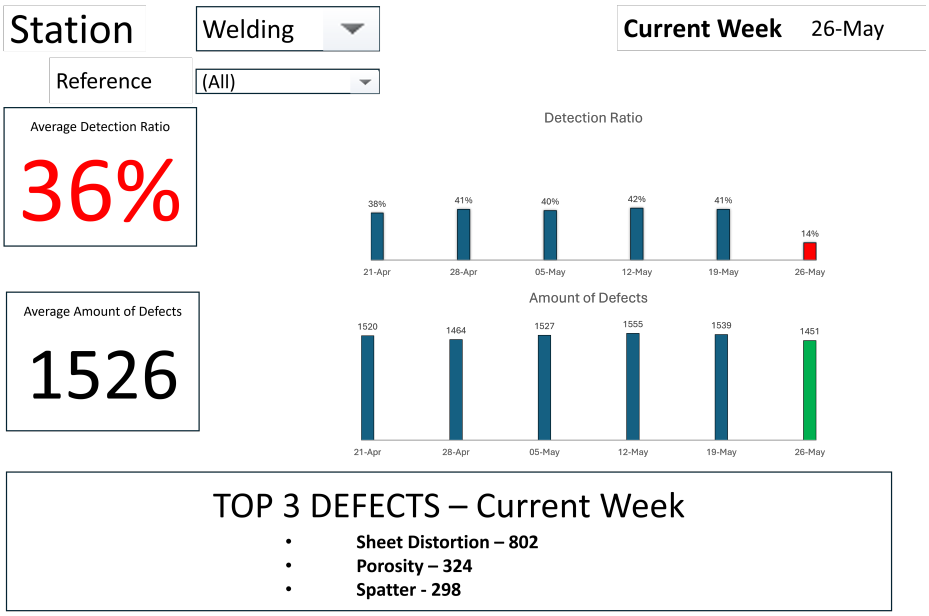


Figure G.1: Dashboard Example – Stamping

The current week values on the graph would be displayed in either red or green, if it was a positive or negative evolution compared to the average for the 6 week period. One example of an implementation that resulted from the weekly analysis was the following.

Appendix H

Initial Asssessment Results

Sector	Metric	Baseline	Target	Percentual Increase
Stamping	MTBF	15,5h	19h	22,5%
	MTTR	2.85h	1,2h	68%
	OEE	47,7%	67,7%	20%
Welding	MTBF	32h	56h	75%
	MTTR	0.9h	0.25h	68%
	OEE	46,9%	66,9%	20%
Overall	OEE	47,3%	67,3%	20%

Figure H.1: Initial Assessment Results