

FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Application of Toyota Production System Principles to Improve Process Flow, Safety and Efficiency in Automotive Final Assembly

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July 15, 2025

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Abstract

This dissertation presents a practical application of continuous improvement methodologies in an industrial environment, within the framework of the Toyota Production System (TPS). Conducted during a project at Toyota Caetano Portugal, the project focused on three main areas: the analysis and redesign of the value stream (VSM), the structured resolution of a critical defect through the Problem Solving methodology, and the implementation of several kaizen improvements based on direct shop floor observation.

The VSM analysis enabled the identification of key improvement opportunities and supported the proposal of a Future State Map, aiming to reduce lead time and increase value-added activity. The Problem Solving project addressed recurrent window scratches, leading to the implementation of effective countermeasures that improved detection flow, standardisation, and overall quality control. Lastly, the kaizen improvements targeted safety, ergonomics, and workplace environment through low-cost, operator-driven actions.

The results demonstrated measurable gains in efficiency, quality, and process stability, while reinforcing the alignment with TPS principles. The project also provided an opportunity to integrate academic knowledge with industrial reality, particularly within the field of production management and continuous improvement, contributing to the development of both technical and operational competencies.

Resumo

Aplicação dos Princípios do TPS para Melhorar o Fluxo do Processo, a Segurança e a Eficiência na Montagem Final Automóvel

Esta dissertação apresenta a aplicação prática de metodologias de melhoria contínua num ambiente industrial, no contexto do Toyota Production System (TPS). Realizado durante um estágio na Toyota Caetano Portugal, o projeto focou-se em três áreas principais: a análise e redesenho do fluxo de valor (VSM), a resolução estruturada de um defeito crítico através da metodologia de Problem Solving, e a implementação de várias melhorias kaizen baseadas em observação direta no chão de fábrica.

A análise VSM permitiu identificar oportunidades de melhoria e suportou a proposta de um Future State Map, com o objetivo de reduzir o lead time e aumentar as atividades com valor acrescentado. O projeto de Problem Solving abordou a ocorrência recorrente de riscos nos vidros, levando à implementação de contramedidas eficazes que melhoraram a deteção dos mesmos, a padronização e o controlo de qualidade. Por fim, as melhorias kaizen visaram a segurança, ergonomia e o ambiente produtivo, através de ações de baixo custo promovidas pelos próprios operadores.

Os resultados demonstraram ganhos mensuráveis em eficiência, qualidade e estabilidade dos processos, reforçando o alinhamento com os princípios do TPS. O projeto constituiu também uma oportunidade de integração do conhecimento académico com a realidade industrial, especialmente na área da gestão da produção e melhoria contínua, contribuindo para o desenvolvimento de competências técnicas e operacionais.

Acknowledgements

Before anything else, I want to thank Professor Eduardo Gil da Costa, my academic supervisor, for the guidance and support throughout this thesis. His help was essential in navigating both the technical content and the writing process.

I also want to thank Toyota Caetano Portugal, in Ovar, for welcoming me and providing a rich experience in a real industrial setting. The opportunity to be trained in Toyota methodologies and to actively contribute to factory activities was invaluable. I'm especially grateful to the entire engineering and production teams for their openness and support, and for creating a positive, collaborative environment.

Special thanks go to Rui Mané, my factory supervisor, for the guidance, advice, and for helping me deal with challenges as they came, always with a calm and practical approach. And to Gonçalo Vieira, my tutor at Toyota, who followed my projects from start to finish, helped me overcome initial roadblocks, opened doors to new responsibilities, and always showed a willingness to share knowledge and work as a team. Alongside him and with João Pinho, I felt integrated into the final assembly engineering team, living the day-to-day life of a Toyota engineer.

I would also like to thank my desk colleague Rui Matos for his daily availability, good energy, and support throughout the project, and my colleague Bruno Fernandes for the many constructive discussions and his help in developing several projects on the shop floor.

To FEUP, for the education and the platform that allowed me to access an experience like this, which will surely mark the beginning of my professional path as a mechanical engineer.

I would also like to thank my friend and colleague Miguel Gamito for his support during both the project and the writing of this thesis.

Finally, to my parents: my father, Firmino Oliveira (also a FEUP mechanical engineer), for the many technical discussions, support, and patience; and my mother, Teresa Oliveira (an industrial management engineer), for providing guidance my first steps into the industrial world. Without them, this path wouldn't have started, much less ended, the way it did.

Firmino Pinho Oliveira

*“Problems are rolling all around in front of your eyes. Whether you pick them up and treat them
as problems is a matter of habit.”*

Eiji Toyoda

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List of Acronyms

TPS	Toyota Production System
VSM	Value Stream Map
VSD	Value Stream Design
JIT	Just In Time
DMAIC	Define, Measure, Analyse, Improve, Control
EWS	Element Work Sheet
ROI	Return On Investment
PDCA	Plan, Do, Check, Act
WSS	Work Step Sheet
WIP	Work In Process
VA	Value Added
NVA	Non Added Value
LT	Lead Time
FSD	Future State Design
PPE	Personal Protective Equipment
LC70	Land Cruiser 70 Series
AMAP	Any Member, Any Process
TCAP	Toyota Caetano Portugal
TSAM	Toyota South Africa Motors
TME	Toyota Motor Europe
ED	Electrodeposition
PT	Pre-treatment
CKD	Complete Knocked Down
FIFO	First-In, First-Out
MIZU	Mizusumashi
PxP	Part by Part
MPC	Monthly Production Compilation
CBU	Complete Build Unit
AGV	Automated Guided Vehicle
FTR	First Time Right
QC	Quality Control
TR	Trimming
FA	Final Assembly
CH	Chassis
LH	Left-Hand
RH	Right-Hand
SWRS	Standardised Work Recording Sheet
ECU	Electronic Control Unit
CAD	Computer-Aided Design
KPI	Key Performance Indicator
FSO	First Sheet Order

Chapter 1

Introduction

The automotive industry continues to play a central role in the global manufacturing landscape. Although often associated with high levels of automation and mass production, there are also operations, particularly in specialised or regional contexts, where production is characterised by low volume, high variability, and strong reliance on manual processes, as the Center for Automotive Research points out in its study [6]. In such settings, maintaining consistency, quality, and efficiency presents a unique set of challenges that demand structured methodologies and close engagement with shop floor realities.

To meet these operational demands, many automotive manufacturers adopt Lean Manufacturing principles and, more specifically, the Toyota Production System (TPS). The TPS stands out not only as a framework for reducing waste and improving process flow, but also for its emphasis on human centred design, respect for people, and continuous improvement through problem solving. These principles are especially valuable in production environments where the flexibility and insight of operators are critical to maintaining quality and stability [21].

Modern manufacturing excellence also requires attention to broader factors such as workplace ergonomics, operational safety, and the ability to react to problems in real time. These goals are best achieved through a combination of structured tools, such as standardisation, visual management, and root cause analysis, and an organisational culture that empowers employees to identify and resolve issues proactively [3].

Within this context, the present project was carried out in the Final Assembly area of Toyota Caetano Portugal (TCAP), located in Ovar. The focus of the work was to analyse and improve various aspects of the production process through the practical application of Toyota Production System (TPS) principles in a real manufacturing environment.

1.1 Company Overview

Toyota Caetano Portugal, S.A. (TCAP), formerly known as Salvador Caetano IMVT – S.A. until 2006, is one of the most historic automotive companies in Portugal, originally founded in 1946.

Its early activity focused on vehicle bodywork manufacturing, a legacy that continues today within the group through CaetanoBus.

In 1968, Salvador Caetano signed an exclusive import and distribution agreement for Toyota vehicles in Portugal, marking the beginning of a long-standing partnership with Toyota Motor Corporation.

In 1971, the Ovar plant was inaugurated, becoming the first Toyota manufacturing facility in Europe. Over the years, this factory has assembled some of the brand's most recognisable models, including the Corolla, Corona, Starlet, Land Cruiser, Hilux, Hiace, Dyna, and Optimo. In addition to supplying the national market, the plant has served more than 16 export destinations.

Today, the Ovar plant is exclusively dedicated to the assembly of the Toyota Land Cruiser 70 Series, which is produced solely for export to South Africa. The production system is characterised by a low-volume, highly manual operation, with a daily output of approximately 15 vehicles. This environment places particular emphasis on standardisation, continuous improvement, and the practical application of Toyota Production System (TPS) principles, especially in the areas of safety, ergonomics, and built-in quality.

TCAP's operations are split between two main locations:

- **Vila Nova de Gaia**, which houses vehicle import, parts logistics, technical support, and the commercialisation of industrial equipment and minibuses;
- **Ovar**, home to the company's production plant and vehicle assembly operations (Figure 1.1).



Figure 1.1: TCAP, Ovar plant

1.2 Project Overview

This dissertation presents the results of an industrial project carried out at Toyota Caetano Portugal (TCAP), in the company's manufacturing plant located in Ovar. The project was developed over a five-month period and was focused on the Final Assembly area of the plant.

The primary motivation for this project was the need to enhance key operational aspects within the production line, namely **safety, quality, efficiency, continuous improvement, and standardization**. Several performance indicators and observations revealed opportunities to enhance existing processes and reduce losses, especially related to material waste, ergonomics, and lack of standardized work procedures.

To address these issues, the project was structured to deliver targeted interventions that contribute to TCAP's strategic priorities and operational excellence. The project scope was not limited to isolated tasks. Instead, it followed a systemic approach inspired by the Toyota Production System (TPS) to generate value through continuous and incremental improvement.

The main problem addressed in this project was the presence of inefficiencies and inconsistencies in the Final Assembly area, particularly those leading to **material waste and rejection, non-standardized operations**, and **ergonomic risks** for operators. Additionally, **a lack of structured visibility over the factory's value flow** limited the identification of improvement opportunities across departments.

In response to these challenges, the following objectives were established:

- Development of a complete **Value Stream Map (VSM)** of the factory to visualize process flows and identify waste.
- **Reduction of the number of glass windows discarded** during the assembly process.
- Introduction of improvements focused on **reducing safety and ergonomic risks** at workstations.
- Implementation of Kaizen initiatives supporting continuous improvement.
- Ensuring **standardization** in final assembly operations to promote consistency and quality.

The project implies close collaboration with the engineering and production teams, with a strong emphasis on field observation and cross-functional coordination.

1.3 Research Methodology

The research methodology applied in this project was developed based on the specific problems and objectives identified for the project, as outlined in the previous section. These challenges, related to value stream flows, material waste, non-standardized operations, and ergonomic risks, guided the selection of appropriate tools and approaches.

The identification of problems and improvement opportunities within this project was guided by the TPS principle of *genchi genbutsu* — going to the source to understand the actual situation. This included regular meetings with production team leaders, direct feedback from line operators, and coordination with the TPS support team to ensure alignment with local improvement needs.

Once the intervention priorities were defined and all subprojects aligned, each initiative followed a structured methodology based on the DMAIC framework (Define, Measure, Analyse,

Improve, Control). This approach provided a consistent problem solving structure across different topics and allowed for clear communication with engineering and production teams. A strong emphasis was placed on analysing and documenting the **current state** in detail, enabling a reliable foundation for comparisons with post-improvement conditions and facilitating objective assessment of impact.

After a matured assessment of the current condition, a comprehensive review of standard factory documentation was also conducted, including internal guidelines for problem solving, TPS process standards, and work instructions (EWS), ensuring that all proposed actions complied with existing norms and respected the company's operational procedures. One of the project's key priorities was to ensure that **all analyses, improvement proposals, and implementations were fully documented and standardised**, so that results could be sustained and integrated into routine operations over the long term.

A combination of TPS tools was used during the project and all improvements were validated on-site through direct observation, operator feedback, and measurable data, ensuring that results were both practical and meaningful to the organisation.

1.4 Dissertation Structure

This thesis is divided into six chapters. It begins with the **Introduction**, which provided the overall framing of the project in the context of the project at Toyota Caetano Portugal's production plant.

The **second chapter** presents the **literature review**, focusing on the methodologies related to the development and design of a Value Stream Map (VSM), including the transition towards a Future State Design (VSD). It also explores Lean tools adapted to the automotive industry context, with emphasis on the Toyota Way, the Toyota Production System (TPS), and the importance of the Kaizen mindset in promoting continuous improvement, both in product quality and in working conditions for operators.

The **third chapter** initiates the core project, with an evaluation of the general current state of the factory. This analysis serves as the starting point for the improvement actions developed in the following chapter.

The **fourth chapter** presents the main improvement initiatives carried out during the project. It is divided into three subchapters:

- **4.1 – Value Stream Mapping (VSM):** development of a factory-wide value stream map and identification of improvement opportunities.
- **4.2 – Problem Solving:** analysis and mitigation of a recurring quality and safety issue related to vehicle glass installation.
- **4.3 – Kaizen:** execution of continuous improvement actions focused on safety, ergonomics, and process stability.

The **fifth chapter** consolidates the results obtained across all three project areas, highlighting the overall impact of the project in terms of safety, quality, cost reduction, ergonomics, innovation, and working conditions.

Finally, the **sixth chapter** provides the overall conclusions and final reflections on the project experience and the project's contributions to the company.

Additional material, such as figures, technical documents, and visual elements, is provided in the appendices. These elements are structured according to the thesis layout and are essential to fully understanding the scope and outcomes of the work.

This thesis ultimately reflects the ongoing effort of the factory to build and maintain a strong and standardised operational structure, with a focus on robust processes and the consistent reinforcement of the Toyota mindset throughout the organisation.

Chapter 2

Literature Review

This chapter presents the theoretical foundations that support the work developed in this dissertation. It focuses on the methodologies related to Value Stream Mapping (VSM) and the design of Future State Maps (VSD), as well as the application of Lean tools within the automotive industry context. Core principles of the Toyota Production System (TPS), the Toyota Way philosophy, and the role of continuous improvement (Kaizen) are also discussed, with particular emphasis on their impact on operational efficiency, product quality, and working conditions. All concepts covered in this review are directly linked to the practical interventions and objectives described in the subsequent chapters.

2.1 Lean Manufacturing and the Toyota Production System (TPS)

The evolution of Lean Manufacturing is inseparable from the Toyota Production System (TPS), which laid the foundations for what would become a global reference in operational excellence. More than a set of tools, TPS represents a structured philosophy for creating value, eliminating waste, and empowering people through disciplined processes. This section outlines the historical origins of TPS and the fundamental principles that underpin its application, particularly in contexts of manual and low-volume production.

2.1.1 Origins and Fundamental Principles

Lean Manufacturing emerged as a systematic approach to process improvement, rooted in the practices developed by Toyota in the post-war period. The Toyota Production System (TPS), primarily shaped by Taiichi Ohno and Eiji Toyoda, was designed to cope with limited resources by maximizing value while eliminating waste. Over time, TPS evolved into a comprehensive production philosophy, combining technical rigor with a strong human-centered management culture [31][20].

At its core, TPS is built on two fundamental pillars: Just-In-Time (JIT) and Jidoka (automation with a human touch)(Figure 2.1). These principles are not merely operational but are embedded in a broader system that values long-term thinking, respect for people, and continuous improvement.

Unlike many Western productivity systems, TPS integrates process efficiency with organizational learning and leadership development [20][16].

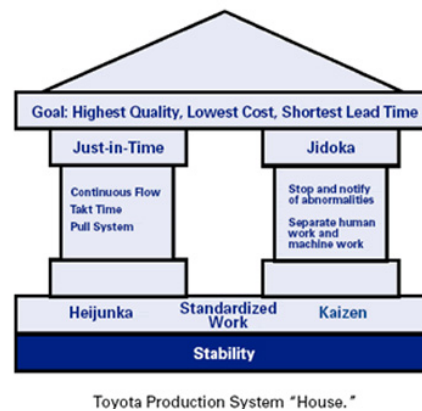


Figure 2.1: Simplified "House of TPS" diagram

Source: <https://www.lean.org/lexicon-terms/toyota-production-system/>

2.1.2 TPS in Manual and Low-Volume Production Contexts

While TPS is often associated with high volume, automated production, its principles have proven highly adaptable to manual, low-volume contexts such as those found in specialized automotive assembly. In these environments, the emphasis on flow, standardization, and visual control enables consistent performance even in the absence of complex automation [5].

Standardized work, for instance, becomes a tool not only for efficiency but for safety and learning. Even in settings where variability is high, principles like takt time and pull systems help stabilize operations and expose problems early. Flexibility within structure is key, and TPS provides the framework to maintain order in the face of frequent change [5][20].

2.1.3 Core Concepts: Muda, Jidoka, Pull, Heijunka, Stabilization

TPS is anchored in several interdependent core concepts:

Muda refers to all forms of waste, activities that consume resources without adding customer value. Toyota originally classified waste into seven types: overproduction, waiting, transport, motion, overprocessing, inventory, and defects. A commonly cited eighth waste is the underutilization of human potential, which highlights the importance of engaging employees in improvement and decision making processes [27].

Jidoka, or built-in quality, allows processes to stop automatically when a problem occurs. This prevents the flow of defects and promotes immediate problem resolution [20].

Pull production synchronizes workflow with actual demand. Rather than pushing inventory downstream, parts are only produced or moved when requested by the next process, often regulated through Kanban systems and FIFO lanes.

Heijunka (production leveling) aims to distribute workload evenly over time, smoothing out demand fluctuations and reducing mura (inconsistency) and muri (overburden) [20].

Process stabilization is achieved through standard work, takt time, and visual management. These tools form the operational backbone of continuous improvement and are especially vital in environments with high variability [18].

2.2 The Toyota Way and the Culture of Continuous Improvement (Kaizen)

Toyota's approach to excellence goes beyond processes and tools. It is shaped by a long-term philosophy known as the Toyota Way, which promotes a culture of discipline, respect, and continuous improvement across all levels of the organization.

2.2.1 Principles of the Toyota Way

The Toyota Way is the philosophical backbone of the Toyota Production System (TPS), encompassing not only tools and practices but also deeply held organizational values. Its principles are structured around two core pillars: respect for people and continuous improvement. These guide all operational decisions, leadership behaviors, and problem-solving processes [16].

A key aspect of this approach is the belief that excellence arises from the daily discipline of structured thinking, rather than sporadic breakthrough innovation. The system favors consistency and long-term thinking over short-term gains, and holds that leadership must model the behaviors expected from teams. By embedding this philosophy into daily routines and leadership development, Toyota ensures that improvement becomes a sustained, organization-wide responsibility.

2.2.2 Kaizen as a Foundational Philosophy

Kaizen, literally “change for the better”, is central to Toyota's approach to improvement. It emphasizes small, incremental changes implemented regularly by those closest to the work. This philosophy stands in contrast to Western innovation models, which often prioritize large-scale, disruptive transformations. Kaizen focuses on low-cost, low-risk adjustments that, over time, yield substantial organizational improvements [10][30].

Toyota's approach to Kaizen is methodical and deeply integrated into its training and leadership systems. As Kato and Smalley explain, Toyota's internal Kaizen development program is based on a six-step improvement cycle that includes identifying potential, analyzing current methods, generating original ideas, creating an implementation plan, executing the plan, and evaluating the outcome [12]. This structured method is not only a technical framework, but also a development tool for cultivating employee problem-solving capabilities.

Outside of Toyota, the concept of “Kaizen events”, short-term improvement workshops, has gained popularity in Western industry [25]. While these events can lead to meaningful change, they often lack the long-term developmental perspective that characterizes Toyota's internal Kaizen

practice. As noted by Martin and Osterling, the essence of Kaizen lies in developing a continuous improvement culture, not in isolated activities. True Kaizen requires consistency, leadership involvement, and integration into daily operations [19].

2.3 Lean Tools in the Automotive Context

The application of Lean thinking in industry relies on a core set of operational tools that translate its principles into daily practice. In the automotive sector, these tools have been adapted to meet the challenges of variability, complexity, and high-quality demands across both automated and manual production environments.

2.3.1 Adapting Lean Tools to the Automotive Industry

The automotive sector has played a central role in the development and dissemination of Lean practices. Originally applied in high-volume, repetitive production lines, tools such as Kanban, Andon, and Poka-Yoke were adapted to address variability and ensure quality at the source. As production systems evolved toward mixed-model assembly and shorter product life cycles, these tools were refined to maintain operational control and support rapid problem detection, even in manual, low-automation environments [4, 14].

Visual management systems like Andon have been shown to enhance line performance by making abnormalities visible and reducing response time to faults, thus improving productivity and quality assurance [8, 29].

2.3.2 Key Lean Tools: 5S, Standardized Work, Kanban, Andon, and Poka-Yoke

Among the most impactful Lean tools commonly implemented in the automotive industry are:

- **5S:** Enhances organization, safety, and productivity, widely cited as critical for efficient workplace performance in automotive manufacturing [22].
- **Standardized Work (EWS/WSS):** Creates takt-aligned work routines, serving as stable reference points for Kaizen and ensuring repeatability in operations.
- **Kanban:** Regulates material flow and prevents stockouts or overproduction, particularly in variable-demand environments.
- **Andon:** A real-time signaling system enabling operators to flag issues instantly; improves reaction time, reduces downtime, and strengthens quality culture [8, 29].
- **Poka-Yoke:** Simple error-proofing mechanisms, mechanical, visual, or procedural, that reduce human error, particularly valuable in manual operations.

These tools, when used in an integrated way, reinforce Lean principles by improving visibility, responsiveness, and standardization across manufacturing systems.

2.4 Value Stream Mapping and Future State Design

One of the most powerful tools in Lean thinking is Value Stream Mapping (VSM), which enables a structured analysis of how value flows through a process. By identifying inefficiencies and designing a more effective future state, connecting improvement initiatives to concrete operational outcomes.

2.4.1 Definition, Objectives, and Methodological Steps

Value Stream Mapping (VSM) is a Lean tool used to analyze and visualize the flow of materials and information required to bring a product or service to the customer, in a holistic way, step by step, from the customer request to the material suppliers [7]. It aims to expose inefficiencies, identify non-value-adding activities, and provide a baseline for improvement. The map represents the current state of operations and serves as the foundation for designing an improved future state [17, 19].

The VSM process typically includes the following stages: (1) define the scope and select a product family; (2) map the current state, capturing data such as process time, inventory levels, and communication flows; and (3) design the future state with a focus on flow, pull systems, and takt alignment [13].

2.4.2 Key Indicators: Lead Time, Takt Time, WIP, VA/NVA

Key performance indicators commonly used in VSM include:

- **Lead Time (LT):** Total time from order to delivery, including both value-adding and non-value-adding activities [17].
- **Takt Time:** The rate at which products must be completed to meet customer demand, calculated as available time divided by demand [19].
- **Work-in-Progress (WIP):** Quantifies in-process inventory, providing visibility into delays and bottlenecks [13].
- **Value-Added (VA) / Non-Value-Added (NVA):** Differentiates productive from wasteful steps, often visualized via process timelines [13].

2.4.3 Future State Design: Purpose and Construction

The Future State Design (FSD) is the central objective of VSM. It provides a vision of an optimized flow that eliminates waste and aligns operations with Lean principles. The future state is not an idealized end state, but rather a realistic and incremental improvement over the current process [17].

The design focuses on synchronizing production with takt time, introducing pull mechanisms, reducing lead times, minimizing inventories, and improving communication. Future state maps often challenge existing constraints and are accompanied by implementation strategies [13].

2.4.4 Kaizen Bursts and Improvement Opportunities

Kaizen bursts are visual icons placed on the future state map to highlight areas that require focused improvement. They represent specific actions or projects necessary to close the gap between the current and future states [19].

These improvement opportunities can include line balancing, changeover time reduction, layout redesign, or standard work development. Each Kaizen burst is linked to a root cause or inefficiency identified during the current state analysis.

2.4.5 Evaluation of Proposed Improvements and Feasibility

The transition from current to future state is not automatic. It requires structured planning, resource allocation, and feasibility analysis. Teams must assess the impact, complexity, and resource requirements of each proposed improvement, often using simple prioritization matrices or A3 problem-solving formats [17].

Success depends on aligning improvements with broader organizational goals and maintaining cross-functional engagement throughout the implementation process.

2.5 TPS Problem-Solving methodology

At the heart of the Toyota Production System lies a disciplined approach to problem solving. Rather than reacting to symptoms, TPS promotes structured analysis and team-based learning to uncover and address root causes. This section presents the framework, tools, and cultural foundations that support this process.

2.5.1 8-Steps structure

Problem solving in the Toyota Production System (TPS) is built around a robust and standardized methodology known as the Eight-Step Problem Solving Process, also referred to as Toyota Business Practices (TBP) or Practical Problem Solving. This approach emphasizes structured thinking, clarity of problem definition, and root cause analysis based on the PDCA (Plan–Do–Check–Act) cycle (Figure 2.2) [9, 16].

The eight steps are:

1. Clarify the Problem;
2. Describe the Current Situation;
3. Define the Target;

4. Identify the Root Cause;
5. Develop Countermeasures;
6. Implement Countermeasures;
7. Evaluate Results;
8. Standardize / Yokoten.

This sequence reflects Toyota's focus on careful planning before action, and on sustained learning and improvement after implementation.



Figure 2.2: PDCA Cycle

Source: <https://www.passionned.com/pdca-cycle/>

2.5.2 TPS tools: Ishikawa, 5 Whys, EWS

Tools such as the Ishikawa (fishbone) diagram and the 5 Whys are deeply embedded in the TPS approach to root cause analysis (Figure 2.3). These tools provide structure and depth to the process of uncovering the underlying causes of problems, ensuring that solutions target systemic issues rather than symptoms [9, 19].

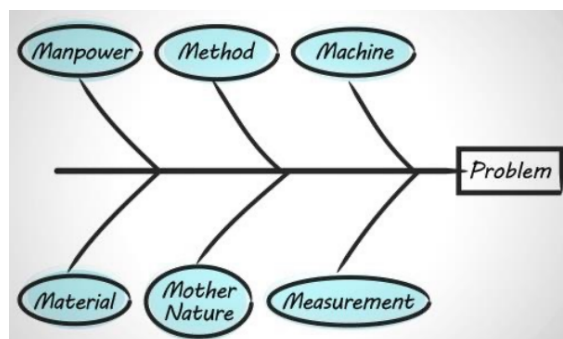


Figure 2.3: Ishikawa diagram

Source: Lecture slides from Prof. José António de Sousa Barros Basto, *Implementation of Process Improvement – 4*, F.E.U.P., 2021.

The 5 Whys technique is particularly valued for its simplicity and directness, while the cause-and-effect diagram encourages collaborative, categorical brainstorming. Additionally, standardized work (EWS – Element Work Sheets) acts as a foundation for stabilizing and sustaining improvements once solutions are implemented [26].

2.5.3 Alignment with TPS Principles

Problem solving in TPS is not a technical task delegated to specialists but a cultural expectation shared across all levels of the organization. It reinforces key TPS principles such as Genchi Genbutsu (go and see), Jidoka (built-in quality), and Kaizen (continuous improvement). Operators are expected to identify and resolve abnormalities at their level, with escalation structures in place for more complex issues.

This decentralized, structured problem solving model cultivates engagement, ownership, and learning, embedding continuous improvement in daily operations.

2.6 Improving Safety, Ergonomics, and Working Conditions

In the Toyota Production System, improving safety, ergonomics, and working conditions is not an optional concern, but a foundational element of operational excellence. These aspects are fully integrated into Lean practices and reflect Toyota's commitment to respecting people while ensuring stable, efficient, and sustainable processes.

2.6.1 Safety and Ergonomics as Pillars of Quality

Within the Toyota Production System (TPS), safety is regarded as a precondition for production. It precedes quality, cost, and delivery in priority and is explicitly considered a foundational requirement in daily operations. The principle of respect for people underlines that no improvement can be sustainable if it compromises physical safety or exposes workers to harm [1, 16].

Toyota's safety culture promotes proactive hazard identification, standardized risk-reduction measures, and visual management. Practices such as andon alerts for unsafe conditions, regular safety walks by leadership, and the enforcement of Personal Protective Equipment (PPE) reflect this systemic approach. Moreover, 5S activities frequently begin with safety-focused inspections to eliminate risks from the work environment [2].

Ergonomics is treated not just as comfort, but as a factor of operational performance. The concept of *raku*, or making work easier, exemplifies this integration: processes are designed to minimize strain, eliminate unnecessary motion, and ensure that operators can work safely, consistently, and without fatigue [23].

Tools like standardized work (EWS), visual work instructions, and adjustable workstations are applied to avoid musculoskeletal disorders and human error under stress. Even in highly manual environments, such as forklift assembly or heavy logistics, Toyota implements design principles to reduce injury risk and enhance long-term health outcomes [11].

Ultimately, safety and ergonomics are not isolated concerns but intrinsic components of TPS and Lean implementation. They support quality, flow, and employee engagement, and as such, are treated as essential elements of continuous improvement and operational excellence [24].

Chapter 3

Current Situation Analysis

Understanding the current condition of the production system is a fundamental step in any improvement initiative. Within the Toyota Production System (TPS) philosophy, analysing the present state enables the identification of inefficiencies, risks, and areas of opportunity that can be addressed through structured problem solving and continuous improvement. This chapter provides a technical assessment of the current situation at Toyota Caetano Portugal's manufacturing plant in Ovar, with particular focus on the Final Assembly area.

3.1 Overview of the Production Area

The factory operates as a continuous flow production system, in which vehicles are progressively assembled from the beginning to the end of the line. The product manufactured is the Toyota Land Cruiser 70 Series (Figure 3.1), with nine model variants derived from combinations of single and double cab configurations and several engine types. During the period under analysis, the production cadence was 15 units per day, corresponding to a takt time of 29 minutes per workstation.

As a low-volume facility with limited automation, especially when compared to other Toyota plants in Europe, the Ovar factory relies heavily on manual operations. This makes operator performance and consistency a central factor in maintaining quality and productivity. In this context, effective communication and the transfer of operational knowledge are critical for long-term performance stability.

The production line is currently in a mature stage, given that the LC70 is an established project. The operational focus has therefore shifted towards process consolidation, standardisation, and long-term sustainability, supported by continuous improvement principles and TPS methodologies.



Figure 3.1: Toyota Land Cruiser 70 series

3.2 Quality and Process Risks

One of the main risks identified in the Final Assembly area concerns quality defects introduced during operations involving fragile or sensitive components, notably vehicle glass installation. Analysis of the defect detection process showed that most non-conformities were identified only during the final inspection phase, with limited traceability to earlier process stages.

This inspection logic poses a risk to the plant's built-in quality pillar. The lack of intermediate detection opportunities allows defects to propagate downstream, leading to rework, material loss, and increased response time. The situation underscores the need for greater alignment between inspection points and operational risk, as well as process-level robustness to ensure defect prevention. These findings contrast with the TPS principle: *"I do not produce defects, I do not pass on defects."* [28]

3.3 Safety, Ergonomics and Operator Environment

Several ergonomic concerns and safety limitations were identified across different workstations in the Final Assembly area. While not classified as critical, these issues include tasks that require repetitive motion, constrained posture, or physical strain, which can negatively affect operator comfort and process stability over time.

The observed conditions highlight the importance of assessing workstation design in line with updated safety and ergonomic standards, especially considering the factory's integration into the AMAP (Any Member, Any Process) framework. Improving these aspects would contribute to a more inclusive and standardised work environment while reducing variability between operators.

3.4 System Limitations

In addition to specific process risks, the production system presents several structural limitations that constrain its ability to sustain and scale improvement efforts:

- **Lack of an updated, comprehensive Value Stream Map (VSM):** The absence of a full-system VSM limits strategic visibility and the identification of cross-functional improvement opportunities.

- **Inconsistent documentation of TPS methodologies:** Many problem-solving activities, including root cause analysis and A3 reports, are handled informally or locally. This reduces the ability to replicate successful interventions, weakens long-term learning, and increases dependency on individual experience.
- **Limited standardisation of work instructions:** Key operational knowledge is often retained by experienced workers and not formally recorded. This jeopardises process consistency and increases the risk of performance loss due to staff turnover.
- **Low digitalisation maturity:** Although digital systems could support better data collection and real-time monitoring, the current strategic direction prioritises the stabilisation and standardisation of processes before further technological integration.

3.5 Kaizen Culture and Improvement Potential

Despite the limitations observed, the plant demonstrates a strong culture of continuous improvement. Kaizen is encouraged across all levels of the organisation — from line operators to administrative teams — fostering a proactive environment in which small, incremental improvements are valued. This mindset supports the evolution of operational practices and aligns with the long-term philosophy of the Toyota Production System.

Chapter 4

Project Development

In order to respond to the needs identified in the Current Situation Analysis, a set of improvement projects was developed during the project. These projects aimed not only to address specific operational issues, but also to contribute to the factory's long-term performance by reinforcing key pillars such as built-in quality, safety, standardisation, and continuous improvement.

To ensure coherence and strategic alignment, the project followed the structure of a *Hoshin Kanri* matrix — a policy deployment tool used within Toyota to translate strategic goals into concrete actions across all levels of the organisation [15]. This matrix provided a clear visualisation of how each improvement initiative corresponded to broader priorities, established measurable targets, and defined the overall objectives of the project. It served as a central reference for organising tasks, monitoring progress, and maintaining alignment between the proposed improvements and the company's operational vision.

The matrix, presented in Figure 4.1, was developed at the beginning of the project in collaboration with the engineering team, and acted as the foundational structure upon which the improvement projects were built. It links company priorities with project deliverables, ensuring that each project addressed real factory needs while supporting Toyota's long-term vision.

This matrix helped define and structure the three main improvement axes that shaped this project:

- A factory-wide Value Stream Mapping (VSM) study to understand material and information flows;
- A problem-solving project focused on reducing quality issues related to glass windows installation in final assembly;
- A set of Kaizen actions to address safety, ergonomics, and process variability.

4.1 Value Stream Mapping Development

As stated in the literature review, Value Stream Mapping (VSM) is a key Lean tool that provides a systematic view of the production flow, from order placement to final delivery, enabling the identification of waste, improvement opportunities, and value-added vs. non-value-added activities.

At TCAP Ovar, the first task of the project within the TPS context was to develop a general VSM of the Toyota Land Cruiser Series 70, covering the full production flow from customer order (TSAM/TME Head Office, Brussels) to final delivery in South Africa (TSAM). To achieve this, it was necessary to fully understand the LC70 production process within the factory, as well as all external processes, including vehicle order placement, sales and production planning, transport of materials and components from Japan to Ovar, and final product shipment to the customer.

The construction of the VSM followed the steps below:

- Identification of the target product and its corresponding flow;
- Data collection and validation at key stages of the production process (manpower, cycle times, layouts, etc.);
- Current State Mapping;
- Identification of critical points and waste, along with improvement proposals;
- Discussion and development of the Future State Map (VSD), addressed in the Results Chapter.

4.1.1 Target Product and Flow Identification

Although simple, this initial step is crucial as it defines the approach for developing the VSM. The focus is on a complete unit of the Toyota LC70, and the analysis of material and information flow is divided into two stages. First, the internal processes at the factory are examined (welding, painting, final assembly, logistics, etc.), followed by all the external processes (planning, transportation, etc.).

While the main focus lies on internal operations, a comprehensive view of the external processes is essential to understand the factors that influence the overall lead time, making it possible to identify relationships and constraints that go beyond the physical boundaries of production and directly impact system efficiency.

4.1.2 Data Collection and Validation in Key Production Stages

The collection of relevant information for the VSM represented the most extensive and detailed stage of its development. It was based on Gemba Walks, the analysis of standard documentation, and continuous communication with line operators, Team Leaders, Group Leaders, and Engineering.

To ensure consistency, it was first necessary to define the type of data to be collected. This began with distinguishing the different production areas and identifying their main processes and subprocesses. For each, the following key elements were recorded:

- Cycle times, distinguishing value-added from non-value-added operations;
- Lead time, per station;
- Manpower, per station;
- Work-in-process (WIP);
- Inventory/stock quantities;
- Type of flow (e.g., Push, Pull);
- Layout of each production area.

Final Assembly

The first production area analysed was Final Assembly, beginning with a review of its layout and workstations. To support this, the Yamazumi file (detailing cycle times per station) and the Manpower file (showing workstation layout and worker allocation) were collected and examined. These are provided in Appendix A, Figures A.1 and A.2. Following several Gemba walks and validation sessions with the Final Assembly team, the data was obtained and represented in Appendix A, Figure A.3.

Key details from this area include:

- The entire assembly line operates at a constant speed, defined by a conveyor system to match the cycle time assigned to each station;
- All stations are arranged in series, forming a continuous line through which the complete vehicle is assembled;
- The Trimming and Chassis sub-lines operate in parallel and join at the beginning of the Final Assembly sub-line, where the cabin and deck of the LC70 are combined;
- The times used in the study reflect only **value-added activities** at each station;
- Idle stations (TR1, FA2, and TRANSFER), as well as Quality/Inspection stations (PA1, PA2, PA3), are recorded with zero value-added time;
- The line is considered to operate under a **Pull system**, as any unresolved issue in an upstream process leads to a complete line stoppage;
- Cycle times for different LC70 variants (suffixes) were weighted according to the production mix defined by planning;

- Separate time values were calculated for single-cabin and double-cabin vehicles, with an average time also considered.

As a result, all the inputs required for the construction of the VSM in this area were successfully gathered, as illustrated in Figure 4.2.

Em relação ao Lead Time	Temp. VA méd. D/C	Temp. VA méd. S/C	Média VA	Temp. VNA D/C outros	Temp. VNA S/C outros	Média VNA Outros	Temp. VNA Stocks D/C	Temp. VNA Stocks S/C	Média VNA s/ Stocks	VNA Total	Lead Time	Lead Time real
M.F. CH	74,74	75,95	75,35	70,3	69,1	69,65			0,0		145,00	348
M.F. TR	67,43	64,71	66,07	77,57	80,29	78,93			0,0		145,00	
M.F. FA	96,95	73,38	85,16	77,05	100,62	88,84	29,00	29,00	29,0		203,00	
TOTAL	171,7	149,3	160,5	147,3	169,7	159,5	29,0	29,0	29,0		348,0	
Horas (hh:mm)	2:51	2:29	2:40	2:27	2:49	2:38	0:29	0:29			5:48	
%	49%	43%	46%	42%	49%	46%	8%	8%	8%	54%	100%	

(só considera Chassi e Trimming)

WIP	12
-----	----

Process	T/M	T/L	G/L	TOTAL
Assembly	20			24
Quality Gate	3	3	1	3
Rectifier	1			1
Relief / Absent	3			3
Total in Shop	27	3	1	31

Figure 4.2: Lead time - Final Assembly

Final Inspection

Following the previous analysis, the next area to examine was **Final Inspection**, which directly follows *Final Assembly* and represents the final step before the Toyota LC70 is considered complete.

The layout of this section is simpler, as it consists of a single in-series line beginning at the last station of Final Assembly (PA3) and ending at the Rectification area, where final adjustments to the vehicle are carried out. The analysis followed the same methodology as the previous stage, resulting in the values presented in the table in Appendix A, Figures A.4, which were used directly in the VSM.

Key points to consider in this analysis include:

- As before, the five stations operate under a **Pull system**, with a defined cycle time of **29 minutes**;
- Regarding value-added classification, since inspection activities do not directly add value to the final product, only operations that physically impact the vehicle were considered — these are marked in green;
- The analysis was differentiated between single cabin and double cabin vehicles.

Welding

The welding process follows a methodology that closely resembles that of Final Assembly, where each station is assigned a defined cycle time (referred to as the takt time within the factory) to complete all required operations. It only differs from Final Assembly because it consists of **two production lines operating in parallel**.

One line is exclusively dedicated to **chassis welding**, beginning with material supply from logistics and ending with delivery to the intermediate stock area between Welding and Painting (**Night Storage**). The second line focuses on **welding the cabin and deck** of the Toyota LC70. These begin in separate areas (body and deck), and once both welding processes are completed, they merge into the **deck and body pairing** corresponding to one vehicle. These are then sent to Night Storage at the end of the Metal Finish process.

After gaining a clear understanding of the welding process through several Gemba Walks and interactions with operators and the engineering team, the necessary data for the VSM was collected and summarized in table presented in Appendix A, Figure A.9. This was supported by technical documentation such as the **Manpower/Layout** files and the complete list of times per operation (WSS), all included in Appendix A, Figures A.10 and A.11.

Painting

The painting area was the next stage analysed for the VSM, requiring a more detailed study due to specific differences compared to other areas of the factory.

Starting with the process itself, painting begins by receiving transporters carrying **chassis, deck, and cabin**, previously stored in stock (six complete units) and supplied from the welding area. The fixed input sequence is as follows: one transporter with two chassis, followed by one with a deck, one with a cabin, another with a deck, and another with a cabin, forming the complete input for two vehicles.

It is important to note that each operation is calculated per transporter; therefore, time-per-vehicle values must be adjusted accordingly. The Figure 4.3 illustrates the standard transporter input sequence in the painting area.

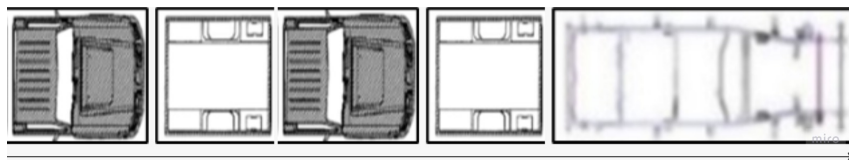


Figure 4.3: Chassis, Deck, and Cabin sequence

The three vehicle structures (chassis, deck, and cabin) initially undergo a sequence comprising **pre-wash, pre-treatment, and a second washing** phase before reaching the first painting application, which is performed by **electrodeposition (ED)**. This step provides full surface protection and results in a black coating. Upon exiting the ED tank, each structure is rinsed and passes through a curing oven with a controlled temperature and cycle time, determined by the speed of the conveyor system to which the transporter is attached. At the oven's exit, the structure reaches the **Metal Repair station**, which marks the end of the PT/ED phase.

Once this stage is completed, **the transporter carrying the two chassis is removed from the painting process** and sent to stock near the Final Assembly area, where it enters the Chassis line. From this point on, only the deck and cabin proceed through the remaining painting stages. The

process then continues to the **Sanding/PVC line**, which involves surface treatment (sanding) and application of sealants and PVC, followed by the **Topcoat line**, where the final paint colour (**white or beige**) and finish are applied.

Afterwards, the deck and cabin pass through a **final inspection and rectification stage**, before being transferred to **FBS stock**, which feeds the start of Final Assembly. Only in this last stage of the painting process do the workstations align with the factory's standard 29-minute cycle time, to synchronise with the continuous flow of the downstream assembly processes.

This detailed breakdown of the painting stages was necessary due to the following factors:

- The need to establish cycle times per vehicle, consistent with the global VSM approach;
- The PT/ED section operates as a **continuous line**, with varying cycle times across tanks and stations, and follows a production logic equivalent to two vehicles at a time;
- There is a functional **split in the vehicle flow mid-process**, requiring the VSM to follow the longest path (deck and cabin);
- Intermediate stocks are formed due to cycle time differences across operations, which must be accounted for in the analysis.

To define accurate cycle times and collect the required inputs for the VSM, the analysis was supported by technical documentation such as the **Paintshop Layout, Manpower files, and Work Step Sheets (WSS)** for each workstation. Examples are included in Appendix A, Figures A.5 to A.7. Additional assumptions were made with the support of the engineering team assigned to the painting area, ensuring alignment with the data structure used in the other sections:

- The initial Night Storage was considered to hold a standard stock of 6 complete units, corresponding to 3 sets of 2 chassis, 6 decks, and 6 cabins;
- For the PT/ED section, the cycle time per vehicle was defined based on the pre-wash time (25 minutes), since the line operates as a **Push system**, and the tank times are significantly shorter. The 25 minutes derive from 10 minutes per transporter, totalling 50 minutes for two vehicles. As the **bottleneck** is the pre-wash operation, it was confirmed on-site that tanks may remain idle at times;
- Whenever cycle time changes occur between stations or processes, a stock is either **consumed or accumulated**, and must be reflected in the mapping;
- For the Sanding/PVC and Topcoat lines, such specific considerations are no longer required, as the chassis transporter is no longer part of the system at that stage.

It was therefore possible to obtain the results presented in the Table presented in Appendix A, Figure A.8.

The time values were defined for each of the painting lines and their respective operations/stations, with distinctions made between single cabin and double cabin models. Stock levels were represented based on the initial production moment, as intermediate inventories tend to shift between stations depending on their cycle times.

With this, the remaining key data required for the VSM, including lead time, WIP levels, and number of operators, was successfully gathered, as shown in Figure 4.4.

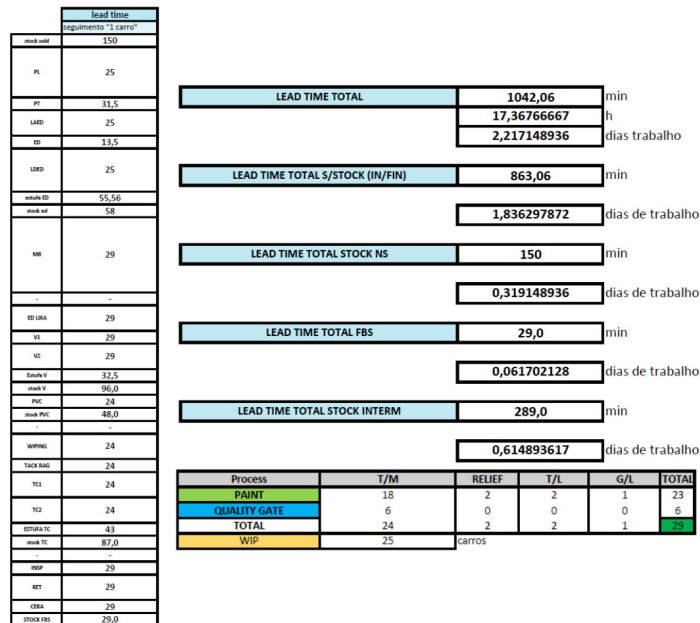


Figure 4.4: Lead Time - Painting

Logistics

With all Toyota LC70 production processes defined and the relevant data collected and processed, the final step in analysing the **internal factory flow** was to assess the contribution of the Logistics area to the construction of the VSM.

The internal logistics system is divided into **Welding, Final Assembly (comprising Trimming, Final Assembly, and Chassis lines), and Forklift operations**. Within this structure are included key support processes such as CKD unpacking, picking and delivery by Mizusumashi, and all tasks performed by forklifts throughout the plant.

As a support area that does not add value to the product directly but is essential to ensure continuous flow in production, it was important to identify logistics processes that **trigger the start of production**, and to measure the total logistics time per vehicle. This time is considered **non-value-added** within the VSM framework.

The following processes were therefore analysed:

- Supply, unpacking and picking of material for the **Welding area** (starting point of the production line);
- Unpacking and picking for the **Chassis line in Final Assembly** (starting point for that area).

These analyses allowed for the identification of logistics cycle times relevant to the VSM, as summarised in table presented in Appendix A, Figures A.12 and A.13.

Interface with External Stakeholders

To conclude, it was necessary to collect information related to the processes that occur **outside the factory**, specifically the flow of incoming materials to TCAP Ovar and the handling of the finished product (Toyota LC70) in relation to its delivery to the customer.

This required coordination with the **Purchasing and Sales departments**, as well as the **Production Planning team**, resulting in the conclusions presented in Appendix A, Figures A.14 and A.15.

4.1.3 Current State Mapping

This section presents the mapping of the current state of the VSM, following the definition of the product and data collecting and validating it throughout the main phases of the production process. The objective of this mapping was to provide a clear and structured view of how material and information flow, currently, in the production system, ensuring an accurate representation of the existing conditions.

In order to ensure a standardized and clear visual communication, the Value Stream Map was developed using conventional VSM symbols aligned with Lean manufacturing methodology, providing a consistent language for representing both material and information flows across the value stream. The most used icons can be seen in Figure 4.5.

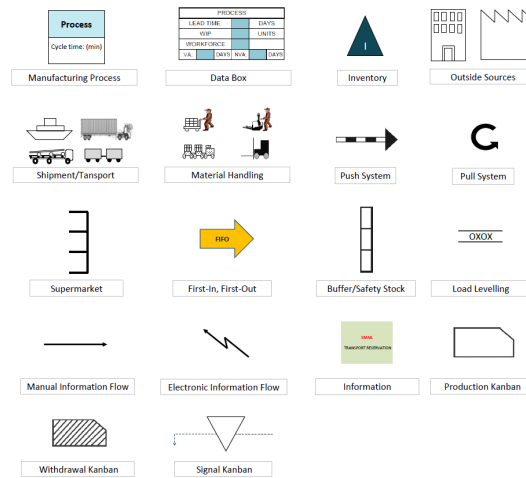


Figure 4.5: VSM icons, used in mapping

Mapping the Internal Production Flow

Firstly, the map was created focusing on activities within the factory, including all key process steps, from CKD storage and unpacking to final inspection and repair. This map aims to illustrate work-in-progress units, stocks, cycle times, lead times, workforce and flow of information between stations and control departments.

An overview of the internal production flow, including the initial VSM representation, can be found in Appendix A, Figures A.16 and A.17.

As illustrated in the Value Stream Map (VSM), the internal production process begins with the unpacking of CKD (Completely Knocked Down) components, following a storage period. These components are stored in a supermarket area until required downstream. The **Kanban system** at the beginning of the production line is linked to the consumption of empty dollies, meaning that once a dolly is emptied (typically in line with the defined cycle time of 29 minutes), material replenishment is triggered following a **First-In, First-Out (FIFO)** methodology.

The process continues with the **welding process**, which includes Body, Deck, Frame Welding, and Metal Finish & Inspection, and after these steps, **six units are stored as safety stock** in the **Night Storage** area. To be noted that within the Metal Finish process, the Kanban signal refers to specific components such as doors, hoods, grilles, and others, which are supplied into the line in batches of five units.

This is followed by the **painting process**, which comprises several stages and includes intermediate inventories resulting from differences in cycle times across operations (e.g. Sanding and PVC). Unlike the welding area, in which the processes operate on a **Pull system**, the material flow in painting follows a **Push system**. Additionally, a supermarket is maintained for painted grilles and trims, which are supplied in batches of seven units for the final assembly. A **FIFO-controlled stock area for chassis** is positioned at the output of its painting section, enabling scheduled feeding into the final assembly line according to the production plan. Finally, the painting process

concludes with the "**Wax and FBS**" storage area, which supplies Bodies and Decks to the initial stages of final assembly using a **Pull approach**.

Similarly to the welding process, **final assembly** operates with a Kanban system based on dolly consumption. Two dollies are assigned for their position in the workstation, one actively supplying parts and the other being refilled through a picking process and then returned to the station by the **Mizusumashi routes**.

Once the final assembly process is completed, which includes trimming, chassis, and final assembly, all entirely **Pull-driven**, the vehicles proceed to the inspection and rectification line. After approval, they are transferred to the **yard area** following a **Push logic** at this final stage of the process.

The VSM also details the entire **information flow** related to production control and planning, including **production sequencing**, **daily reports**, and **sequence change instructions** sent to the respective area offices. It also maps all supporting data flows handled by **Process Engineering**, **Quality Control**, and **Warehouse** departments, integrated within the **SAP system**, with information specific to each unit. To be noted that in the VSM it is highlighted every **scanning checkpoint** along the process, where the vehicle model and its production sequence are verified, ensuring validation and traceability across the line.

Mapping the Inbound Flow from Suppliers

The inbound logistics illustrated on the left-hand side of the VSM represent the structured sequence in which CKD (Completely Knocked Down) components and related materials are sourced from external suppliers, packed in Japan. This flow covers both the **physical transport of materials** as well as the **information exchange** that supports planning, ordering, and inventory control. This part of the VSM is illustrated in Appendix A, Figure A.18.

Material Flow: The material flow begins with CKD production and packing at the supplier's location (Japan), followed by international sea transport and national handling. The entire lead time from the supplier (order) to the factory (CKD arrival) is approximately **90 to 100 days**, distributed as follows:

- CKD order: **15 days**
- CKD production and packing: **1 day**
- Transport to port: **1 week**
- Sea travel: **approximately 65 days**
- Transport to TCAP: **5 days**

Once the materials are received into the warehouse, they are temporarily stored (up to **16 days**) before being unpacked and beginning the process. The storage area usually holds a stock equivalent to **120 to 180 units** in CKD, due to the long lead time between ordering CKD and receiving it at the factory. This buffer helps prevent any production interruptions caused by material shortages.

Information Flow: The information flow and the entire order planning is guided by a **Getsudo Flow**, a structured multi-phase scheduling framework based on **backward planning principles**. It enables early material ordering while maintaining flexibility for later confirmations. The process is divided in three steps:

Capacity Calculation (D-4): An initial assessment of **production capacity**, **stock levels** and **takt-time based constraints**. This step establishes the foundation for material planning.

FSO1 – Preliminary Planning Phase: This step consists of early planning and communication with suppliers:

- D-16: Reception of CBU (Complete Build Unit) orders from the customer (TSAM and TMC);
- D-14: Placement of preliminary CKD and PxP orders based on forecasted requirements;
- D-11: Feedback and adjustment phase, allowing revision of the initial order plan.

FSO2 – Confirmation Phase: This final step is fully integrated into the SAP system, formalizing the production plan:

- D-10: Final confirmation of CBU order volume;
- D-9: Final confirmation of CKD and PxP orders and conclusion of the MPC (Monthly Production Compilation).

Although the capacity calculation begins at D-4, earlier steps such as D-16, D-14 and D-11 are initiated in advance for upcoming production periods. In practice, while the plant is at D-4 for one planned week, it is simultaneously handling earlier planning steps for future weeks.

Information throughout this process is exchanged via **SAP**, **Excel-based planning files** and **e-mail**, depending on the supplier systems.

Outbound Flow to Customer

The outbound flow of finished vehicles is illustrated on the right-hand side of the VSM, representing the logistical and informational processes involved in transporting CBU's from the end of the internal production line to the final customer, TSAM, located in Durban. This part of the VSM is illustrated in Appendix A, Figure A.19.

Material Flow: After successfully passing final inspection and being approved, vehicles are transferred to the yard where they remain for approximately **2 days** before beginning the final transport to the client. This transport involves two stages:

- Transport, by truck, from the plant to the port (Santander Seaport) – **2 days**;
- Shipping from port to Durban (TSAM), via sea freight – **approximately 20 days**.

This results in a total lead time of **24 days**.

Information Flow: The outbound flow is supported by an **information exchange framework**, granting the vehicle delivery is synchronized with customer requirements and shipping constraints. The **TCAP Sales Department** operates as the coordination hub between production and distribution, gathering and combining vehicle order data, shipping schedules and transportation reservations, via **SAP**, **Excel files** and manual communication. This includes:

- **Shipping plans and schedules**, defining vehicle batches per shipment;
- **Reservations** with transportation companies (RODOCARGO, WALLENIUS WILHELMSEN);
- **Invoices and Shipping Confirmations** with TME (Toyota Motor Europe) and TSAM.

Full Value Stream Map

Finally, the full Value Stream Map is presented in its complete form in Figure 4.6. This consolidated view brings together all relevant **material and information flows**, **cycle and lead times**, **inventory levels**, **planning systems**, and **coordination points** across the supply chain.

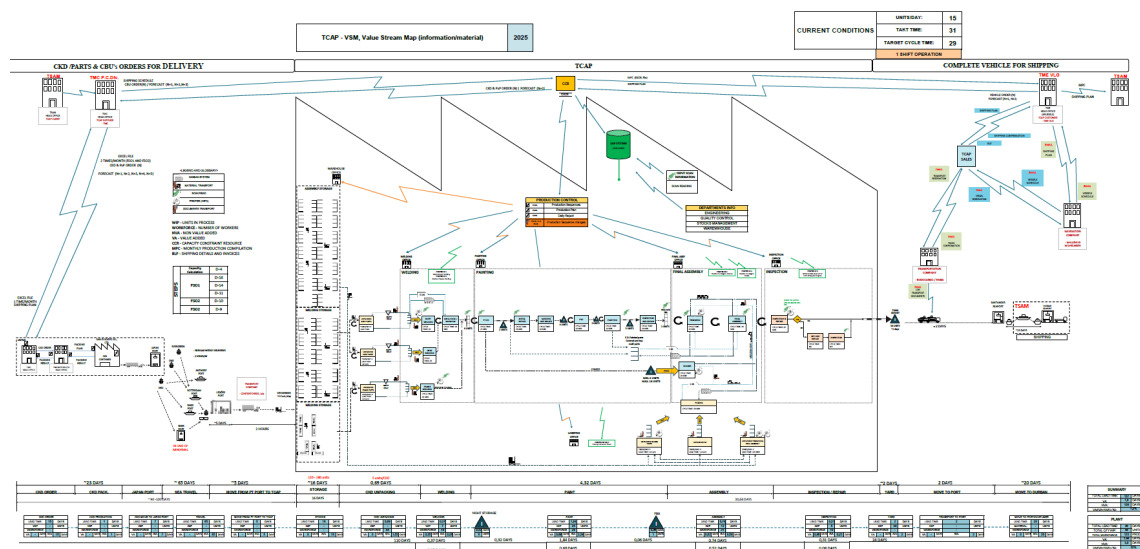


Figure 4.6: VSM - full version

Up to this moment, there are some KPI's that can be highlighted:

- **Total Lead Time** for a vehicle, since order to delivery – 137 days;
- **Total Lead Time, in TCAP** – 20 days (16 days in warehouse and 4.3 days production);
- **Total WIP, in TCAP** – 49 units;
- **Total Added Value** – 1.64 days;
- **Total Non-Added Value** – 3.5 days;
- **Value-Added Ratio** ($VA/(VA+NVA)$) – 32%, meaning that only a third of the total processing time effectively contributes to product value from customer's perspective;
- **Total Stocks Time**: 17 days.

This Value Stream Map serves as the baseline for identifying improvement opportunities and will support the development of the future state map discussed in the following chapters, in line with the continuous improvement principles of the Toyota Production System.

4.1.4 Analysis of Critical Points and Improvement Opportunities

Based on the current state map and the observations gathered throughout the value stream analysis, this section identifies key areas with **improvement potential** across the production process. Each improvement opportunity is presented using **Kaizen Bursts**, visually placed on the current state VSM to highlight the critical zones. The current state VSM was displayed on a wall at the Process Engineering Office, and inputs on improvements were given, as shown in Appendix A, Figure A.20. These will form the foundation for the definition of the **Value Stream Design**, future state map, aligned with Lean and TPS principles.

Each Kaizen Burst is described according to:

- The identified problem;
- Its impact on the process;
- The corresponding proposed improvement.

The list below presents all key improvement points identified, used as Kaizen Bursts in the future state map.

Kaizen Burst 1 – “Reduce transport time from Japan – seek faster alternatives”

- **Identified Problem:** Long international transport lead time from Japan to the plant (65 days), affecting responsiveness.
- **Impact:** Affected responsiveness, reduced flexibility in reacting to demand changes or supply issues and high inventory levels.

- **Proposed Improvement:** Analyze/update faster or more direct shipping alternatives.

Kaizen Burst 2 – “Avoid opening CKD without near-term use of all 5 units”

- **Identified Problem:** CKD is opened even for the less produced models, when the complete set of 5 units is not expected to be used in a short term.
- **Impact:** Accumulation of unused parts, leading to storage ageing and potential degradation, and limitations in supermarket layout optimization.
- **Proposed Improvement:** Improve planning to avoid opening CKD unless full consumption is scheduled in a short term (add this constraint).

Kaizen Burst 3 – “Increase FBS stock – avoid Final Assembly line stoppages”

- **Identified Problem:** The Final Assembly line experiences line stoppages due to an inconsistent flow of vehicles from the painting area.
- **Impact:** Unplanned line downtime, affecting production stability in Final Assembly.
- **Proposed Improvement:** Increase FBS stock level (currently 2) to ensure a stable car flow from Painting to Final Assembly.

Kaizen Burst 4 – “Improve chassis logistics and transport – ensure sequence flexibility”

- **Identified Problem:** Chassis are stored in pairs after the painting area. Manual handling of heavy chassis transporters.
- **Impact:** Sequence changes can cause delays and occasional line stoppages. Manual handling increases ergonomic risk.
- **Proposed Improvement:** Improve chassis logistics to allow sequence flexibility and explore automated transport alternatives, e.g., AGVs.

Kaizen Burst 5 – “Repurpose idle stations in trimming/assembly line”

- **Identified Problem:** Unused workstations in trimming and final assembly, located within a continuous-flow line, which prevents their removal or rearrangement.
- **Impact:** Space is underutilized, leading to layout inefficiencies and missed opportunities for process optimization.
- **Proposed Improvement:** Assess potential to repurpose the stations for other activities (e.g., repairs) or expand adjacent workstations to improve ergonomics and process flow.

Kaizen Burst 6 – “Reduce dependence on rectification – improve First Time Right (FTR)”

- **Identified Problem:** Vehicles are not approved directly at inspection, requiring rectification before final acceptance.
- **Impact:** Additional time and resources are consumed in rework, reducing overall process efficiency.
- **Proposed Improvement:** Reinforce Built-in Quality practices during assembly to reduce defects at source and increase FTR, aiming to reduce reliance on rectification.

Kaizen Burst 7 – “Enable real-time shop floor data collection - digitalisation”

- **Identified Problem:** There is no real-time data collection from the production line back to departments, such as Engineering, Production and Logistics
- **Impact:** Slow and sample-based data collection limits the frequency and accuracy of process analysis, and delay in reaction to changes in process.
- **Proposed Improvement:** Enable real-time data collection from the shop floor through digitalisation.

Kaizen Burst 8 – “Balance painting cycle times – reduce intermediate stock”

- **Identified Problem:** Different cycle times across painting processes result in intermediate stocks along the line.
- **Impact:** Increased WIP and space occupation in the painting area.
- **Proposed Improvement:** Assess the feasibility of implementing continuous flow solutions (e.g., conveyor systems, like final assembly) to reduce intermediate stocks.

The identified improvement opportunities were mapped onto the current state VSM in the form of Kaizen Bursts, as shown in Figure 4.7.

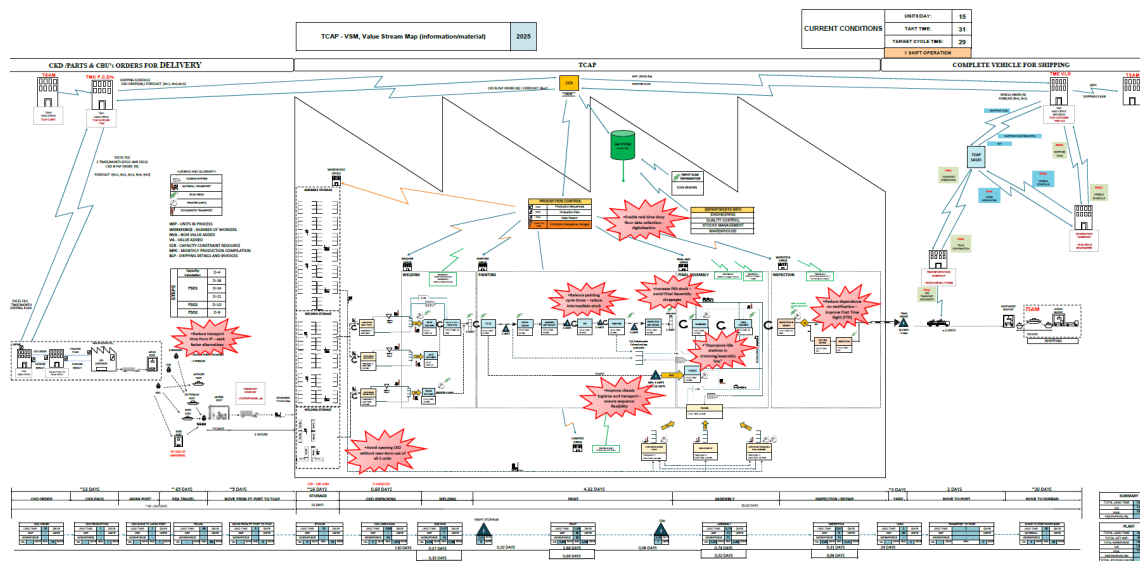


Figure 4.7: VSM with Kaizen Bursts

This consolidated map will be the base for the **Future State Map**, guiding the definition of **realistic and impactful improvement scenarios**, identifying these opportunities and converting them into **actionable improvement plans** within the production system.

4.2 Problem Solving in Front Side Window Defects

This section presents a practical application of the TPS problem-solving methodology in response to a recurrent quality issue identified on the vehicle assembly line. The focus is placed on defects affecting the front side windows, which served as a real world case to apply structured root cause analysis and continuous improvement principles. The project illustrates how Lean thinking can be translated into concrete actions on the shop floor, linking systematic investigation with measurable operational results.

4.2.1 Introduction to the Problem

This project addresses the occurrence of defects detected on the outer surface of the front side windows during the vehicle assembly process. These defects, most commonly identified as fine scratches, were classified as **non-conformities** during final inspection and frequently resulted in the rejection and replacement of the affected glass. The presence of such defects had a direct impact on **production efficiency**, increased **internal costs**, and the **perceived quality** of the final product.

The issue, although persistent over time, had not been previously investigated using a **structured and data-driven approach**. It was formally highlighted during a regular production meeting (*Seri-ichi*), prompting the launch of a dedicated problem-solving initiative. At that point, no

formal records or standardized data collection methods were in place, which made identifying the source and frequency of the defect particularly challenging.

This case forms part of the broader scope of the thesis, which focuses on the application of **Toyota Production System (TPS)** methodologies in an industrial context (Figure 4.8). It represents an opportunity to apply TPS principles, such as **problem definition**, **root cause identification**, **standardization**, and **continuous improvement** through a practical intervention aligned with real production needs.

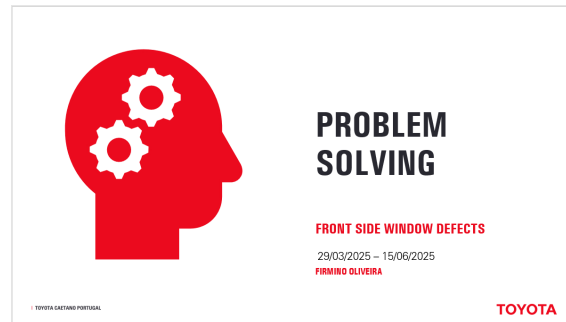


Figure 4.8: Problem Solving - TCAP, Ovar

4.2.2 Methodological Framework

The approach adopted for this project is based on the **8-step Problem Solving methodology** developed and widely applied within the **Toyota Production System (TPS)**. This structured method supports continuous improvement by guiding teams through a logical progression of problem clarification, root cause analysis, countermeasure development, and standardization of successful solutions. It emphasizes **direct observation (Genchi Genbutsu)**, team collaboration, and the use of visual and analytical tools.

The eight steps followed throughout the project are as follows:

- Clarify the **Problem**;
- Describe the **Current Situation**;
- Define the **Target**;
- Identify the **Root Cause**;
- Develop **Countermeasures**;
- **Implement** Countermeasures;
- Evaluate **Results**;
- **Standardize** / Yokoten.

This method aligns closely with TPS values such as **kaizen** (continuous improvement), **ji-doka** (built-in quality), and **respect for people**, particularly through close involvement of shop floor operators in the development and testing of countermeasures. It also promotes the use of supporting tools such as **5 Whys**, **ishikawa diagrams**, and **standard work forms**, all of which were integrated into this project where relevant.

Although conceptually similar to the **DMAIC** (Define, Measure, Analyze, Improve, Control) methodology used in Lean Six Sigma, the 8-step structure was selected due to its direct alignment with Toyota's internal practices and its formal adoption in TCAP. The execution of this project followed this sequence, and the structure of the following sections reflects the logical order of these eight steps.

4.2.3 Step 1 – Clarifying the Problem

The specific non-conformity addressed in this project was the presence of **surface scratches** on the **outer face of the front side windows** (Figure 4.9). These scratches were considered defects when they could be felt with a fingernail, according to the established quality criteria. Their classification as non-conformities led to the **rejection and replacement** of the glass, generating internal cost and operational disruption.



Figure 4.9: Window Rejected - Markings from station "P"

Although already mentioned in internal discussions, the issue had not previously been analyzed or addressed using a structured approach. Detection points were not only the final **Quality Control (QC)** station, but the scratches were also being identified earlier in the process: within the trimming area, both at the **TR3 workstation** and the **“P” quality checkpoint**, and even at the logistics stage during the picking and handling of the windows, although not registered. While “P” is not formally part of the Inspection line, it functions as an **intermediate quality gate** within

the assembly flow. Its main purpose is to detect potential issues as early as possible, helping to prevent defects from going down the line and concentrating detection only at the final stage.

The clarification of the problem involved understanding **where and how the defect was being detected**, confirming the **evaluation criteria used**, and recognizing the need to implement a **consistent and reliable data collection system** to support the next stages of investigation and resolution.

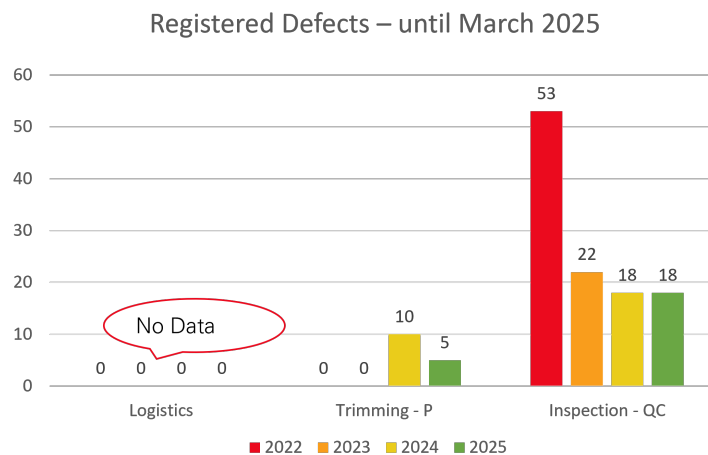


Figure 4.10: Data collected - Defects

As shown in Figure 4.10, the only data available at the start of the problem-solving process referred to overall scratch detections from 2022 onward, with records limited to the trimming area (“P”) and final inspection (QC). Although defects were also being detected in Logistics, no data was formally recorded at that stage.

4.2.4 Step 2 – Describing the Current Situation

A clear understanding of the existing process was essential to identify the conditions under which the surface scratches were appearing. To achieve this, a **comprehensive process mapping** was conducted, supported by visual documentation of each stage in the handling and assembly of the front side windows.

A **swim-lane diagram** was developed to represent the complete lifecycle of the windows, from their unpacking in the logistics area to the final quality approval of the vehicle (Figure 4.11). This visual tool highlights responsibilities across the different functional areas: Logistics (Log), Assembly (Assy), Inspection (Insp), and Rework (Rep), clarifying where the glass is manipulated, inspected, accepted or rejected throughout the process and how it is handled in case of abnormalities.

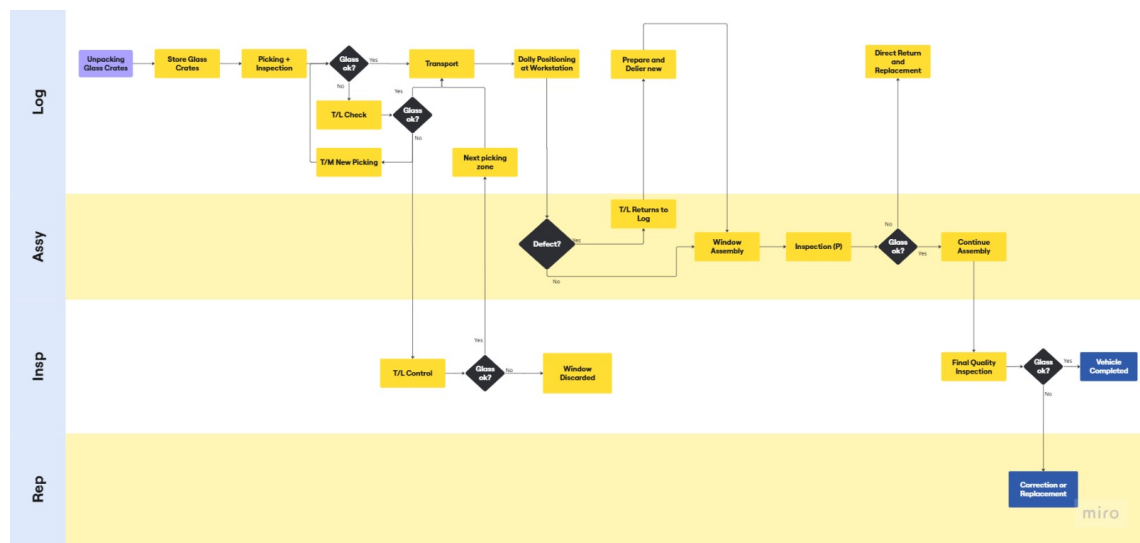


Figure 4.11: Process flow and decision points in the handling and inspection of front side windows.

In parallel, photographs were taken to document the actual working conditions and handling practices prior to the implementation of the study.

Logistics

The first handling of the glass occurs in the Logistics area, where windows are unpacked from their original shipping crates. This is the point at which the glass **leaves its supplied condition**. Once a window is picked, it undergoes an inspection to confirm its quality as received from Japan. Afterwards, the window is placed onto internal transport dollies, with the outer face positioned against the dolly's inner structure.

Although a visual inspection was performed, there was no formal cleaning procedure in place. The inspection relied on **non-ideal lighting conditions and subjective operator judgement**. Additionally, **no data was recorded** for any defects detected at this stage, highlighting several improvement opportunities.

For visual reference, these are represented in Appendix B, Figures B.13 to B.15, which illustrate the unpacking, inspection, and dolly loading operations.

Transport

During internal transport (Mizusumashi), the windows **remain stored on the dollies**. The outer side of the glass, which is oriented inward toward the dolly structure, stays exposed to potential damage throughout the entire transport process. This face of the glass is in **close proximity to other stored parts and surfaces**, increasing the risk of accidental contact. Additionally, some dollies showed **visible signs of wear and lacked sufficient protective padding**, which may have been a contribution to the appearance of scratches.

For reference, in Appendix B, Figures B.16 and B.17, it is illustrated the typical dolly configuration and condition at the beginning of the study.

Trimming Area (Final Assembly)

Once on the line, the glass is first handled in the trimming area, specifically at station TR3, where the **initial installation and movement inside the door take place**, being one of the first high-risk stages in terms of physical contact. The door structure is already partially assembled, and the window is positioned inside the frame for tightening and verification of fitment and movement.

At this point, **there is no protection between the glass and the surrounding elements**, not only the internal door components, but also the door frame itself. Since the door is still in a bare metal state, the sharp edges around the glass channel represent critical contact points that increase the likelihood of scratching during handling and assembly.

After the glass is installed, a second checkpoint exists at station “P”, a designated quality control point prior to the next step in the final assembly line. A brief visual and functional inspection is performed here; however, **when defects are identified, they are not formally recorded**. The only established procedure in such cases is the replacement of the window.

It is important to note that after the check at station “P,” the window remains **fully lowered inside the door until the vehicle reaches the final inspection area**. It is only raised again at the QC station for a last visual inspection, meaning no defects can occur during this intermediate period.

For visual reference, in Appendix B, Figures B.18 to B.24, it is illustrated the installation at TR3, the bare door frame condition during installation and inspection at P.

Final Inspection

After passing through the entire Final Assembly line in the lowered position, a **more detailed inspection takes place at the Quality Control station (QC1)**, where the window is inspected from both the interior and exterior sides of the glass. It is at this point that the **majority of defects were being detected**, as scratches became clearly visible under proper lighting and in the final context of the fully assembled product.

As a result, any rejection at this stage leads to complete removal and replacement of the window, generating additional rework, delays, and internal cost.

For visual reference, in Appendix B, Figures B.25 and B.26, it is shown the inspection setup and the typical glass position during the final quality check at QC1.

The mapping and analysis of the current process provided a clear understanding of how the front side windows are handled across the different stages of production, serving as a foundation for guiding the next steps of the structured problem-solving approach.

4.2.5 Step 3 – Defining the Target

In order to ensure a clear and structured problem solving direction, the project objectives were defined across three levels: **global, logistics, and assembly**. These levels are illustrated in Figure 4.12, which outlines the hierarchy and scope of each objective.

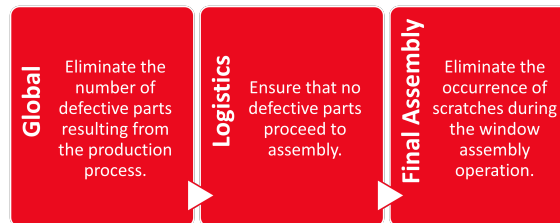


Figure 4.12: Structured project objectives by scope

This layered objective structure provided clarity to the investigation and served as a reference for evaluating results in each area as the project progressed.

4.2.6 Step 4 – Identifying the Root Cause

Before implementing any countermeasures, it is essential to **identify the true root causes of the problem**. Addressing only the symptoms may result in partial or temporary solutions, whereas a proper root cause analysis allows for the development of effective and sustainable actions that directly impact the origin of the defect.

To conduct this analysis, the full flow of the front side windows, previously mapped in this study, was reviewed step by step and, together with team leaders and shop floor operators, a brainstorming effort was carried out to identify all possible factors that could contribute to the occurrence of surface scratches throughout the process. This initial investigation focused on practical knowledge and real working conditions observed in each workstation.

The causes identified were organized using an **Ishikawa Diagram** (Figure 4.13), grouping them into five categories: **Material, Man, Environment, Method, and Machine**. This visual tool allowed the team to consolidate observations and highlight potential weak points in the process.

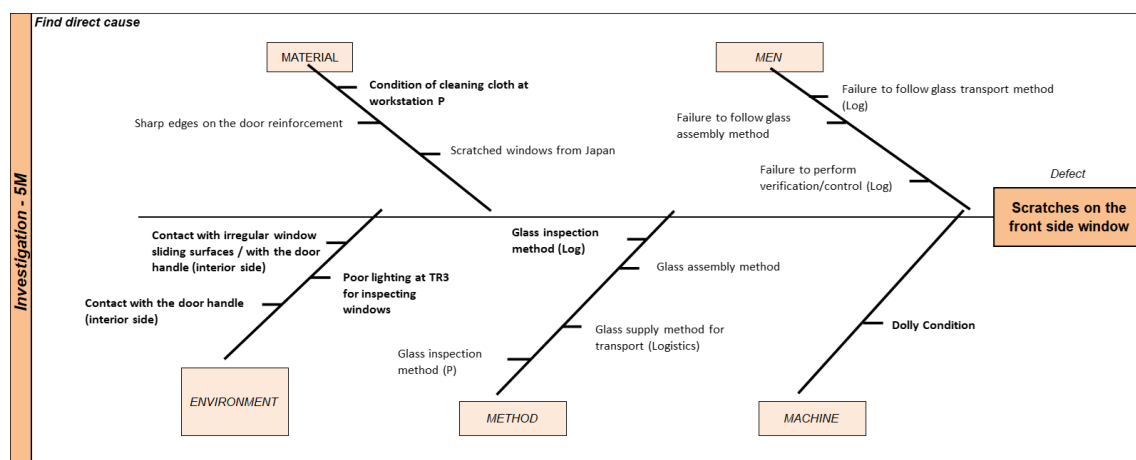


Figure 4.13: Ishikawa Diagram with potential causes of surface scratches on front side windows.

Following this identification, a review session was held with the group leader from the final assembly area to **analyse all the causes identified**. The goal was to prioritize the most critical ones, those that most directly explained the defect or had the highest impact on the process.

Once the key causes were selected, the **5 Whys method** was applied to each one of them, to dig deeper and distinguish between current symptoms and root causes. This analysis also helped to define the most appropriate zones for implementing countermeasures later in the project as well as defining a priority in which they should be addressed, shown in Figure 4.14.

Find root cause							
Investigation - 5 why	Direct Cause	Why?	Why?	Why?	Why?	Why?	
	Condition of cleaning cloth at workstation P	The cloth may cause light scratches on the glass	The cloth may contain particles that lead to scratches	The cloth is not cleaned or replaced regularly	There is no maintenance plan for the cloth's condition	No maintenance plan for the cloth's condition	2
	Dolly Condition	The glass can be scratched by components inside the dolly	The glass is facing components inside the dolly	There is insufficient protection between the glass and the components		Insufficient protection inside the dolly	3
	Contact with irregular window sliding surfaces / with the door handle (interior side)	The glass can be scratched upon contact	There are areas unprotected			Lack of protection on the outer side of the glass inside the door	1
	Poor lighting at TR3 for inspecting windows	The operator checks the glass after removal, in a poorly lit area	There is no designated area for visual inspection			No dedicated area for glass inspection at TR3	5
	Glass inspection method (Log)	The glass is inspected but scratches may go undetected	The glass is not fully clean during inspection / Poor light conditions	No cleaning is performed before and after inspection		No cleaning is performed before and after inspection (Log)	4

Figure 4.14: 5 Whys analysis applied to the main causes.

The combination of shop floor collaboration, technical review, and structured analysis tools provided by TPS ensured a comprehensive understanding of the defect's origin, forming the basis for the following improvement actions directly applied to the root causes, as described in the following sections.

4.2.7 Step 5 – Develop Countermeasures

Once the root causes had been clearly identified and prioritised, the next step consisted of **developing appropriate countermeasures** to address each of them directly. In this phase, no action was implemented yet, the focus was on designing solutions that were technically feasible, aligned with the production environment, and supported by TPS, and developed with direct inputs from operators.

Planning countermeasures plays a fundamental role in structuring a problem solving approach, defining the path towards root cause elimination and ensuring alignment with the project's targets, providing a **solid reference for follow-up and evaluation**. Moreover, it allows the actions to be sequenced in a logical, coordinated, and timely manner. The countermeasures were structured across different areas of the process: logistics, assembly, and inspection, and distributed over a defined time window (**the entire month of April**), with clear milestones. Planning was carried out

in close collaboration with team leaders, operators, and supporting departments, ensuring realistic execution and field validation.

The implementation plan was formalised in the form of a **Gantt chart**, as seen below, which summarises the timeline of each action, including phases of analysis, development, implementation, and monitoring.

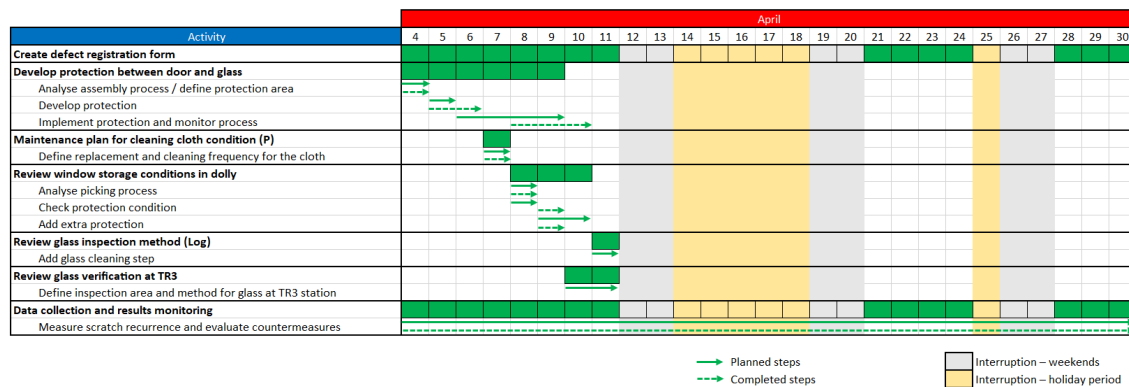


Figure 4.15: Countermeasure implementation plan by area and activity timeline (April 2025)

Although the majority of the planned activities were completed within the expected timeframe, **two actions required adjustments**.

The first one was **the Review of the glass verification method at TR3**, which was ultimately not carried out. After discussions with team leaders and the group leader of final assembly, it was concluded that, by providing a robust inspection process ensured in Logistics, a simple and quick verification at TR3, as already in place, would be sufficient. Once all countermeasures were implemented, the risk of scratches occurring between Logistics and final installation was considered negligible, therefore, a second inspection step would only duplicate effort without adding value.

The second deviation was about **the Review of the inspection method in Logistics**, which was not concluded within the initial planning window due to delayed arrival of necessary materials, meaning that the required components could only be installed at the end of May and beginning of June. To ensure robustness during this transitional period, a temporary control measure was implemented: team leaders performed a parallel inspection at the TR3 station on all windows until the end of the first half of May. This served as a safeguard to confirm that the logistics inspection process was functioning correctly and that no defective parts entered the assembly line.

These adjustments reflect the **flexibility and responsiveness of the planning process**, ensuring that countermeasure implementation remained aligned with quality objectives, even in the face of unforeseen constraints.

4.2.8 Step 6 – Implement Countermeasures

Following the structured planning phase, all countermeasures were implemented progressively across the process. Each action was designed to address each specific root cause previously identified, ensuring a targeted and effective approach to the problem solving.

The implementation was carried out in close contact with the production environment, involving direct testing, operator feedback, and visual confirmation of results. In some cases, solutions were tested in stages and adjusted before full deployment, ensuring the countermeasures were not only effective in theory, but also **practical and sustainable** under real shop floor conditions.

Defect Registration Form

Firstly, to address the **absence of structured data regarding scratch occurrences**, a monthly defect registration sheet was developed and introduced for the assembly process (Figures 4.16 and 4.17). This tool allows for the collection of detailed data on defect occurrence and location, enabling both traceability and future analysis, particularly important for monitoring the effectiveness of each countermeasure implemented.

This form/sheet includes the following features:

- Separation between single-cabin and double-cabin vehicles;
- Distinction between left or right side windows;
- Operators register the defect by marking the affected area directly on the schematic;
- Each defect is categorised by the station in which it was detected (TR3, P, QC);
- Updated monthly (sheet).

This approach not only **standardises** the way information is recorded, but also supports root cause tracking and allows for statistical evaluation of defect trends over time.

Folha de registo de Defeitos	2025
Montagem	Abril
Riscos - vidro da frente	

Verde - Processamento T&E

Azul - Processamento P

Vermelho - Processamento DE

CABINE SIMPLES

Lado esquerdo

Lado direito

CABINE DUPLA

Lado esquerdo

Lado direito

NOTAS:

Toyota Caetano Portugal, S.A.

Procedimento
1. Identificação do defeito no vidro.
2. Identificação do tipo de cabine (simples ou dupla) e lado (esquerdo ou direito).
3. Registo com uma marcação "x" na zona do vidro onde ocorreu o defeito/risco, com a cor respetiva ao posto.
4. Se possível, indicar numa zona próxima ao desenho o dia de ocorrência do defeito/risco.
5. Se necessário, no espaço de "Notas" indicar alguma informação.
6. No fim do mês é representada a distribuição dos riscos no vidro, indicando as zonas recorrentes e também os dias de ocorrência.

Exemplo:

CABINE DUPLA

Lado esquerdo

Lado direito

Figure 4.16: Defect registration sheet for assembly, 1

Figure 4.17: Defect registration sheet for assembly, 2

A similar sheet was also being developed in parallel for logistics to support inspection at the picking stage, further reinforcing the standardisation of defect tracking across process areas. Represented in Appendix B, Figure B.27.

Protection between door and glass

Root cause: Lack of protection on the outer side of the glass inside the door structure, allowing direct contact with metallic edges and components during assembly.

Countermeasure: Development and progressive implementation of a protective barrier between the glass and the inner door frame.

To eliminate the risk of contact between the glass and exposed door surfaces/components during assembly, a protective cover was developed to isolate the outer face of the window from the surrounding structure. The solution was applied before window installation and remained in place throughout the process, only removed upon window installation.

The development of the protection followed an **iterative approach**, tested directly on the shop floor and refined with **operator feedback**:

1. Initial Prototype – Fabric positioning and first test

A fabric layer was positioned inside the door to create a buffer between the glass and the metal, with magnets used to fix the protection to the outer door panel, as shown in Figures 4.18 and 4.19.

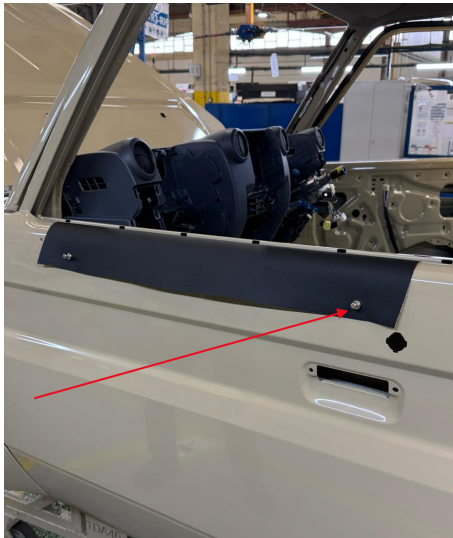


Figure 4.18: Fabric layer, prototype, 1



Figure 4.19: Fabric layer, prototype, 2

Issues observed / Operators Feedback:

- Insufficient magnet strength to hold the protection;
- Dark protection made installation more difficult due to reduced visibility.

2. Magnet Reinforcement and Visual Adjustment

To improve the fixation and ease of use, a second version of the protection was developed. **The two were replaced by four stronger magnets** to ensure a more stable attachment to the door frame and the lighter side of the fabric was positioned inward, improving visibility during the window installation (Figures 4.20 and 4.21). To be noted that each magnet was wrapped in **protective tape** to avoid damaging the paint.



Figure 4.20: Magnet reinforcement

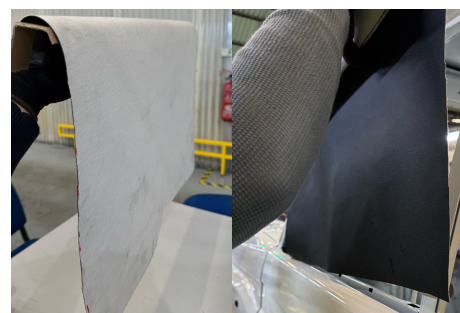


Figure 4.21: Visual adjustment on protection

Operators Feedback:

- Fixation was noticeably more consistent and reliable across repeated uses;

- The improved visibility inside the door frame made it easier to align and install the glass;

3. Final Adjustments – Usability and Handling improvements

In the final stage of development, after proving its functionality and effectiveness, the protection was further **refined to improve handling and integration into the operator's routine**, adding a handle to one end of the cover, allowing for faster and easier manipulation, as shown in Figure 4.22 and 4.23. This also made it possible to store the protection on the dolly when not in use, avoiding unnecessary floor contact or misplacement.



Figure 4.22: Protection testing



Figure 4.23: Handle installation

Operators Feedback:

- The handle improved control when inserting and removing the cover;
- It reduced setup time and made the process more fluid;
- Storing the cover on the dolly helped keep the station organised and avoided downtime looking for the material.

This final adjustment ensured that the protection was not only functional, but also intuitive and easily adopted by the operators, a key factor for **long-term sustainability of the countermeasure**.

4. Field Testing and Validation

Once the final version of the protection was completed, it was tested in real production conditions over a **sample of five vehicles, operated by two different workers**. The objective was to validate its effectiveness, usability, and overall integration into the workstation routine. Images related to the field testing phase can be seen in Appendix B, from Figure B.28 to B.33, including the final version of the protection in use, operator positioning, and post-use condition.

Operators Feedback:

- The protection was easy to position and did not interfere with the glass installation;
- Operators felt more confident during handling, knowing the glass was safeguarded;

- The repetitive use showed no signs of detachment, misalignment, or process disruption.

The results confirmed that the solution was **robust and compatible with the operating conditions**. However, a few points were identified for complete implementation:

- Define a fixed location to store the cover when not in use (granted);
- Establish a regular cleaning and condition check routine (the same as the other protections being used);
- Monitor and update all standard information, for any time impact during the assembly operation.

This field validation phase confirmed that the countermeasure was not only technically effective, but also fully aligned with shop floor realities, supporting its long-term **sustainability**.

Maintenance control of cleaning cloths at station P

Root cause: No maintenance or control plan existed for the cleaning cloths used at station P, creating the risk of particle accumulation and potential scratching.

Countermeasure: Implementation of a structured cloth rotation and cleaning plan.

To ensure that cleaning cloths used during glass handling remained clean and effective, a clear maintenance plan was introduced (Figure 4.24), defining the quantity, usage cycle, and cleaning frequency of cloths at station P, removing the informal and inconsistent practices previously in place.



Figure 4.24: Cloths (in use, used, and new ones)

Plan details:

- Five cloths are assigned, per week;
- One clean cloth is used, per day;
- All cloths are collected weekly and cleaned, according to internal standards;
- Team Leaders are responsible for ensuring the routine and verifying cloth condition daily.

Operators Feedback:

- Greater confidence in handling the glass due to visibly clean cloths;
- Elimination of uncertainty around whether a cloth was safe to use;
- The routine was easy to follow and became quickly integrated into the workflow.

This countermeasure brought a simple but impactful standardisation to a previously unstandardised variable, improving process consistency and reducing the risk of invisible causes of scratches.

Protection Reinforcement of Glass Transport Dollies

Root cause: Lack of protective material inside the dollies used to transport the glass, especially on the left-hand side (LH), where contact with other stored components could occur.

Countermeasure: Inspection and reinforcement of the two LH (left-hand) side dollies with added protection to prevent potential impact between the glass and internal components.

An inspection was conducted on all four dollies used for transporting the front side windows, revealing that the **two LH dollies**, where a significantly higher number of scratch occurrences had been recorded, did not have any protective barrier between the stored glass and the adjacent components placed inside the dolly (Figure 4.25). This meant that, during part handling or placement, there was a **real risk of unintended contact** with the exposed surface of the window.



Figure 4.25: Dolly, before

To address this problem, custom protective panels were created and installed in both dollies, as shown in Figure 4.26 and 4.27. The solution was developed using **repurposed/residual materials**

available on-site, including scraps of polypropylene sheets and foam padding, effectively creating an impact-absorbing surface between the window and any stored parts.



Figure 4.26: Creating protections



Figure 4.27: Finished protection

The intervention was simple but highly effective, bringing the dolly condition in line with process requirements and significantly reducing the risk of incidental damage to the glass during transport or parts handling. The final state of the dolly with the protections can be seen in Figure 4.28.



Figure 4.28: Dolly, after - with protection

Redesign of lighting and cleaning routine in logistics inspection

Root cause: Insufficient lighting and lack of standardised cleaning in the logistics inspection method, resulting in poor visibility and dirty glass surfaces entering the assembly line.

Countermeasure: The countermeasure consisted of two complementary actions:

1. **Improving the lighting conditions** in the logistics' inspection area;
2. **Extending the cleaning routine (previously implemented at station P) to Logistics**, applying a Yokoten approach.

The initial lighting system used for glass inspection in Logistics consisted of a **single 6500K, 2340-lumen lamp**, positioned at the base of the inspection site, as shown in Figure 4.29.

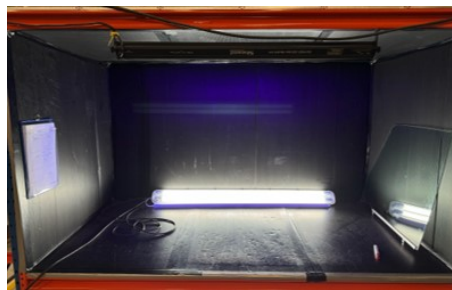


Figure 4.29: Logistics Inspection site (before)

This setup presented several limitations:

- It illuminated only a narrow zone of the inspection area (lower section);
- The lamp's size and position made inspection difficult, as the light shines directly from behind the glass, and only from below (shown in Appendix B, Figure B.34, for better understanding);
- The color temperature (cold white) was not optimal for detecting fine scratches, a warmer tone would offer better contrast;

The new lighting setup was designed to address these limitations, improving visibility and making defect detection more reliable. The configuration consists of four LED lighting units (shown in Appendix B, Figure B.35):

- Two horizontal lights (2250 lumens, 150 cm), one mounted on the base and one on the top;
- Two vertical lights (1400 lumens, 90 cm) installed on the corners of the back wall.

All lamps operate at a **color temperature of 4000K**, providing a warmer and more neutral light compared to the previous 6500K lamp. This temperature was selected based on operator feedback and visual trials, as it provides **better contrast** for detecting surface scratches.

Advantages observed with the new inspection system:

- **Full-surface illumination** from all directions, eliminating shadows and improving inspection control;
- **No backlighting behind the glass**, which previously caused glare and reduced defect visibility;
- **Slim format lights** positioned at the edges reduce obstruction and interference during inspection;
- The black background was maintained to enhance visibility of fine marks and isolate reflections.

In parallel, the same glass cleaning standard used at station P was adopted:

- Each window is cleaned before inspection using a designated cloth;
- Cloth rotation and condition control are maintained under the supervision of the Team Leader.

As a result, all windows are properly cleaned prior to inspection and reach the assembly line in a proper clean condition.

These improvements turned the inspection station at logistics into a controlled visual environment, combining proper lighting and a structured cleaning routine. Together, these changes **increased the likelihood of early defect detection and reduced the chance of scratches reaching assembly undetected.**

Use of Residual Materials – A Practical Sustainability Approach

Several of the countermeasures developed during this project made use of materials that had been previously discarded or considered residual within the factory, such as cardboard, PP sheets and surplus fabric. These materials were repurposed in a practical and low-cost manner, either to prototype solutions or to implement improvements directly on the shop floor.

While the primary objective was to eliminate defects and improve quality, this approach also contributed to **resource optimisation and waste reduction**. Rather than sourcing new materials for every test or solution, the team applied a **lean mindset**, using what was available, functional, and safe, to respond quickly to problems without compromising effectiveness.

This reuse strategy reflects not an ideological stance, but a practical embodiment of TPS principles: **minimising waste (muda), maximising resource efficiency, and adapting solutions to the reality of the production environment.**

4.2.9 Step 7 – Evaluate Results

This step corresponds to the structured evaluation of the effectiveness of each implemented countermeasure and their overall impact on the reduction of surface scratches on the front side windows.

According to the TPS methodology, this phase involves the analysis of collected data, confirmation of target achievement, and identification of remaining gaps or unexpected outcomes.

Given that the quantitative and qualitative results of this project are analysed in detail in the Results Chapter of this thesis, this step is developed in that section to ensure clarity and avoid redundancy.

This approach does not interfere with the logical flow or the methodological integrity of the TPS Problem Solving structure, and allows for a more comprehensive and focused presentation of the results obtained.

4.2.10 Step 8 – Standardization / Yokoten

Following the implementation and validation of the proposed countermeasures, attention was focused on ensuring that the improvements would be maintained over time and properly integrated into the daily routine. This was achieved through the **standardisation of work practices, the revision of relevant documentation, and the establishment of regular data collection and review routines.**

A key element was the introduction and standardisation of defect registration sheets, both in the assembly and logistics areas. These sheets are now being used regularly and consistently, allowing for clear and structured collection of data in case defects reoccur, providing essential information for traceability and monthly follow-up, ensuring that deviations can be quickly identified and addressed.

All documentation related to the window installation process in Final Assembly was reviewed and updated, including standard operation procedures (**EWS**) and standard times (**WSS**) (shown in Appendix B, Figures B.1 to B.6 for reference). To be noted that the introduction of the protective cover did not lead to a significant increase in operation time, although it requires placing and removing the protection, the improved handling made installation smoother and faster overall.

In terms of **Yokoten** (the horizontal deployment of good practices), this project opens the possibility for similar problem-solving approaches to be applied to other glass components. In particular, the **rear side windows** and even the **front windshield** could benefit from a dedicated study, if similar defects are observed. The tools and structure developed during this project can be directly reused or adapted to investigate and address quality issues in those components.

By consolidating the improvements into standard routines and spreading the learning across similar applications, the project aligns with the TPS principle of building quality into the process and fostering a continuous improvement culture.

4.3 Complementary Improvements in the Production Environment

In addition to the main projects developed during this overall project, several smaller scale improvements were carried out across different areas of the production environment.

Although independent from one another, these initiatives shared a common purpose: to **enhance safety, ergonomics, process efficiency, or work conditions**, in alignment with the **Toyota Production System (TPS) principles**.

Some of these actions were proposed and implemented from the ground up, while others involved collaboration with engineering and production teams or contribution to ongoing projects already under development.

This section compiles and summarises these complementary improvements, all of which, despite their scale, contributed to strengthening the overall workplace environment through a mindset of continuous improvement (**kaizen**), respect for people, and built-in quality.

4.3.1 Safety Improvement: Overhead Crane Controller System

During the early stages of the project, an operational safety concern was identified in the hangar area involving the overhead crane controller used to manoeuvre the vehicle cabin from the trimming line to the chassis line. The wired controller was suspended from the crane by a long cable, and its resting position had been recently adjusted to a lower height, following an operator's feedback that it was too high to handle comfortably.

However, this new position caused the controller to hang excessively low, leading to frequent and uncontrolled contact with surrounding structures, components, and dollies during crane movement (shown in Appendix C, Figures C.9 to C.12 for better understanding). This introduced a persistent risk of material collisions and potential operator accidents, along the process. It is important to note that, for safety reasons, the use of a **wired controller** is a current requirement for this equipment, as it prevents accidental activations through wireless interference or unintended signal transmission. Therefore, any solution should need to maintain the use of a cable-based system while addressing the positioning issue.

To understand the contributing factors behind the unsafe behaviour of the controller, an **Ishikawa diagram (5M)** was used to map possible causes, including limitations of the spring mechanism, interference from surrounding equipment, restrictions due to operator's height, and the need to **keep the controller accessible at all times**, as can be seen in Figure 4.30.

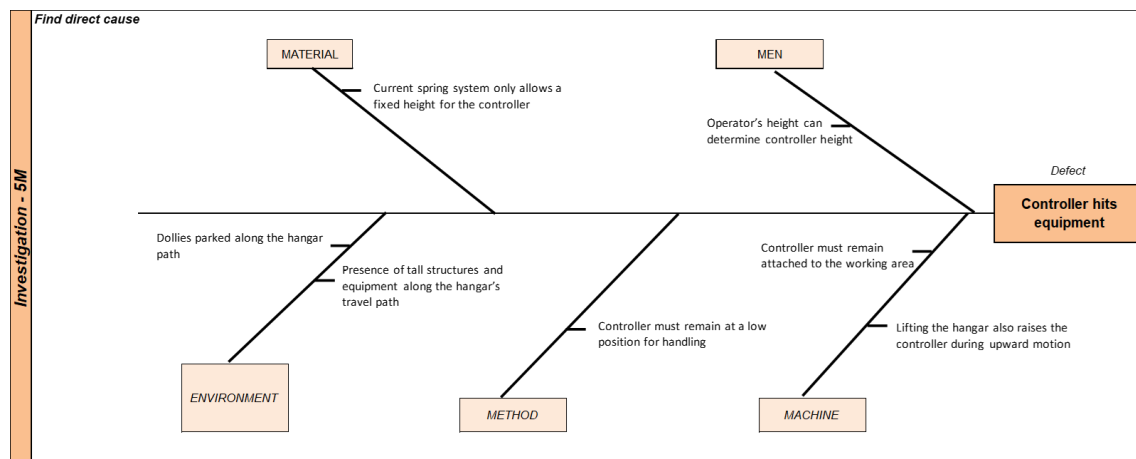


Figure 4.30: Ishikawa diagram, hangar controller

To complement this diagram, an **Impact Effort Matrix** was developed (Figure 4.31) to support the decision process between the four alternative improvements considered:

1. Replacement of the controller with a **wireless system**;
2. Substitution of the **spring mechanism**;
3. Addition of a **spring balancer system**;
4. Removal or reorganisation of equipment along the hangar path.

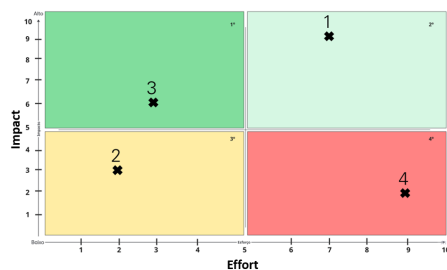


Figure 4.31: Impact Effort Matrix, controller solutions

As indicated by the priority defined in the matrix, the first solution to be considered was the **installation of a spring balancer system**, which represented the best balance between low implementation effort and high expected impact. This was selected as the most immediate and practical option.

In parallel, the **possibility of replacing the controller with a wireless system** was not discarded, although it required further study and technical validation before implementation.

Additionally, while the two main alternatives were being evaluated, a temporary mitigation measure was tested in collaboration with the Maintenance department: **replacing the existing spring with an existing lower stiffness variant**. The goal was to shorten the cable to reduce

the intensity of controller impacts without affecting usability. This setup aimed to assess whether the operator could work comfortably with a slightly shorter cable. However, in practice, **the change had minimal impact** on the behaviour of the controller and did not solve the core issue, reinforcing the need for a more effective solution.

Finally, the **reconfiguration of layout and removal of equipment along the crane path** was excluded entirely. This approach would have involved significant disruption and would not have addressed the root cause of the problem. Instead, it would simply have forced the environment to adapt to the existing issue.

Comparison between the Spring Balancer System and Wireless Controller

As mentioned earlier these two main solutions were considered to eliminate the issue identified: switching to a **wireless controller**, or installing a **spring balancer system**.

Wireless Controller

Advantages:

- Solves the root cause by removing the cable entirely;
- Offers full operator freedom;
- Adaptable across other similar systems.

Disadvantages:

- Raises **safety concerns** (false triggers, long-range activation);
- Requires dual-action safety protocols and secure resting point;
- Higher cost, complexity and technical validation needed;

Spring Balancer

Advantages:

- Easy to install and low cost;
- Retains wired control, maintaining operational safety;
- Viable for quick implementation and Yokoten.

Disadvantages:

- Effectiveness may vary with layout or environment changes;
- Controller still present along crane path, although not a risk.

While the wireless option offered a more radical solution, it introduced new safety risks and implementation challenges, so the **spring balancer system** was chosen as the most practical, low

risk, and TPS aligned solution, offering an effective solution with immediate applicability. A summarised comparison is shown in Figure 4.32.

Wireless Controller	Spring Balancer
Price ↑	Price ↓
Ease of implementation ↓	Ease of implementation ↑
Compliance with safety requirements ↓	Compliance with safety requirements ↑

Figure 4.32: Wireless controller vs Spring balancer

Selection of the Spring Balancer

To guarantee the proper functionality of the spring balancer mechanism, two technical requirements were considered: **stroke length** of approximately 1.2 to 1.3 meters, based on the vertical difference between the controller's working position and its resting height; and **weight support capacity** of approximately 4 kg (controller and cable combined). (shown in Appendix C, Figures C.13 to C.15)

Based on these parameters, a market survey was carried out and a commercial supplier was selected, **SIRA S.p.A.** From all models given, two of them, from the FLEX series, were identified as suitable candidates: the **FLEX 3-6A** and the **FLEX-5**, both compliant with the required range and load specifications, as shown in in Appendix C, Figures C.16 and C.17, being the first one the chosen.

Installation of the Spring Balancer

The selected suspension unit (**FLEX 3-6A**) was installed on the hangar system and the anchoring position was adjusted to allow free and stable movement of the controller while ensuring that it returned to the selected **safely elevated position** when not in use, as shown in Appendix C, Figure C.18 and C.19.

Visual comparisons were made between the controller's position **before and after** installation to confirm that the equipment no longer hung within the collision zone (Figure 4.33).

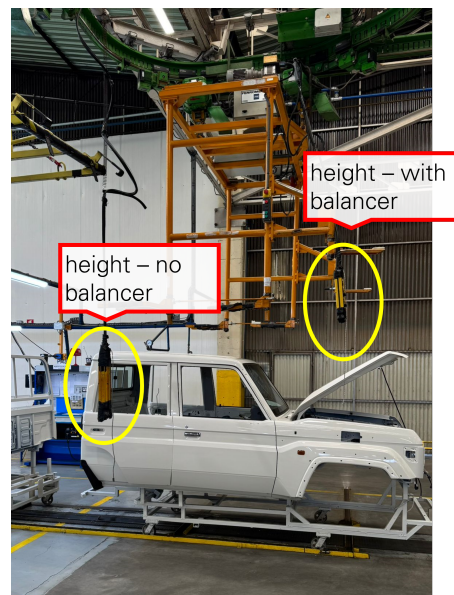


Figure 4.33: Comparison before and after balancer system

Finally, operational testing was carried out in real working conditions with the production team and the tests demonstrated that the controller remained high enough to avoid collisions and that its handling remained smooth and easy for the operator (Figure 4.34 and 4.35).



Figure 4.34: New system in use by the operator



Figure 4.35: No interference with most critical obstacle

This improvement effectively addressed a recurring safety risk through a simple and low-cost solution, eliminating uncontrolled cable movement without compromising operability, aligned

with TPS principles of built-in safety and standardisation. Due to its success, the solution was replicated (Yokoten) in another hangar at Final Assembly.

4.3.2 Ergonomic Improvement: Dolly Redesign Support

In line with the continuous improvement efforts carried out during the project, a specific ergonomic challenge was addressed in the Final Assembly area, more precisely at station FA3.

In this station, the operator works on an elevated platform to perform assembly operations on the vehicle. Due to its position on the conveyor and the layout of the station, certain areas, particularly the upper sections, remained with difficult access.

This limitation became particularly evident in the case of a shorter operator, who consistently struggled to reach all required zones, despite the presence of the fixed platform. The resulting overextension led to awkward postures, discomfort, and increased ergonomic risk, as shown in Appendix C, Figure C.20.

In this context, a new solution was developed: **a mobile support dolly** designed to ensure safe and ergonomic working conditions while maintaining compatibility with the line's moving conveyor (Figure 4.36). To be noted that implementing fixed steps or auxiliary supports was not viable, as the vehicle is constantly in motion along the conveyor and any static elevation device would create a significant safety risk, particularly in terms of balance and potential falls. Therefore, a new approach was required to improve operator access without compromising safety or disrupting the production flow.



Figure 4.36: Dolly FA3 design

The dolly is designed to couple directly to the rear wheel of the vehicle at the beginning of the FA3 station. Once attached, it moves synchronously with the vehicle along the conveyor,

maintaining a fixed relative position throughout the assembly process.

This allows the operator to step onto a stable and elevated support surface that travels with the car, providing access to upper sections of the vehicle without requiring awkward body movements or overreaching. At the end of the station, the dolly is uncoupled and returned to the start position for the next vehicle.

This system eliminates the need for fixed platforms and ensures safety by **removing the risk of working on static supports while the vehicle is in motion**, while also improving ergonomic reach in a consistent and repeatable way. (Figure in Appendix C, Figure C.21 shows overall structure design - technical drawing)

Although the project had already been initiated prior to this project, participation in the final phase of development focused on preparing the dolly for operational readiness. This included conducting on-site testing and identifying several improvement points based on observed performance and operator interaction. The solution is currently validated and ready for implementation, pending alignment with production scheduling to avoid disruption of normal operations.

Refinements and Improvements Developed

During the testing phase, several improvement opportunities were identified in collaboration with the production team. These focused on usability, operator safety, and robustness of the system. The following key refinements were introduced:

- **Coupling mechanism redesign:**

The attachment system between the dolly and the vehicle's rear wheel was modified to facilitate easier engagement and disengagement, and prevent the system to contact the vehicle's surface (Figure 4.37).

A **new opening handle** was added, and the geometry of the locking system was adjusted to allow single-handed operation while reducing hand entrapment risk.

A buffer was also added to eliminate the gap between the wheel and the coupling area and to absorb potential shocks.

Additionally, a **locking pin** was installed to secure the dolly support during reverse movement, preventing unintended rotation or contact with the vehicle during the return path to the start of the station (shown in Appendix C, Figures C.22 to C.26, comparing the before and after improvements).



Figure 4.37: Final coupling mechanism design

- **Safety lock on step support:**

The original lock mechanism for the dolly step was difficult to reach and operate (shown in Appendix C, Figure C.27). It was replaced with a simplified pin system that is both accessible and secure in the open and closed positions (Figure 4.38).



Figure 4.38: New lock mechanism for step (open position)

- **Auxiliary side platform:**

A side step was added to enable the operator to stand closer to the vehicle during critical operations (Figure 4.39). To address flexing issues caused by span length, a central support wheel was introduced to stabilise the platform during use. (shown in Appendix C, Figures C.29 and C.28)



Figure 4.39: Side step installed in the Dolly

- **Guiding rail system:**

To ensure precise alignment and stable linear motion along the station, a **guiding rail** was designed and installed on the floor, preventing lateral deviation of the dolly as it moves in sync with the vehicle, especially important during transitions at the beginning and end of the station (Figure 4.40).



Figure 4.40: Guiding rail – testing

All improvement points were tested and validated under real working conditions, resulting in a safe, ergonomic, and robust solution. The dolly is now fully optimised and ready for implementation, offering better usability and operator protection in line with TPS principles.

As a potential future enhancement, the implementation of a **motorised wheel system** on the dolly is currently under technical evaluation (Figure 4.41). This feature would allow automatic return of the dolly to its initial position after decoupling, eliminating the need for manual repositioning by the operator and further improving process fluidity, safety, and ergonomics.



Figure 4.41: Motorised wheel, for dolly FA3

4.3.3 Efficiency Study: Pre-Assembly Station for Radiator System

As part of the broader objective to improve efficiency and eliminate waste across production processes, a study was carried out on the **pre-assembly station of the radiator system**, since it was needed to update its operations times (WSS). This station is responsible for preparing the radiator pre-assembly prior to its integration into the vehicle structure further down the line (Figure 4.42).

The purpose of the study was to assess the current performance of the station, identify potential inefficiencies, and propose improvements aimed at reducing unnecessary motion, simplifying work sequence, and optimising the cycle time.



Figure 4.42: Radiator pre-assembly station

Methodology and Analysis

To evaluate the performance of the radiator pre-assembly station, a structured video-based time study was conducted. The software **Kinovea** was used to precisely measure and analyse the duration of each operation performed by the operator.

Two video recordings were collected on-site under normal production conditions. Although ideally three samples would be recommended minimum for higher statistical robustness, each recording had a duration of approximately **10 minutes**, requiring a detailed and time-consuming analysis. Therefore, two full cycles recordings were considered sufficient for extracting reliable and consistent results in this context.

Each video was reviewed to identify and break down the **job elements**, individual tasks performed by the operator throughout the cycle. These tasks were then recorded in a **Standardised Work Recording Sheet (SWRS)**, where the duration of each job element was documented, and categorised into Value-Added Work (VA), Non-Value-Added (NVA) or Waste (MUDA). Special attention was given to identifying and classifying forms of **Muda**, including:

- Unnecessary operator movement between tools and parts;
- Repetitive or redundant motions;
- Excessive parts transportation within the station layout.

An example of the time study conducted in Kinovea can be seen in Appendix C, Figure C.1, where each job element was individually segmented and timed with frame-accurate precision.

This categorisation made it possible to clearly distinguish productive and non-productive activities. It allowed for the update of standard operation times and supported the identification of inefficiencies (Appendix C, Figures C.2 and C.3, show complete SWRS sheet), serving as a basis for improvements to increase workstation efficiency.

Improvement Proposals

This analysis enabled a detailed breakdown of the current process performance, revealing that approximately **55% of the cycle time** was spent on value-added work (VA), while **44% corresponded to non-value-added but necessary activities (NVA)**. Only **1% was identified as clear waste (Muda)**, identified as operations that clearly were not established as standard.

Among the NVA activities, two repetitive tasks stood out for their frequency and duration:

- **Picking and placing the electric screwdriver:** 26.4 seconds (4% of the total cycle time);
- **Picking and placing the pliers:** 13.2 seconds (2% of the total cycle time).

Together, these accounted for nearly **6% of the cycle**, without contributing directly to the product, highlighting a clear improvement opportunity. To address this, several proposals were developed:

- **Repositioning of tools:** placing the electric screwdriver and pliers closer to the radiator fixture to eliminate unnecessary movement;
- **Layout adjustments:** optimising parts and tool locations to reduce unnecessary movements and improve reachability;
- **Sequence optimisation:** restructuring the work sequence to improve flow and reduce unnecessary rotations of the radiator on the dolly.

Implementing these changes would eliminate the identified inefficiencies and result in a projected **efficiency gain of 6%**.

Project Status and Follow-up

Although the proposed improvements were not directly implemented during the project period, the study was fully documented and transferred to the responsible engineering teams. The data collected, the time breakdown analysis, and the identified improvement opportunities are currently being considered as part of a broader optimisation project led by another internal team.

This ensured that the work carried out continues to add value beyond its initial scope. The analysis not only supported the standard time update but also laid the groundwork for structured process improvement in efficiency of the workstation.

4.3.4 Proposal for 3D Printing Implementation in Engineering

In the context of continuous improvement and technical autonomy, a proposal was developed for the integration of a **3D printer** into the engineering department's toolkit. This initiative aimed to enable **fast prototyping, low-cost development of internal solutions, and faster response to shop floor needs**, in line with TPS values, particularly by supporting the creation of kaizen improvements.

Background and Problem

During a recent internal assessment to the Final Assembly area, a specific issue was raised regarding the **handling and protection of electronic control units (ECU's)** before installation in the vehicle. The exposed pins of these components presented a risk of damage during handling and logistics operations (Figure 4.43).



Figure 4.43: ECU stored with no protections

Typically, developing a physical protection for such components would require either outsourcing the design or manufacturing process, which is a time-consuming and costly option. In addition, **small design changes and prototype testing** are often slow and costly, and there is frequently a **lack of agility** in testing experimental components before placing part orders. These constraints delay validation cycles and reduce the engineering team's ability to respond quickly to improvement opportunities on the shop floor.

Proposed Solution

The proposed solution involved designing the required **custom protection for the ECU** (3D CAD) and producing it using **in-house 3D printing**. Beyond this specific case, the goal was to demonstrate the broader applicability and value of a 3D printer in the following contexts:

- Rapid prototyping of new ideas (e.g., supports, component testing);
- Development of temporary or emergency replacement parts (e.g., dolly protections or supports);
- Fabrication of small kaizen tools and component protections;
- Enhanced freedom to innovate and iterate internally without supplier dependence.

These examples demonstrate how additive manufacturing could enhance the engineering team's responsiveness, enabling the design, testing, and refinement of components or supports without long lead times or external dependencies.

Technical and Financial Feasibility

To support the proposal, a financial and operational feasibility analysis was conducted using two reference models, the **Creality K1** and the **Prusa MK4S** as examples. These printers were not pre-selected but served as realistic benchmarks to evaluate viability. The primary goal was to assess potential cost savings and return on investment under **highly conservative assumptions**: (All calculations are shown in Appendix C, Figures C.4 and C.5)

- Analysis for both printer models, with distinct pricing and capabilities;

- Filament costs were estimated at €29.99 and €13.39, using the more expensive options for simulation;
- The first month assumed exclusive use for printing ECU protections (30 units);
- In subsequent months, a much lower production rate was considered, simulating minimal usage;
- Additionally, future months assumed smaller savings per part than in the first month;
- For external printing comparisons, the lowest market price available was used, deliberately reducing the calculated savings margin.

Despite this cautious approach, the analysis indicated:

- An estimated **payback time of 8 months** for the Creality printer and **16 months** for the Prusa model (shown in Appendix C, Figure C.6);
- Continuous savings over time even under modest use scenarios (shown in Appendix C, Figure C.7).

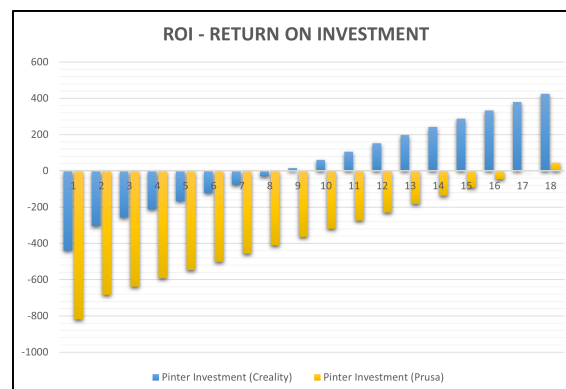


Figure 4.44: ROI for the two printers

Conclusion

The integration of a 3D printer within the engineering department was shown to be a practical and cost-effective solution, even when evaluated under highly conservative usage and cost assumptions.

As a follow-up to this proposal, the next step outlined was to initiate direct engagement with multiple 3D printer suppliers. This would allow for a broader evaluation of available technologies, materials, and support conditions, ensuring the selection of a printer that best matches the operational needs and long-term sustainability of the engineering team. This initiative reflects the TPS spirit of equipping teams with the right tools to build quality into the process and foster technical creativity in solving real production challenges.

4.3.5 Kaizen Improvements from Direct Observation

In parallel with larger projects, several small-scale kaizen improvements were identified and implemented during the project. These actions did not originate from any structured problem-solving activities, but rather from **direct observation on the shop floor and informal feedback from operators**. Each one addressed a specific, real-world issue and was registered in the company's internal kaizen system, in line with its policy of encouraging every team member to contribute actively to continuous improvement.

Kaizen: Mizusumashi Ramp for Dolly Stabilisation

During the early stages of the project, a recurring issue was observed along the route taken by both mizusumashis. At a particular section where the dollies crossed an embedded rail track, responsible for taking the body and deck transporters to the trimming line, the dollies would frequently bounce excessively, causing the stored components to shift position or, in some cases, fall to the floor.

Upon investigation, it was concluded that the geometry of the metal rail track caused a steep transition for the dolly wheels, resulting in a high angle of approach and a noticeable impact during crossing, as shown in Figure 4.45.

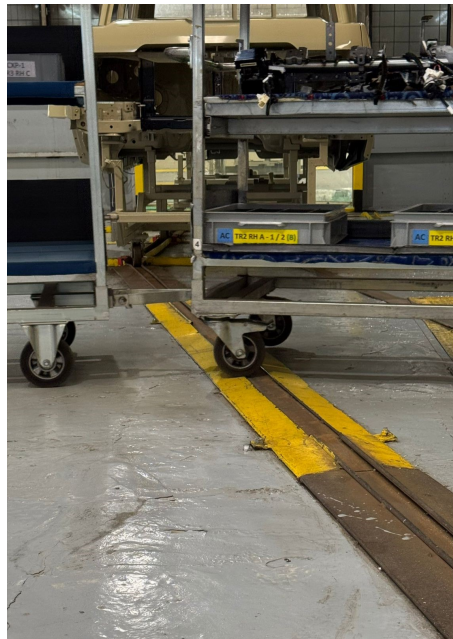


Figure 4.45: Rail track, before - dolly instability

To address the issue, a **custom steel ramp** was designed and welded directly onto the existing metal track (technical drawing is shown in Appendix C, Figure C.30). This ramp reduced the angle of approach and enabled a smoother, more gradual transition, significantly improving wheel stability during passage. The solution eliminated the bouncing effect, reduced noise, and improved the protection of in-process components (Figure 4.46).



Figure 4.46: New ramp installed - smoother dolly transition

A complementary action was also proposed, which was the introduction of a **defect sheet** to monitor any occurrences of fallen parts along mizusumashi routes (shown in Appendix C, Figure C.31). This would allow the team to track recurring patterns (most affected dollies) and identify further improvement opportunities.

Kaizen: Handbrake Torque Measurement Standardisation

During the assembly of the handbrake system, it was observed that torque adjustment was being performed based on a subjective method: operators would tighten the adjustment bolt until the handbrake lever produced a predefined number of audible “clicks” (typically 7 to 9)(Figure 4.47). While this approach was simple and fast, it lacked objective verification and did not align with the assembly manual, which specified a force value of 192 N.

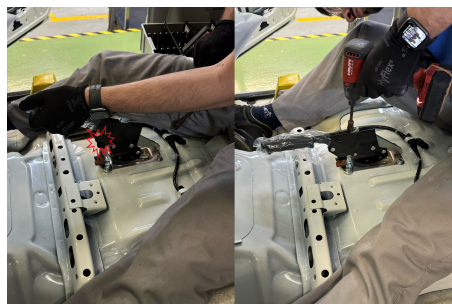


Figure 4.47: Operation before kaizen - handbrake system

To address this, a more precise measurement method was introduced using an existing, previously unused instrument found at the factory. The device is based on a **load cell connected to**

a **digital pressure gauge**, allowing the applied force to be read indirectly as pressure (shown in Appendix C, Figure C.32).

The implementation steps included:

- Measuring the diameter of the load cell's contact surface to calculate the area;
- Converting the target force (192 N) to pressure using the equation $P=F/A$, resulting in a target reading range of approximately 0.200–0.210 MPa;
- Testing the device directly in the assembly process to validate usability and accuracy (Figure 4.48).



Figure 4.48: Handbrake assembly with measuring instrument in use

Once validated, this measurement method was integrated into the **standard operating documentation (EWS – Element Work Sheet)** for the handbrake assembly process. Operators now follow a defined procedure that includes using the gauge to ensure consistent application of the required force, eliminating reliance on subjective feedback (clicks) and ensuring alignment with OEM specifications (EWS is shown in Appendix C, Figure C.8).

This improvement not only enhanced process accuracy and quality control, but also reflected core TPS values of **jidoka** (built-in quality) and **kaizen** (continuous improvement), leveraging available resources to eliminate variability and reinforce operational standardisation.

Kaizen: Visual Identification for Primary Adhesive Bottles

As a result of an assessment of the Final Assembly area, a small but relevant improvement opportunity was identified concerning the **handling of primer bottles** used in the windshield application process.

The process involved two different types of primer products, each stored in a **similar-looking bottle but serving different purposes**. Previously, there was no visual aid to distinguish between

the two beyond the cap color, which could create a risk of confusion when replenishing the bottles on the workstation, as shown in Figure 4.49.



Figure 4.49: Primer stored, before kaizen

To address this issue, a quick kaizen was implemented: **a colored visual aid matching the bottle cap** was applied around each bottle's insertion point (Figure 4.50). This ensured instant identification of which bottle belonged to which position, simplifying replenishment and **minimising errors**.

This low-cost solution exemplifies the value of quick kaizen actions, simple yet effective measures that, when consistently applied, improve workflow clarity and strengthen visual management on the shop floor.



Figure 4.50: Primer stored, after Kaizen

4.3.6 Conclusion – The Impact of Small-Scale Improvements

Although individually modest, all improvements presented in this section illustrate how continuous observation, collaboration with operators, and rapid action can generate meaningful impact.

From safety enhancements to visual management and ergonomics, each intervention responded to a real shop floor need using simple and cost-effective solutions.

These examples reinforce a core TPS principle: **small improvements, consistently applied, lead to significant long-term gains**. More importantly, they promote a proactive culture of ownership and accountability, where every team member is empowered to contribute to a safer, more efficient, and more stable production environment.

Such initiatives, while not tied to large scale projects, represent the daily spirit of **kaizen** that sustains and elevates operational excellence.

Chapter 5

Results and Evaluation

This chapter presents the results obtained through the implementation of the three main improvement efforts developed during this project: the Value Stream Mapping project, the structured Problem Solving focused on window scratches, and the set of complementary improvements applied across different areas of the production environment.

Each section evaluates the effectiveness of the respective initiative, using **quantitative data and qualitative** insights where applicable, and reflects on its contribution to the company's continuous improvement efforts.

The chapter concludes with a **summary of the three projects**, highlighting their relative scope, impact, and alignment with TPS principles.

5.1 Value Stream Design (VSD) – Future State Map

As the main outcome of the Value Stream Mapping (VSM) project, this section presents the **proposed Future State Map (VSD)**, which consolidates the improvement opportunities previously identified during the current state analysis. The VSD represents a conceptual scenario of the ideal process configuration, aligned with lean principles and the factory's long-term development goals.

Although the overall structure of the value stream remains mostly unchanged, several improvements are highlighted in the map, specifically marked in blue.

To be noted that this proposed future state map does not represent a complete implementation, but rather a conceptual scenario that reflects the intended direction of process development, requiring the initiation of dedicated projects and ongoing monitoring over the medium to long term, for each improvement opportunity identified.

As such, this Future State Map, represented in Figure 5.1, serves both as a **visual summary of the identified priorities** and as a **strategic reference for the continuous improvement roadmap**.

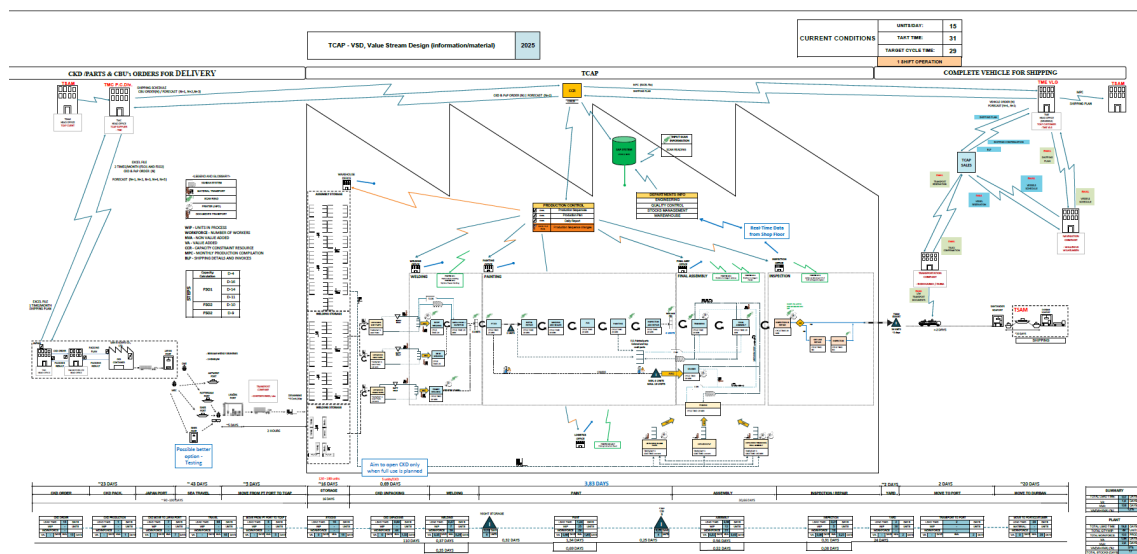


Figure 5.1: Value Stream Design - TCAP 2025

As mentioned before, some improvement proposals for the VSD are **not explicitly visible in the map**, but were considered relevant in the design process and are expected to contribute to the system's overall efficiency and adaptability. These include:

- **Repurposing of idle workstations** – Not visible in the map but considered as an opportunity for improving efficiency in trimming and assembly lines.
- **Chassis stocks and handling during sequence changes** – Although the need for increased flexibility in chassis rearrangement was recognised, there was no definitive solution approved, so this point is not visually reflected in the future state map but is considered a relevant open topic for future development. Nevertheless, AGV solutions for chassis transportation are currently under evaluation and have been represented in the VSD to reflect ongoing efforts towards this improvement.
- **Reduce transport time from Japan** – Ending of Evergreen route and testing the railway possibility via Sines, aiming to reduce the overall shipping lead time to 43 days, which was the usual time before the war and route constraints.

This Future State Map represents a more stable and efficient production system with the integration of digitalisation — a big step for the factory — highlighting better flow control, reduced rework, improved data collection from the shop floor, and greater alignment with Lean principles, providing a strong foundation for continuous improvement.

Some KPIs can be compared between the VSM and VSD, shown in Figure 5.2:

KPI	VSM	VSD	Variation
Complete Supply Chain			
Total Lead time (days)	137,3	114,8	-22,5 ↓
Total VA (days)	1,64	1,64	0,0
Total NVA (days)	138,38	115,89	-22,5 ↓
Value-Added Ratio	1,2%	1,4%	0,22% ↑
Plant - Dock to Dock			
Total Lead time (days)	20,3	19,8	-0,5 ↓
Total VA (days)	1,64	1,64	0,0
Total NVA (days)	3,48	2,80	-0,7 ↓
Value-Added Ratio	32,1%	36,9%	4,89% ↑
Total Stocks (days)	17,0	16,7	-0,3 ↓

Figure 5.2: VSM vs VSD - KPI comparison

Based on the KPIs considered, the main conclusions that can be drawn relate to two key improvements: firstly, **a reduction of overall lead time by 22.5 days** and secondly, **the increase in the value-added ratio within the factory by almost 5%**. These results demonstrate that even without major structural changes to the value stream map, targeted improvements and future projects can lead to meaningful gains in efficiency.

The lead time reduction reflects the **impact of optimising the inbound logistics** (CKD shipping routes and internal material handling), while the increase in value-added activity confirms a **shift towards leaner operations**, with a higher proportion of productive time across the system — fundamentals of TPS.

5.2 Problem Solving in Front Side Window Defects

Following the actions detailed in Chapter 4, referring to the problem solving, this section presents the evaluation of their impact. The results confirm the effectiveness of the problem-solving process and highlight its contribution to quality control reinforcement across key areas.

General Conclusions on Overall Results

The first step in evaluating the impact of this project was to analyse the total number of rejected windows recorded over recent years, categorised by detection point. As shown in Figure 5.3, there was a general **downward trend** in the total number of scratched windows rejected between 2022 and 2024.

However, by the **first quarter of 2025 alone**, the number of rejections had already **nearly equalled** the totals of full previous years, which highlighted the urgency and importance of this **problem solving** initiative.

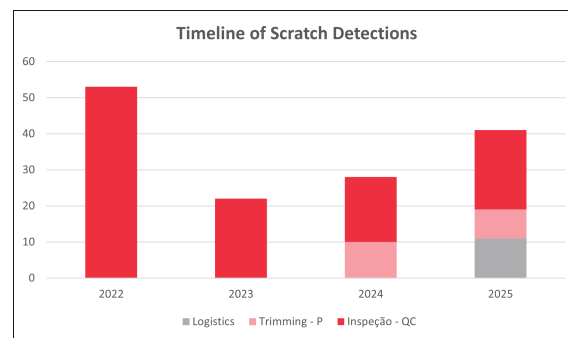


Figure 5.3: Timeline defects

Furthermore, the data revealed another crucial aspect: **until 2023**, all defects, regardless of where they may have been detected, were registered **only at the final inspection (QC)**. **In 2024**, an informal, non-standard recording began to emerge in the **trimming area (P)**, and only **in 2025**, with the start of the problem solving, standardised records were introduced **across all relevant inspection points**, which were QC, Trimming/P, and for the first time, logistics (graph shown in Appendix B, Figure B.7).

Weekly Analysis – April 2025

The month of April represented a key transition period, as it coincided with the start of countermeasure implementation. A detailed weekly analysis, represented in Figure 5.4, allows us to observe not only the effect of the actions and countermeasures taken, but also how the detection points evolved throughout the month (Appendix B, Figures B.10 to B.12, showing all defects registered using the defect sheet implemented).

In the **first week of April (W1)**, most defects were still being detected in Final Inspection (QC), with a smaller portion registered in the Trimming area (P). This mirrors the pre-existing situation, where scratches were often only discovered after full installation, leading to late stage rework and higher internal cost.

As countermeasures were introduced, particularly those related to protection during assembly, a noticeable shift occurred. In **week 2 (W2)**, detection began to move upstream, with all recorded defects found exclusively in the Trimming area (P), meaning they were caught earlier in the process, before reaching final inspection.

By **week 4 (W4)**, detections were no longer occurring in trimming or inspection, but instead had moved further upstream to **Logistics**, the very first handling point in the window's production flow. This evolution reflects a key quality principle: **detecting problems at their source** before they propagate downstream. To be noted that defects detected at logistics are highly unlikely to be house-made, they typically indicate that the window already arrived in that condition from Japan, most likely due to transport-related causes.

It should also be noted that no data appears for week 3 due to a planned production shutdown for holidays during that period.

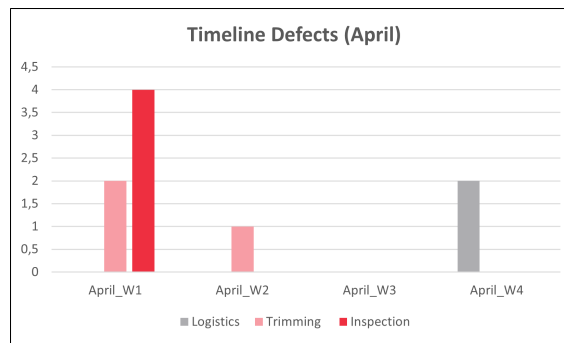


Figure 5.4: Defects timeline, April

This reversal of the detection flow, from final inspection toward logistics, validates the effectiveness of the countermeasures and confirms that the process was gaining robustness in **identifying issues closer to their origin**, a fundamental principle of built-in quality.

Defects Distribution by Vehicle Side – April

In addition to analysing the weekly evolution of detection points, a complementary breakdown was conducted to evaluate defect distribution between the **left-hand side (LH)** and **right-hand side (RH)** of the vehicles. The data from April 2025 clearly showed a disproportionate number of defects occurring on the LH side, as shown in Figure 5.5. To be noted that only **production** related stations were considered (Trimming and QC).

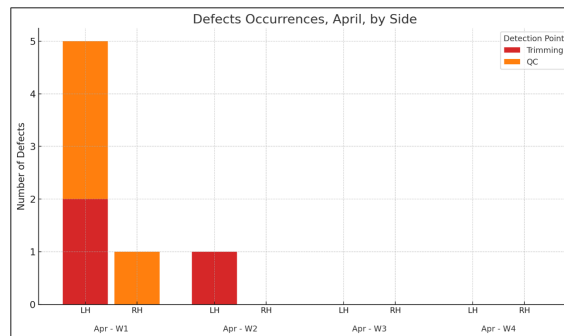


Figure 5.5: Scratch occurrences by vehicle side and detection point – April 2025

This trend strongly correlates with one of the root causes identified: **two dollies that transported the windows (LH) lacked proper protective materials**, unlike the RH ones. As a result, the left-hand windows were more exposed to incidental contact with surrounding parts during transport and handling.

The implementation of protection elements in these LH dollies was one of the first physical countermeasures implemented in this project. While a direct causal relationship cannot be confirmed, it is **highly plausible that this improvement contributed to the reduction** of LH-side defects observed in the following weeks.

Defects Timeline Throughout the Project – 2025

To better understand the progression of the problem and the impact of the implemented actions, all defects recorded in 2025 were grouped by month and detection point, shown in Figure 5.6. This timeline analysis helps visualise both the **effectiveness of the countermeasures** and the moment in which each phase of the problem-solving had influence.

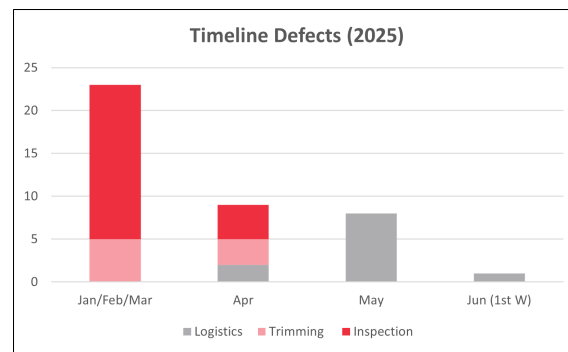


Figure 5.6: Monthly timeline of scratch detections by inspection point – 2025

As said before, in the first three months of 2025 (January to March), the number of detected defects was already comparable to the total recorded for full previous years. Most detections during this period occurred in the **Inspection (QC)** stage, reinforcing the late identification pattern seen in previous years.

With the implementation of countermeasures starting in April, a **notable drop** in the number of recorded defects is observed. Furthermore, detections began appearing more consistently in **upstream stages**, such as **Trimming (P)** and **Logistics**, which is a positive indicator of improved process control and inspection structure.

In May, although a small number of defects were still recorded, all of them were identified in **Logistics**, meaning they were intercepted at the very first handling point, before entering production. In the first week of June, a single defect was also detected at Logistics.

In these cases, since the glass is being removed from its original shipping crate for the first time, **the damage likely occurred upstream, during transport from Japan**. As such, no internal corrective action can be taken beyond early detection.

A possible next step for improvement could involve **collaboration with the suppliers to investigate transport conditions** and explore solutions to avoid such occurrences at the origin.

Window Side Distribution of Defects in Logistics

Since the implementation of the defect registration sheet in the Logistics area, all scratches have been consistently recorded and monitored by side. The data collected between the last week of April and the first week of June shows a relatively **balanced distribution between left-hand (LH) and right-hand (RH) windows**, as illustrated in Figure 5.7.

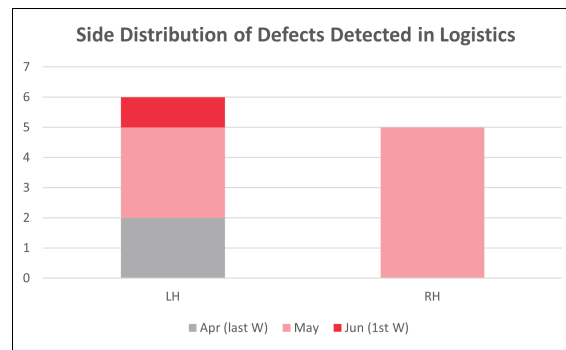


Figure 5.7: LH vs RH Scratch Occurrence - Logistics

This **balanced occurrence** suggests that the scratches detected at this stage, which reflect the condition in which the glass arrives from the supplier, **are not side related**, but rather result from external or transport related factors.

This observation supports the idea that the higher number of LH-side defects identified in the early stages of the project was not related to the condition of the glass, but rather to internal handling during assembly. The lack of protection in the LH-side dollies, combined with specific mounting practices, likely contributed to this imbalance, which was effectively mitigated by the countermeasures implemented.

Estimated Cost Impact and Savings

Beyond operational and quality improvements, it was also important to assess the **financial impact** of the actions taken. A dedicated cost analysis was therefore performed to estimate the **economic benefits** resulting from the project, based on the reduction of window rejections and associated rework.

This allowed for a more complete evaluation of the problem-solving effectiveness, combining technical results with measurable financial gains.

The following considerations were considered in this analysis:

- The analysis only considered defects that progressed into the assembly process, **scratches detected in Logistics were excluded**, as these windows never entered production;
- The cost per rejected window includes materials, labour, process time, and urgent transport;
- The monthly rejection rate prior to countermeasures' implementation was based on the average from the first quarter of 2025;
- The improved projections assume that the defect level remains stable after the implementation of countermeasures;
- A conservative scenario (0.5 defects/month) was included to account for small fluctuations or isolated events.

The total cost of a single rejected window was calculated at approximately **101.74€**, which includes not only the material cost but also the time lost in removing, preparing, and remounting the glass, as well as all the logistics and inspection effort. (Appendix B, Figure B.8 includes a detailed calculation model)

By projecting the average monthly rejection rate observed in early 2025 (before countermeasures), it was estimated that **up to 63 windows** could be rejected by the end of the year if no action was taken, resulting in a total annual cost of approximately **9462€**.

With the countermeasures implemented and stabilised, the number of defects would decrease totally, and projections now indicate a total annual cost of only **3052€**, which is the cost of the actual rejected windows so far in 2025.

A more conservative estimate was also included, considering the possibility of occasional issues, and with that the cost might reach up to **3510€**, still well below the initial estimate. (Appendix B, Figure B.9 includes a detailed calculation model)

These three scenarios are summarised in Figure 5.8:

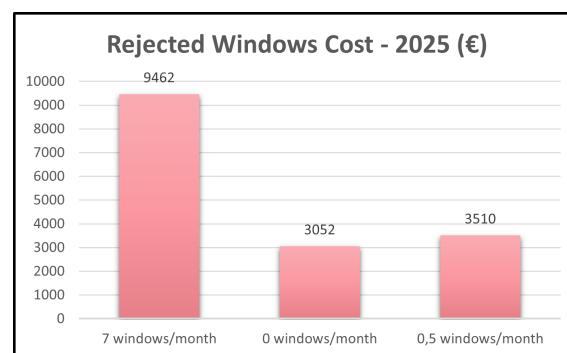


Figure 5.8: Rejected window cost, scenarios

Estimated Annual Cost Savings: 6410€.

Equivalent to a 68% reduction in defect related losses.

This financial result reinforces the value of **proactive quality control** and **structured problem-solving** as mechanisms not only for technical improvement but also to tangible economic benefits.

5.3 Complementary Improvements in the Production Environment

Unlike structured problem-solving or large-scale projects, most of the complementary improvements implemented during the project were kaizen-driven. As such, their impact is typically more qualitative in nature, focusing on dimensions such as safety, ergonomics, process stability, and operator working conditions.

While these initiatives may not generate direct numerical KPIs, they play a fundamental role in sustaining a culture of continuous improvement, as encouraged by the Toyota Production System (TPS). Their effectiveness is often reflected in reduced operational variability, improved workplace usability, and greater involvement of frontline teams in identifying and solving problems.

The following section highlights the main results observed for all of the main improvements discussed in the previous chapter.

Safety Improvement: Overhead Crane Controller System

A positioning issue with the overhead crane controller was resolved by installing a spring balancer, ensuring the controller remained at a safe, stable height. This eliminated uncontrolled swinging and improved operator handling during crane operation.

Results observed:

- Removal of a recurrent safety hazard caused by low-hanging controller movement;
- Improved ergonomics, allowing easier and safer controller access;
- Low-cost, quick implementation with direct replication in a second hangar (Yokoten).

Ergonomic Improvement: Dolly Redesign Support

To address access limitations faced by certain operators at station FA3, a mobile dolly was designed to provide a stable, elevated support that moves in sync with the vehicle. The solution allows safe access to upper sections without the need for overreaching or static platforms.

Results observed:

- Elimination of awkward and unsafe body positions during upper-section assembly;
- Improved ergonomic conditions and comfort for operators of different heights;
- Aligned the process with the “Any Member, Any Process” principle, making it equally accessible to all team members;
- Validated solution ready for implementation with minimal process disruption.

Efficiency Study: Radiator Pre-Assembly

A detailed time study was conducted on the radiator pre-assembly station to identify inefficiencies and update standard operation times. Using video analysis and classification of job elements, the study revealed repetitive handling tasks and layout issues that could be addressed to improve flow.

Results observed:

- Estimated efficiency gain of approximately 6% through proposed improvements;
- Updated standard operation times (WSS) for the station, reflecting real cycle conditions;
- Structured insights and data delivered to the engineering team to support future layout and process optimisation.

Proposal: 3D Printing Implementation in Engineering

A proposal was developed to integrate a 3D printer into the engineering department to support rapid prototyping, low-cost tooling, and kaizen development. The initiative aimed to increase technical autonomy and responsiveness to shop floor needs.

Results observed:

- Estimated cost savings of up to 70% compared to external production of specific parts;
- Significant reduction in lead times for prototype components, enabling faster testing and implementation;
- Expanded engineering capability for internal innovation, supporting agile, low-cost experimentation with new ideas;
- Financial analysis confirmed viability, with projected payback in 8 to 16 months, even under conservative usage.

Kaizen Actions from Direct Observation

Several small-scale kaizen improvements were implemented based on direct observation and informal feedback from the production floor. Though independent and simple, each action addressed a real issue and supported the principles of built-in quality and continuous improvement.

Results observed:

- Reduced risk of part loss and instability during internal transport (ramp for mizusumashi crossing);
- Improved process precision and standardisation using objective torque measurement (hand-brake assembly);
- Visual poka-yoke implemented to avoid errors in primer bottle replenishment;
- All three actions contributed directly to quality improvement through defect prevention, in line with TPS principles.

Final Consideration

When considered collectively, the improvements implemented during this project — from strategic mapping to focused problem-solving and kaizen actions — represent a meaningful contribution to the production environment.

While each initiative varied in scope and complexity, all shared a common goal: to strengthen safety, quality, efficiency, and stability in line with TPS principles. Whether by reducing lead time, preventing quality issues, standardising operations, or improving operator conditions, the combined impact of these efforts brought tangible progress to the factory.

This section illustrates how a structured yet practical approach to improvement, rooted in observation, data and collaboration, can generate significant results, even within a limited timeframe.

Chapter 6

Conclusion

Conclusion on the thesis content

This work addressed three distinct yet complementary areas of continuous improvement: the value stream mapping (VSM), the structured application of a Problem Solving methodology to a critical defect, and the implementation of kaizen actions based on direct observation.

This combined approach enabled not only a deep analysis of improvement opportunities, but also the implementation of solutions with visible impact on key indicators such as lead time, quality, ergonomics, and safety.

Structuring the work into independent yet interconnected projects reinforced the logic of continuous improvement sustained by the Toyota Production System (TPS), ensuring that both large-scale actions and simple improvements remained aligned with the principles of stability, flow, and built-in quality.

Conclusion on the project at Toyota

The project at Toyota Caetano Portugal provided a fully immersive experience in an industrial environment, where TPS is not merely a theoretical reference, but a living philosophy embedded in every process and worker.

Integration into the engineering team allowed active involvement in multiple projects, always guided by the principles of safety, quality, and respect for people. Learning directly from experienced colleagues and working on real production challenges were essential to consolidate academic knowledge.

Beyond the application of tools, the project provided a true understanding of the Toyota Way: improving continuously based on shop floor reality, involving teams, and building sustainable solutions.

Academic alignment of the thesis

This thesis is part of the Master's degree in Mechanical Engineering at the Faculty of Engineering of the University of Porto (FEUP), under the Production Management specialization, so this

project enabled the practical application of key topics covered in multiple courses, such as Lean Manufacturing, Production Systems, Work Methods, Ergonomics, and Quality Management.

It provided a strong foundation to consolidate technical and methodological skills, particularly in the areas of production flow analysis, process optimisation, standardisation, continuous improvement and structured improvement implementation.

It also offered a deeper understanding of how these tools gain significance when applied within a structured organisational culture that promotes stability, standardised work, and the systematic elimination of waste.

Future work and development opportunities

The continuation of this work may be achieved through the launch of several improvement projects identified throughout the project, through the VSM analysis, the problem solving, and through daily interaction with the production environment , such as:

- **Improve chassis logistics and transport – ensure sequence flexibility**, focused on implementing a robust solution for chassis resequencing;
- **Repurpose idle stations in trimming/assembly line**, increasing resource utilisation;
- **Balance painting cycle times – reduce intermediate stock**, to address a critical challenge in flow and process balancing;
- **Enable real-time shop floor data collection – digitalisation**, with the potential to significantly enhance production monitoring;
- Expansion of the structured **problem-solving approach to other types of defects** observed in the process, based on the methodology applied to the window issue;
- Continued engagement in **kaizen improvement activities** as a natural step in contributing to a production environment guided by TPS, where small, incremental improvements are the foundation of operational excellence.

These opportunities reinforce the notion that continuous improvement is not a finite effort, but a long-term process of observation, collaboration, and commitment to the sustained development of the production system.

Ultimately, this project reaffirmed a lesson that transcends technical mastery: excellence is not an end point, but a habit, cultivated daily through humility, discipline, and the relentless pursuit of better ways. In an era that often celebrates speed and disruption, the Toyota Way teaches that true progress is quiet, steady, and human-centered. To improve is to care, for the product, for the process, and above all, for the people. And it's in this quiet care, repeated day after day, that greatness takes root.

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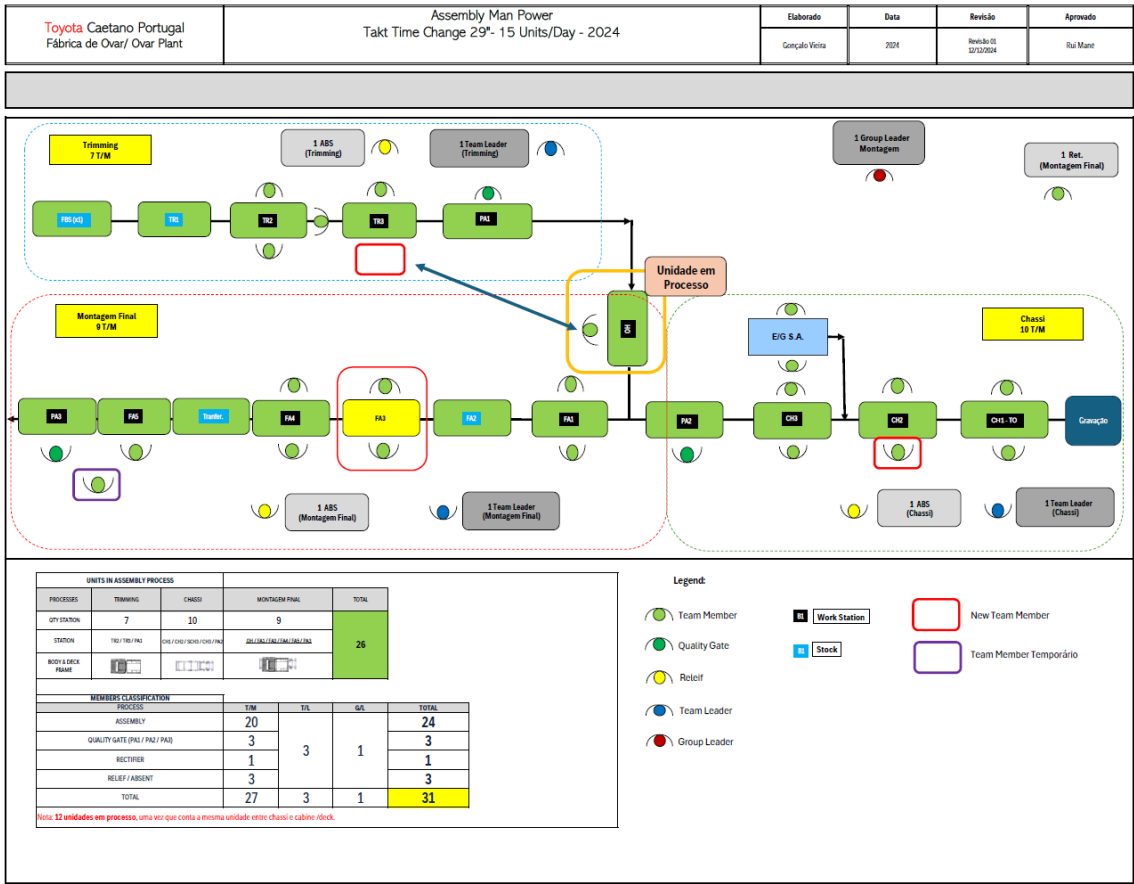


Figure A.2: Manpower - Final Assembly line

		D S S D S D S D S												D 47%							
		0,66 0,28 0,21 0,02 0,04 0,06 0,28 0,26 0,19 2,00												S 53%							
Takt time		28 1																			
		0,31 0,15 0,11 0,01 0,02 0,03 0,15 0,12 0,1																			
DESCRITO		GD				GR				HZ				VD				Nr.Op			
Processo	Sub-Processo	AC	AX	AM	AN	AP	AQ	AR	AS	AT	D/C	S/C	Temp. VA med. D/C	Temp. VA med. S/C	Temp. VA med.	Temp. VNA D/C	Temp. VNA S/C	Temp. VNA med.			
1. TRIMMING	WIP 5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0,0	29,0	29,0	29,0			
	TR1 LH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0,0	29,0	29,0	29,0			
	TR1 RH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0,0	29,0	29,0	29,0			
	TR2 LH	23,2	23,2	23,2	22,7	22,6	23,4	23,3	23,2	23,2	1	1	24,8	19,3	22,0	4,2	9,7	7,0			
	TR2 RH	22,6	23,0	22,0	23,1	22,5	25,6	25,0	23,6	23,0	1	1	24,8	19,3	22,0	4,2	9,7	7,0			
	TR2 EC	24,6	25,4	24,6	26,0	25,4	25,4	24,8	24,8	24,8	1	1	24,8	19,3	22,0	4,2	9,7	7,0			
	TR3	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	24,9	1	1	24,9	24,9	24,89	4,1	4,1	4,11			
	PA1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1	1	0,0	0,0	0,00	29,0	29,0	29,00			
	OH	17,7	20,2	20,2	17,7	21,7	16,9	20,2	18,2	21,5	1	1	17,8	20,5	19,15	11,2	8,5	9,85			
		TOTAL												7	8	64,4	64,7	66,07	17,8	18,7	78,9
2. CHASSIS	WIP 5	14,0	14,0	14,0	14,0	14,0	14,0	14,0	14,0	14,0	0	0	14,0	14,0	14	15,0	15,0	15			
	CH1 LH	21,1	20,8	21,6	21,6	21,2	19,8	19,7	19,3	19,2	1	1	22,1	22,0	22,05	6,9	7,0	6,95			
	CH1 RH	22,3	21,9	22,5	22,8	22,8	21,4	21,7	21,8	21,8	1	1	22,1	22,0	22,05	6,9	7,0	6,95			
	CH2 LH	22,5	24,7	24,7	10,6	12,9	9,2	14,4	8,1	10,3	1	1	20,1	20,3	20,19	8,9	8,7	8,81			
	CH2 RH	13,3	12,8	12,8	14,4	15,5	16,1	16,2	15,6	15,7	1	1	20,1	20,3	20,19	8,9	8,7	8,81			
	CH3 LH	17,3	19,1	19,7	18,1	18,1	17,4	17,3	18,1	18,0	1	1	18,5	19,7	19,10	10,5	9,3	9,90			
	CH3 RH	18,5	19,2	19,2	20,2	20,3	18,1	18,8	18,5	21,3	1	1	18,5	19,7	19,10	10,5	9,3	9,90			
	SH3 LH	21,8	16,1	21,8	18,5	18,5	14,4	14,4	16,8	16,8	1	1	20,0	17,0	18,48	9,0	12,0	10,52			
	SH3 RH	17,3	15,1	17,3	17,0	17,0	8,8	8,8	15,8	15,8	1	1	20,0	17,0	18,48	9,0	12,0	10,52			
		TOTAL												10	8	94,7	93,0	93,8	17,1	16,1	89,2
3. MONTAGEM FINAL	WIP 7	20,2	19,8	19,8	21,5	21,0	19,4	19,0	19,1	18,6	1	1	22,2	22,2	22,21	6,82	6,76	6,79			
	FA1 LH	21,7	21,8	21,3	24,9	24,5	23,3	22,9	23,1	22,7	1	1	22,2	22,2	22,21	6,82	6,76	6,79			
	FA2 LH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0,00	29,00	29,00	29,00			
	FA2 RH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0,00	29,00	29,00	29,00			
	FA3 LH	23,7	0,0	1,5	22,3	0,0	22,3	0,0	23,6	0,8	1	1	24,0	0,9	12,41	5,03	28,15	16,59			
	FA3 RH	21,5	0,0	0,0	21,5	0,0	21,5	0,0	25,2	2,9	1	1	24,0	0,9	12,41	5,03	28,15	16,59			
	FA4 LH	25,2	23,2	24,5	25,1	23,9	25,1	23,9	25,1	23,4	1	1	26,5	26,8	26,66	2,51	2,16	2,34			
	FA4 RH	26,7	26,6	27,0	26,4	26,7	27,1	27,4	25,8	26,1	1	1	26,5	26,8	26,66	2,51	2,16	2,34			
	TRANSFER	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0	0	0,0	0,0	0	29,0	29,0	29			
		TOTAL												9	8	65,9	75,4	85,2	10,1	13,5	117,8
		TOTALS												26	23	259,1	231,0	245,1	262,9	291,0	276,9
														%		50%	44%	47%	50%	56%	53%
														Horas (hh:mm)		4:19	3:51	4:05	4:22	4:50	4:36

Figure A.3: Times per station, Final Assembly (per model and engine variants)

Takt time	29					Tempo de ciclo		Tempo VA		Tempo VNA			
Posto	Ordem da Operação	Descrição das Operações	Tempo Simples (s)	Tempo Dupla (s)	simples	dupla	simples	dupla	simples	dupla			
QC1 IN	1	Montagem e aparência de componentes interior carro	1538	1485	28,63	29,55	0	0	29	29			
	2	Acrescento 1 cabine dupla - montagem e aparência	0	108									
	3	Levar carro para QC seguinte (QC2)	50	50									
	4	Ficha técnica	25	25									
QC1 OUT	5	Folhas técnicas + registros + problema detetado	105	105	28,80	29,37	0	0	29	29			
	4	Ficha técnica	25	25									
	5	Folhas técnicas + registros + problema detetado	105	105									
	6	Autocolante chave ficha técnica + colar etiquetas	25	25									
	7	Aparência exterior e interior carro	1488	1348									
QC1 MED	8	Acrescento cabine dupla - aparência	0	174	28,72	29,46	0	0	29	29			
	9	Folhas + confirmar FT + decaique VIN	85	85									
QC2	14	Pintura compartimento motor + capô	175	175	13,50	29,38	0	0	29	29			
	15	Montagem compartimento motor + capô	75	75									
	16	Inspeção componentes compartimento motor	355	355									
	17	Verificar óleo motor	10	10									
	18	Acrescento 2 cabine dupla - montagem e aparência	0	953									
	10	Confirmar VIN chassis + chapa de identificação + nt motor + VIN para brisas	50	50									
	11	Confirmar FT especificações deck	10	10									
	12	Confirmar FT especificações cabine	80	80									
QC3	13	Confirmar FT especificações compartimento motor	55	55	29,05	29,52	11,8	11,8	17,2	17,2			
	19	Colocar carro elevador alinhamento (QC3) + pratos alinhamento + sensores + trancador	205	205									
	20	Alinhamento	690	690									
	21	Confirmar apertos e selar	217	225									
	22	Montagem componentes inferior carro	330	350									
	24	Guardar EPI's + retirar sensores + retirar trancador	130	130									
	25	Aperto segurança volante e selar	18	18									
	26	Levar carro para posto seguinte	38	38									
QC4	27	Levar comando + colocar filtro carro	40	40	29,13	29,63	15,6	16,1	13,4	12,9			
	30	Confirmar apertos rodas	75	75									
	27	Levar comando + colocar filtro carro	40	40									
	28	Funcionamento chaves	75	75									
	29	Afinação luzes	130	130									
	31	Confirmar aperto volante	15	15									
	32	Teste funcionamento luzes	45	45									
	33	Teste travões + side slip + velocidades + gravar e imprimir dados	415	415									
	34	Rpm motor (Hz)	105	105									
	35	Abzir cortinas + subir rolos	25	25									
	36	Confirmar testes	50	50									
	QC5	37	Leitura dados	121							121	27,8	28,8
38		Inserir dados unidade seguinte	40	40									
39		Montar airbag + confirmar buzina	60	60									
40		Confirmar códigos programa Gk3	337	337									
41		Colocação Wrap Guard	290	320									
41		Colocação Wrap Guard	290	320									
42		Levar carro para elevador QC5 + registrar quadro	70	70									
43		Verificar aperto airbag + montar tampas	25	25									
44		Confirmar fugas compartimento motor + inferior	205	205									
45		Confirmar apertos segurança + selar	100	105									
46		Confirmar especificações FT inferior	30	30									
47		Descer elevador + retirar pedaleira + guardar EPI's	80	80									
48		Teste de pista	515	515									
Total (min)	49	Funcionamento escovas e esguichos + levar carro para QC5	52	52	128,2	146,8	34,1	35,3	110,9	109,7	Lead time	145,0	
	50	Verificar entrada de água	105	120									
	51	Colocar material especificações no carro	85	85									
	52	Registrar saída de linha + levar carro para retificação ou ABC	80	80									
	23	Aplicar sprays	30	40									
									23,5%	24,3%	76,5%	75,7%	
Total (horas)					2,1	2,4	0,6	0,6	1,8	1,8	Lead time	2,42	
							23,9%		76,1%				

Figure A.4: Times per station - Final Inspection

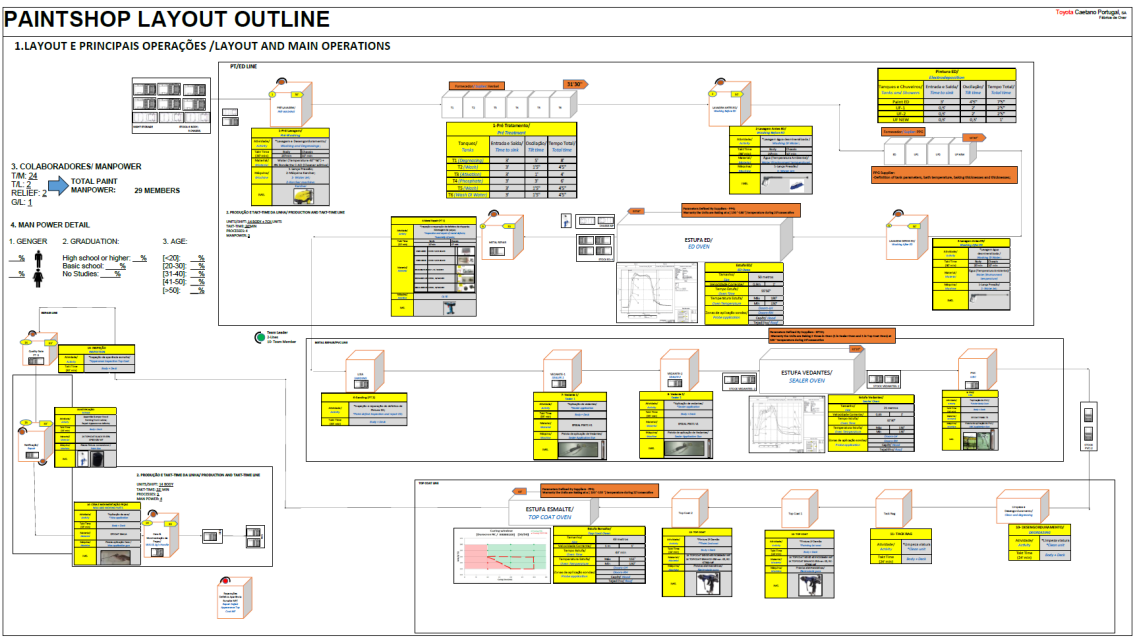


Figure A.5: PaintShop Layout

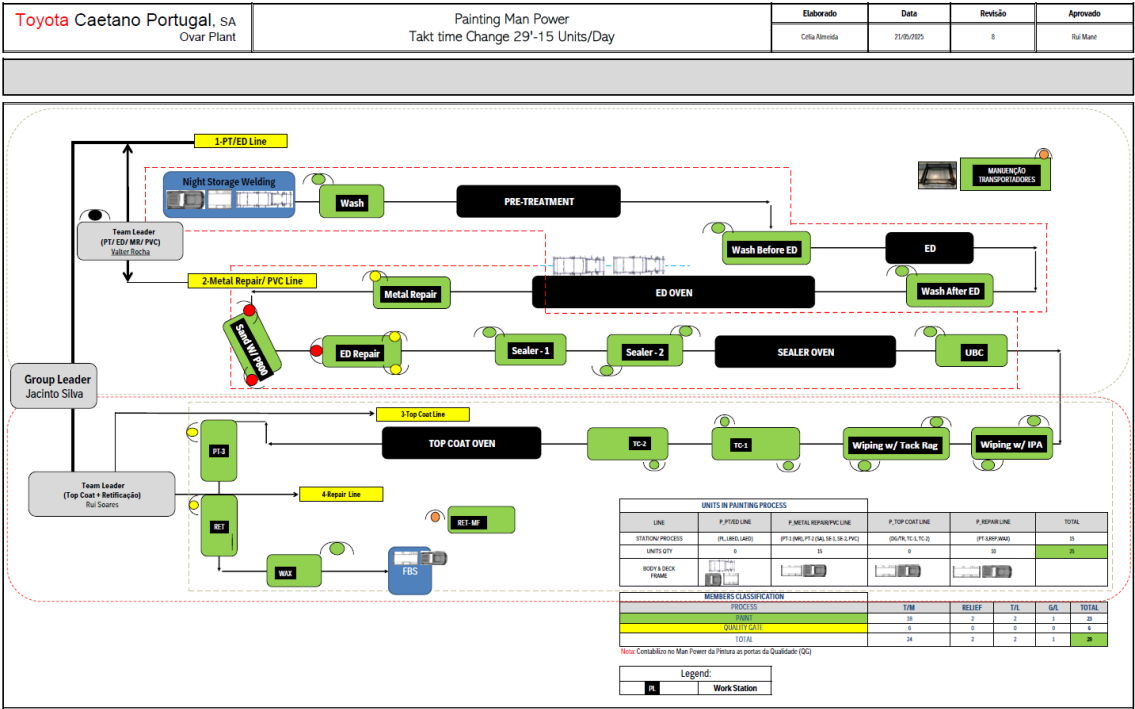


Figure A.6: Manpower - Painting

Takt time		29										
DESCRITIVO		S/C	D/C	Nr. Op		Temp VA S/D	Temp VA D/C	Temp VA Méd.	Temp. V/NA S/D	Temp. V/NA D/D	Temp. V/NA Méd.	Takt time Total
Processo	Sub-Processo			S/C	D/C							
1. SPP Body	B1	14,60	12,60									
	B2	4,50	3,93									
	PMB2	3,23	3,23	1	1	22,33	19,77	21,05	6,67	9,23	7,95	29
	Move body B1-B2	1,00	1,00									
	Move front PM1-B4	0,50	0,50									
	B3 LH	15,63	19,33									
	B3 RH	13,33	16,29	2	2	18,94	21,91	20,43	10,06	7,09	8,58	29,0
	PMB1	5,62	5,62									
	Move body B2-B3	1,00	1,00									
	B4	13,68	13,12									
2. SPP Deck	D1 LH	21,98	17,84									
	D1RH	21,41	17,96	2	2	21,41	17,84	19,63	7,59	11,16	9,375	29
	TOTAL			2,00	2,00	21,41	17,84	19,63	7,59	11,16	9,375	29,0
3. Metal Finish	MF1 LH	9,52	16,45									
	MF1 RH	9,35	15,72	2	2	9,52	16,45	13,0	19,48	12,55	16,01666667	29
	MF2 BODY	17,90	21,68									
	MF2 DECK	23,05	25,15	2	2	23,05	25,15	24,1	5,95	3,85	4,9	29
	QCW2 - BODY	0,00	0,00	1	1	0,00	0,00	0,0	29,00	29,00	29	29
	QCW2 - DECK	0,00	0,00									
4. Frame Line				5,00	5,00	32,57	41,60	37,08	54,43	45,40	49,32	87,0
	F1+F2+F3 LH	22,25	23,07	2	2	26,58	27,07		2,42	1,93		
	F1+F3 RH	26,58	27,07									
	Robot F1	15,03	14,44									
	Picking	5,25	5,25	0	0	15,03	14,44	49,01			8,99	29
	Move frame F1-F2	1,15	1,15						6,42	7,21		
	Robot F2	7,55	7,35	0	0	7,55	7,35					
	Move frame F2-F3	1,15	1,15									
	F3_INSP LH	0,00	0,00	1	1	7,13	5,12	6,13	21,87	23,88	22,88	29
	F3_clean	7,13	5,12	1	1							
TOTAL				4,00	4,00	56,30	53,97	55,14	30,70	33,03	31,87	58,0
Night storage frame 7												#REF!
TOTALS		0,00	0,00	15,0	15,0	165,2	168,2	166,7	124,8	121,8	123,3	261,0
				%		57%	58%	57%	43%	42%	43%	90%
Lead time		174	min	Horas (hh:mm)		2:45	2:48	2:46	2:04	2:01	2:03	4:21

Figure A.9: Times and Lead time - Welding

LOGÍSTICA INTERNA		Operadores	Tempo Total (p/dia, p/ CKD)	Média p/ carro (min)
Processo	Sub-Processo			
1. Logística Soldadura	Unpacking	1	416	29,0
	(+2 porta qualidade)	1	405,4	29,0
	Picking	1	422	29,0
		1	326	16,0
TOTAL		4	1569,4	103
2. Logística MF&Trimming	Unpacking	1	154,0	23,0
		1	153,8	23,0
		1	133,0	26,0
		1	131,6	27,0
		2	177,0	20,0
	BP	1		29,0
		1		21,0
		1		25,0
		1		26,0
	MIZUSUMASHI	1		24,0
	MIZUSUMASHI	1		24,0
	Pré-Montagem	2		36,0
	Porta Qualidade	1		29,0
TOTAL		15	749,3	333,0
3. Logística CHASSI	Unpacking	1	145,2	30,0
		1	145,2	30,0
		1	115,2	26,0
		1	148,9	28,0
	BP	1		27,0
		1		17,0
4. Empilhadores	Picking	1		20,0
		1		17,0
		1		17,0
	Recolha Retomáveis			
	Abs. Unpacking Soldadura	1	185,9	25,0
	Abs. Unpacking M.F&Trimming & pxp	1	185,9	18,0
TOTAL	Troca de contentores ecocentro			
	Baton pass MF	1	56,1	11,0
	Troca base pintura			
	Descarga/Arrumo	1	470	32,0
TOTAL		4	897,9	86,0
TOTAIS		29		717,0
Horas (hh:mm)				11:57
44		VNA		1,53

Figure A.12: Times - Logistics

p/carro	TT Soldadura	TT CHASSIS	TT M.F.	TOTAL min
Abast. Unpack	25,00	-	29,00	54,00
Unpacking	58,00	114,00	119,00	291,00
Picking	45,00	81,00	214,00	340,00
TOTAL	128,0	195,0	362,0	685,0
Horas (hh:mm)	2:08		6:02	11:25
%	19%	28%	53%	72%

TEMPO DE UNPACKING PARA COMEÇAR PRODUÇÃO	323	MIN
WORKFORCE	0,69	DAYS
	13	

Figure A.13: Lead Time - Logistics

Pré-Processo		
Tempo de order-sair Japão	23	~dias
Tempo em mar (Japão-PT)	65	~dias
Tempo Porto ()-TCAP Ovar	5	1~5 dias
Regularidade de envio de Forecasts (Japão-TCAP Ovar)	1-2/mês	
Regularidade entrega CKD (TCAP<->Japão)	3camiões/dia	
Regularidade devoluções CKD (TCAP<->Japão)	-	
Tempo CKD fica em stock (min)	8	120
Tempo CKD fica em stock (max)	12	180
Produção diária	15	un
Tempo total de stock	16	
Unpacking ckd	0,69	
Total antes prod	110	dias

Figure A.14: Pre-process, factory

Pós-Processo		
Tempo em stock (produto acabado em YARD)	2	~dias
Média de unidades em stock (produto acabado em YARD)	30	calculado com base
Tempo transporte SANTANDER	2	
Tempo chegada ao cliente	19	~dias
LEAD TIME TOTAL T-CAP (min)	1216,06	minutos
LEAD TIME TOTAL T-CAP (hh:mm)	17:46	hh:mm
LEAD TIME TOTAL T-CAP (days)	2,59	dias
Nr de min trabalhados por dia	470	min
Takt time	29	min
Units/day	16	un
Units/week	80	un

Figure A.15: Post-Process, factory

A.2 Figures

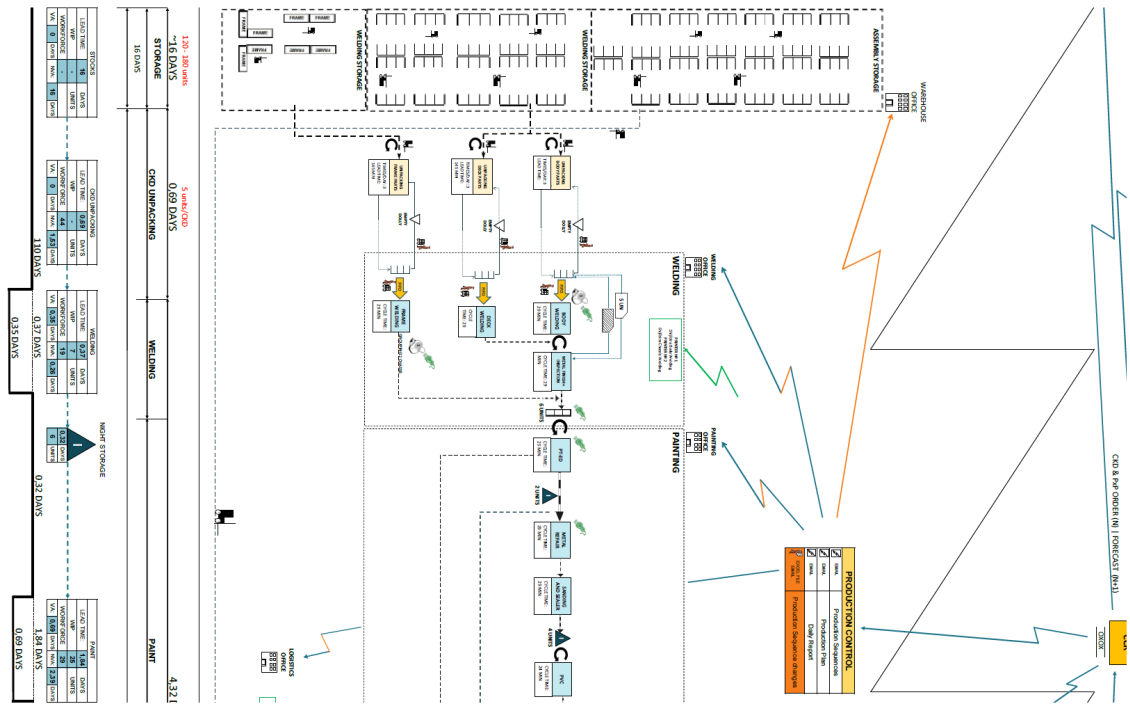


Figure A.16: VSM - Internal, pt1

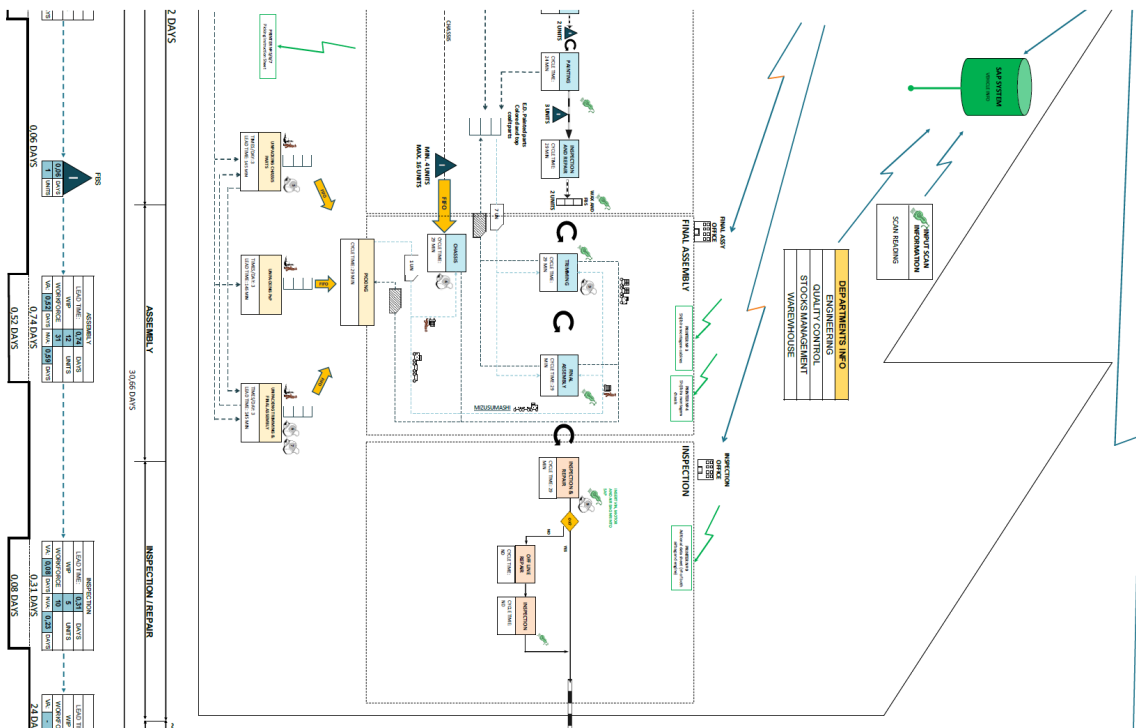


Figure A.17: VSM - Internal, pt2

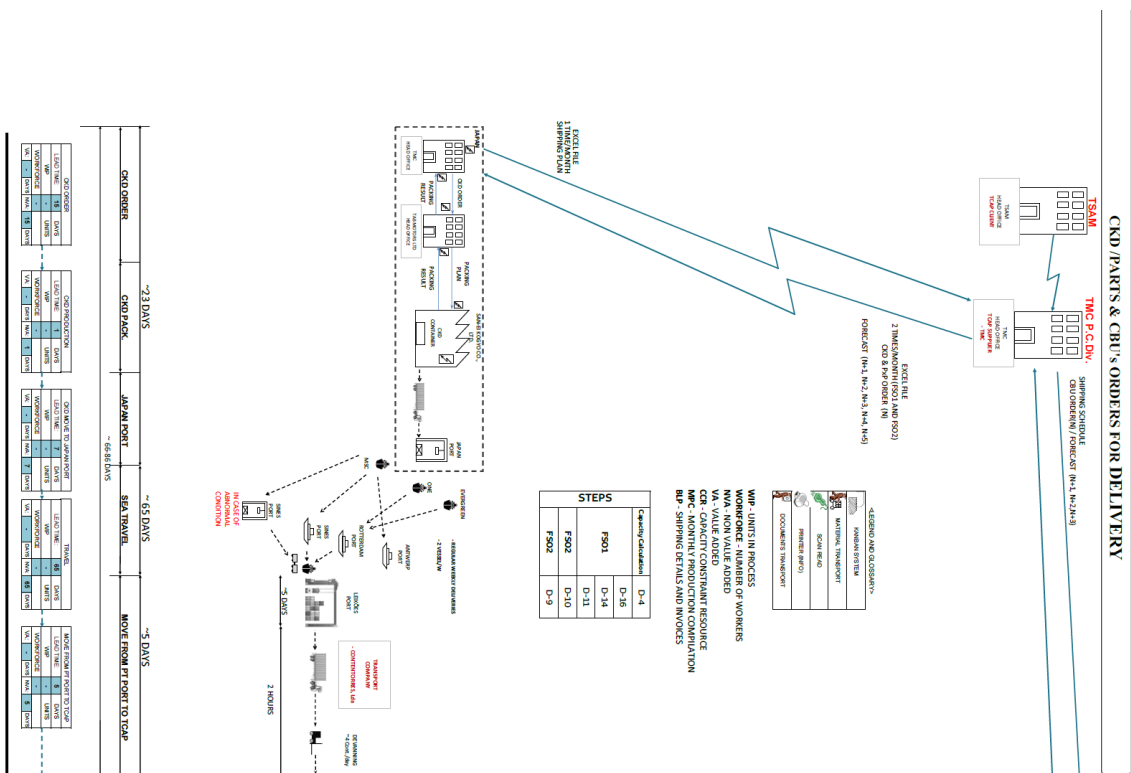


Figure A.18: VSM - Inbound

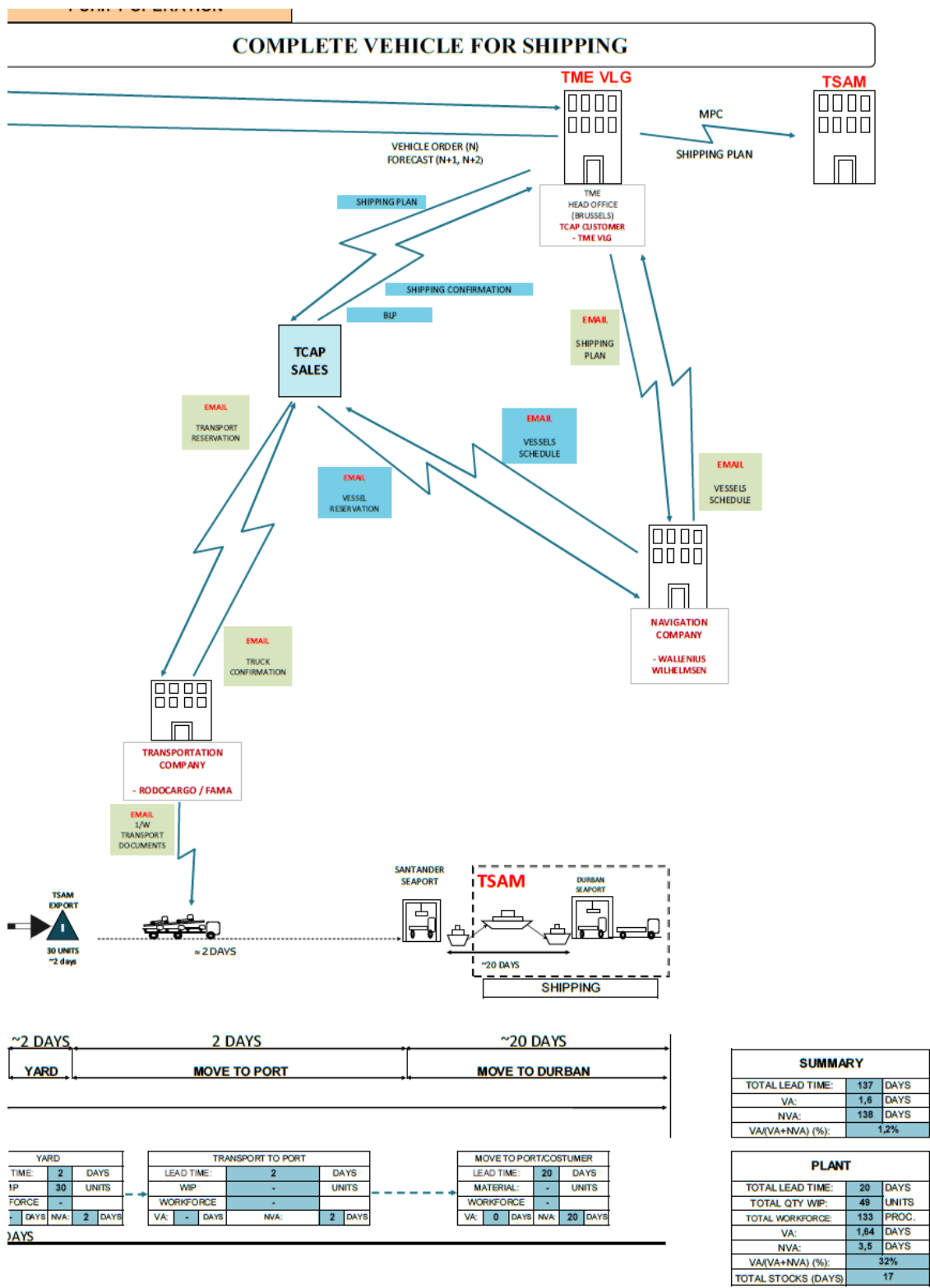


Figure A.19: VSM - Outbound



Figure A.20: VSM displayed at the Engineering Office

Appendix B

Problem Solving

B.1 Tables, Graphs and EWS's

TOYOTA CAETANO PORTUGAL, SA
OVAR PLANT

Folha Detalhe da Operação
ELEMENT WORK SHEET - EWS

Modelo
TOYOTA

Alíquot
-

Processo
-

Seção
M.FINAL

Matéria
1/2

Colocar proteções para montagem do vidro

Forma Proteção

L3

L2

L1

LR

CR

RR

CF

C2

C1

C3

LF

CF

RF

R3

R2

R1

1 Pegar forra

2 Posicionar forra

Pegar forra 1 no dolly de apoio, como ilustrado

Posicionar forra na zona do raspador exterior

1

1

1

2

1º

2º

3º

4º

PEGAR FORRA

POSICIONAR FORRA

1º - INTRODUZIR CANTO INFERIOR DIREITO DA FORRA NA CAVIDADE DO VIDRO, NA PORTA.
2º - INSERIR O RESTANTE DA FORRA NA PORTA ATÉ GABARIT ENCAIXAR NA PORTA.
3º - POSICIONAR GABARIT O MAIS ENCOSTADO À ZONA DO PUXADOR.
4º - POSICIONAR/RODAR GABARIT ENCOSTADO AO LADO EXTERIOR DA PORTA, GARANTINDO QUE OS ÍMANES FICAM ENCONSTADOS À MESMA.

segurança

qualidade

segurança

conexão elétrica

prova de água

data

13/06/2025

MS DS

Item Regulamentado

ISO 14001

autocontrolo

Quality point

Group leader

Team leader

Imprimi

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Figure B.1: EWS Protection installation - 1

TOYOTA CAETANO PORTUGAL, SA
OVAR PLANT

Folha Detalhe da Operação
E252671 WORK SHEET - EWS

Código da operação		Operação	1. desenho	2. ferramenta	3. localização (ou part)	4. material	5. tempo
YJAA00258		Colocar proteções para montagem do vidro		Forra Proteção	L2		
Nº	part number	part name	qtd./vet.	coluna			
1							
2							
3							
4							
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98							
99							
100							

1 Pegar forra

2 Posicionar forra

1º - INTRODUZIR CANTO INFERIOR ESQUERDO/DIREITO DA FORRA NA CAVIDADE DO VIDRO, NA PORTA.

2º - INSERIR O RESTANTE DA FORRA NA PORTA ATÉ GABARIT ENCAIXAR NA PORTA.

3º - GARANTIR CORRETO POSICIONAMENTO (A MEIO) DA PROTEÇÃO NA PORTA (AS DUAS PROTEÇÕES DEVEM FICAR COMO ILUSTRADO NA IMAGEM).

PEGAR FORRA

POSICIONAR FORRA

Segurança

Atenção

Qualidade

Formação

Engenharia

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Figure B.2: EWS Protection installation - 2

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Figure B.3: EWS Window installation - 1

[illegible]

Figure B.5: EWS Protection Removal

Figure B.6: WSS updated - TR3

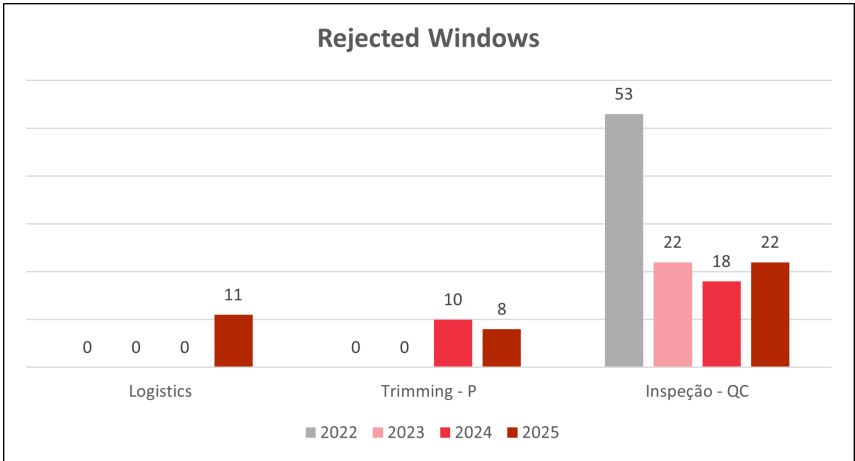


Figure B.7: Rejected Windows - area

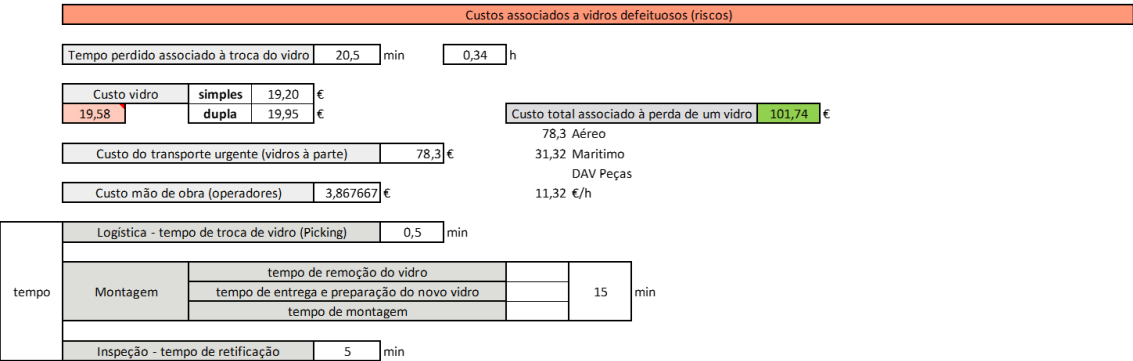


Figure B.8: Cost Analysis

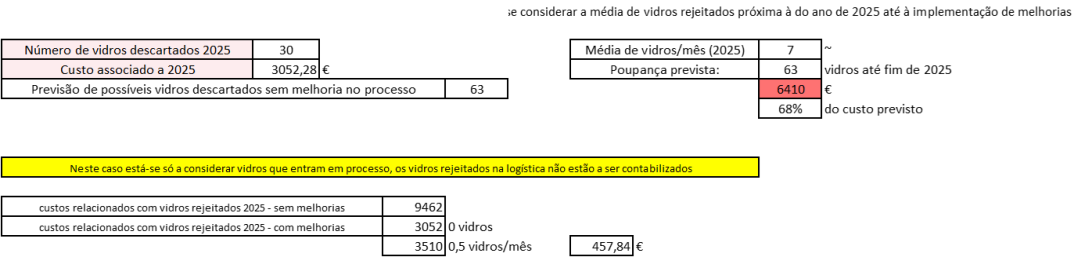


Figure B.9: Cost Analysis - predicted costs

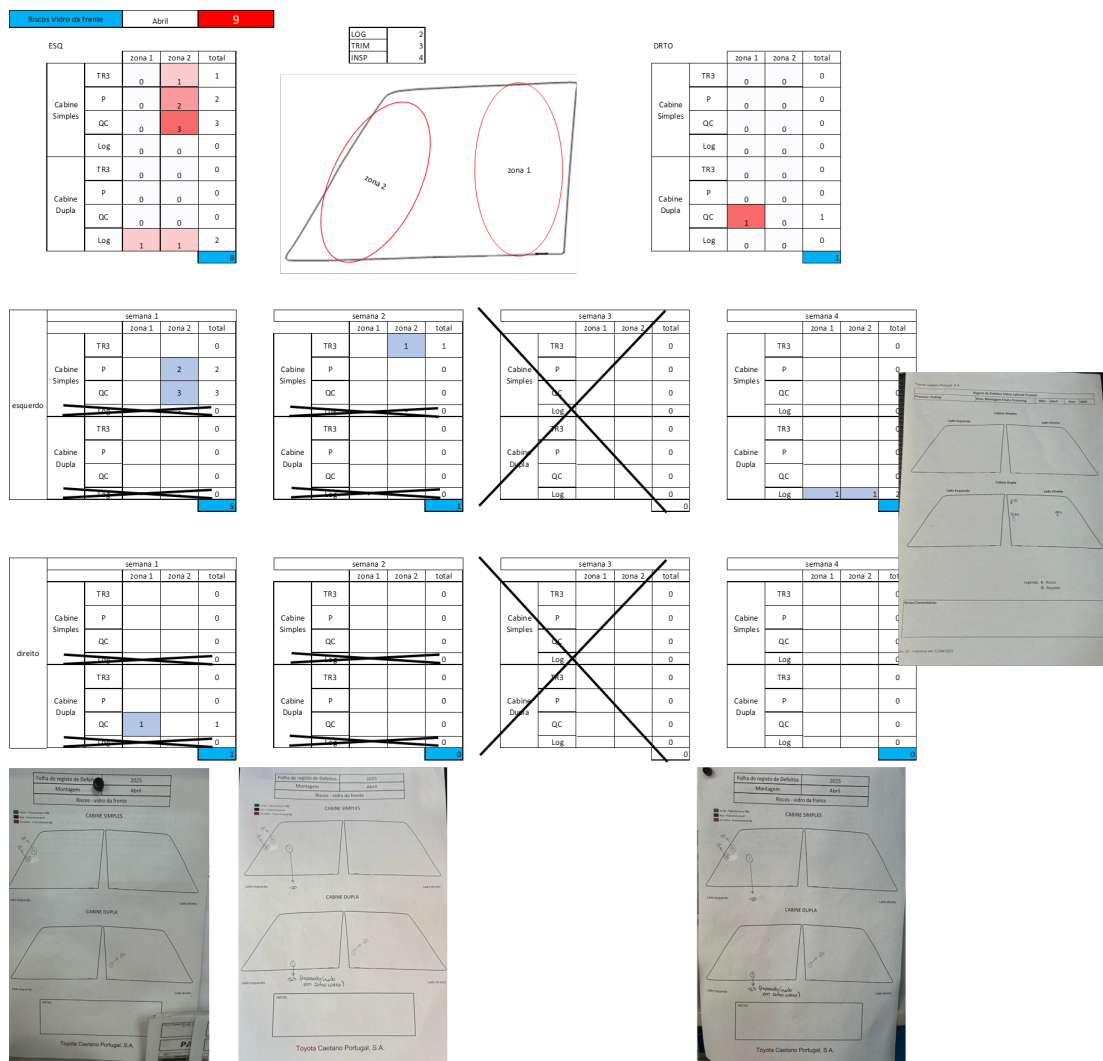
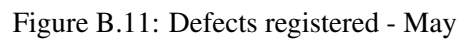


Figure B.10: Defects registered - April



B.2 Figures



Figure B.13: Window unpacking - log



Figure B.14: Window inspection - log



Figure B.15: Window loading to dolly - log



Figure B.16: Window stored in dolly - line



Figure B.17: Dolly in Mizusumashi route - Transportation



Figure B.18: Window handling - TR3



Figure B.19: Window assembly

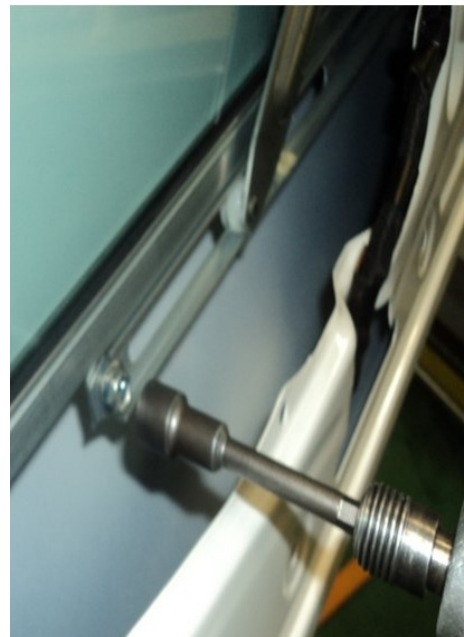


Figure B.20: Window tightening



Figure B.21: Components inside door frame during window installation



Figure B.22: Window functional testing



Figure B.23: Window cleaning and inspection



Figure B.24: Window lowered until Final Inspection



Figure B.25: Raising the window, QC1



Figure B.26: Final inspection window, QC1

Toyota Castano Portugal, S.A.

Registo de Defeitos Vidros Laterais Frontais			
Processo: Picking	Área: Montagem Final e Trimming	Mês: Abril	Ano: 2025

Cabine Simples

Lado Esquerdo

Lado Direito

Cabine Dupla

Lado Esquerdo

Lado Direito

Legenda: X - Riscos
O - Roçados

Notas/Comentários:

Figure B.27: Defect registration sheet for logistics



Figure B.28: Protection testing - inserting



Figure B.29: Protection testing - placing



Figure B.30: Protection testing - window sliding



Figure B.31: - Protection testing – internal



Figure B.32: Protection testing – removal



Figure B.33: Protection testing – storing

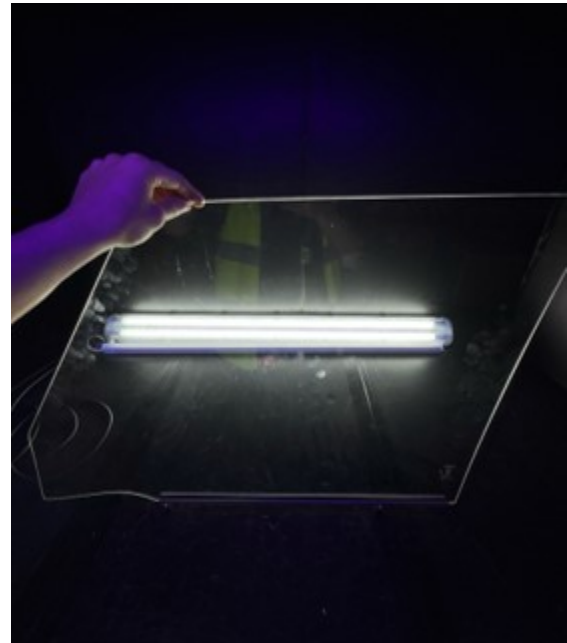


Figure B.34: Window inspection at LOG, before

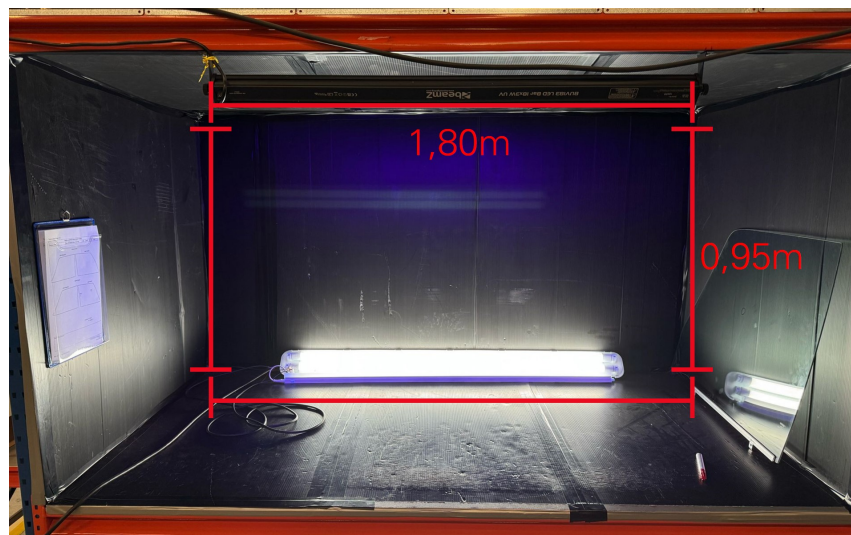


Figure B.35: Light units configuration, idea

Appendix C

Kaizen Improvements

C.1 Tables, Graphs and EWS's

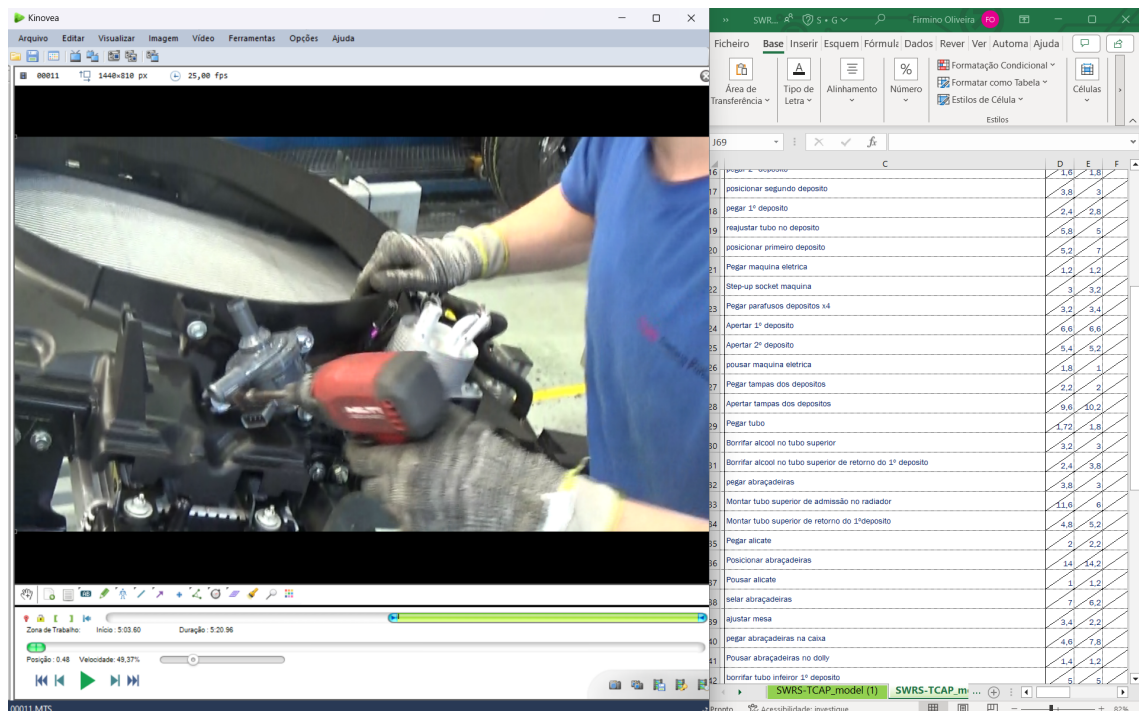


Figure C.1: Time study example in Kinovea

Toyota Cactano Portugal, S.A.			Registo Posição Video Tempo Operação		Modelo: LC70		Posto: CH3 LH								
Our Plant					Linha: Chassi		Produção: 15								
Standardised Work Recording Sheet					Colaborador:		Takt-Time: 29								
					Data:		Página: 1								
Cat.	Nº.	Job Element	Tempo por job element										Min	Max	Flutuação
			1	2	3	4	5	6	7	8	9	10			
AW		Pegar Bulb na caixa	5,56										5,56	5,56	0
VW		Apertar proteção	25	20									20	25	5
AW		Ajustar mesa	2,68	2,8									2,68	2,8	0,12
AW		Pousar máquina	1	1,12									1	1,12	0,12
MU		Pegar e pousar máquina		2,52											
AW		Pegar e pousar intercooler no dolly	2,6	3,12									2,6	3,12	0,52
AW		Pegar bulb na caixa	3,2	2,08									2,08	3,2	1,12
VW		Apointar bulb no intercooler	10,2	9,24									9,24	10,2	0,96
AW		Pegar máquina elétrica	2,4	1,28									1,28	2,4	1,12
VW		Apertar bulb no intercooler	8,28	7,48									7,48	8,28	1,2
AW		Pousar máquina elétrica	1,92	1,8									1,8	1,92	0,12
VW		Posicionar intercooler no radiador	7,8	8,8									7,8	8,8	1
AW		Pegar fêmeas na caixa	3,4	5									3,4	5	1,6
VW		Apointar fêmeas no intercooler	8,2	10									8,2	10	1,8
AW		Posicionar mesa de montagem	2,8	2,24									2,24	2,8	0,56
AW		Pegar máquina e mudar socket	5	5,8									5	5,8	0,8
VW		Apertar fêmeas no intercooler	13	13,6									13	13,6	0,6
AW		Ajustar mesa	3,2	1,44									1,44	3,2	1,76
AW		Pousar máquina		0,88											
AW		Pegar tubo no dolly	1,8	1,8									1,8	1,8	0
AW		Aplicar lubrificante	4	3									3	4	1
AW		pegar abraçadeira na caixa bulb e inserir no tubo	1,4	2,08									1,4	2,08	0,68
VW		montar tubo no radiador	5,4	5,6									5,4	5,6	0,2
AW		Pegar máquina e bulb na caixa	2,8	2,48									2,48	2,8	0,32
VW		Apertar fêmeas no tubo	5,4	6									5,4	6	0,6
AW		Pousar máquina elétrica	1,32	1,28									1,28	1,32	0,04
AW		Pegar alicate no dolly	1	1									1	1	0
AW		Ajustar abraçadeira no tubo	9	11									9	11	2
AW		Pousar alicate	0,8	0,8									0,8	0,8	0
AW		Selar abraçadeira	5,2	5									5	5,2	0,2
AW		Pegar máquina	1,6	1,6									1,6	1,6	0
AW		Pegar parafuso na caixa	5,6	5,68									5,6	5,68	1,08
AW		pegar tubo metálico no dolly	8,2	3,08									3,08	8,2	5,12
VW		apertar tubo metálico ao radiador	18,2	7									7	18,2	9,2
MU		apenhar bulb no chão	2,2										2,2	2,2	0
AW		Pegar radiador do óleo da caixa automática	2,2	3									2,2	3	0,8
VW		Apertar radiador do óleo ao radiador	15	11,4									11,4	15	3,6
AW		Pegar suporte da válvula no dolly	3	3,52									3	3,52	0,52
VW		apertar suporte da válvula ao radiador	8,4	8									8	8,4	0,4
AW		Pousar máquina elétrica	1,4	1,32									1,32	1,4	0,08
AW		Retirar proteções e colocar no fixo	4,8	3,6									3,6	4,8	1,2
AW		pegar abraçadeiras na caixa	4,6	4,6									4,6	4,6	0,2
AW		Borrifar tubos	5,6	3,08									3,08	5,6	2,52
VW		Inserir abraçadeira e posicionar tubo 1	4,4	5,8									4,4	5,8	1,4
AW		Pegar tubos de borracha	2,6	3,6									2,6	3,6	1
AW		Borrifar tubos de borracha do radiador do óleo	5,6	5									5	5,6	0,6
VW		Inserir abraçadeiras	3,32	9									3,32	9	5,68
VW		Posicionar tubo 2	6,2	7,6									6,2	7,6	1,4
VW		Inserir abraçadeiras no tubo	3,2	1,64									1,64	3,2	1,56
VW		Posicionar tubo no radiador do óleo vs radiador	9,2	13,4									9,2	13,4	4,2
AW		Pegar alicate no dolly	1,4	2									1,4	2	0,6
VW		Posicionar abraçadeira nos tubo metálico vs radiador	4,6	6,6									4,6	6,6	2
VW		Posicionar abraçadeira nos tubo 1 vs radiadores	9,6	11,6									9,6	11,6	2
VW		Posicionar abraçadeira nos tubo 2 vs radiadores	13,4	11,4									11,4	13,4	2
AW		Pousar alicate	1,4	2									1,4	2	0,6
AW		Selar abraçadeiras 5x	7,8	11,6									7,8	11,6	3,8
													0	0	0
													0	0	0
			293,9	287,6	0	0	0	0	0	0	0	0	0	293,9	293,9

Figure C.2: SWRS Radiator pre-assy, 1

Toyota Caetano Portugal, S.A.

Over Plant

Registo Posição Video

Tempo Operação

Modelo: LC70

Linha: Chassi

Colaborador:

Data:

Plata: CH3 LH

Produção: 15

Teto-Time: 29

Página: 2

Standardised Work Recording Sheet

Cat.	Nº.	Job Element	Tempo por job element										Min	Max	Flutuação
			1	2	3	4	5	6	7	8	9	10			
AW		Ajustar mesa	1,4	1,8								1,4	1,8	0,4	1,6
AW		Pegar parafusos	2,2	2,2								2,2	2,2	0	2,2
AW		Pegar maquina electrica	2,08	2								2	2,08	0,08	2,04
AW		Pegar bomba	2,52	2								2	2,52	0,52	2,26
VW		Montar bomba electrica de baixa temperatura	8	8								8	8	0	8
AW		pousar maquina electrica	1	1,6								1	1,6	0,6	1,3
AW		ajustar mesa	2,2	2								2	2,2	0,2	2,1
AW		pegar obturadores na caixa x2	2,4	2,8								2,4	2,8	0,4	2,6
VW		montar obturadores no radiador	5	5,8								5	5,8	0,8	5,4
AW		pegar 2º deposito	1,6	1,8								1,6	1,8	0,2	1,7
VW		posicionar segundo deposito	3,8	3								3	3,8	0,8	3,4
AW		pegar 1º deposito	2,4	2,8								2,4	2,8	0,4	2,6
AW		reajustar tubo no deposito	5,8	5								5	5,8	0,8	5,4
VW		posicionar primeiro deposito	5,2	7								5,2	7	1,8	6,1
AW		Pegar maquina electrica	1,2	1,2								1,2	1,2	0	1,2
AW		Step-up socket maquina	3	3,2								3	3,2	0,2	3,1
AW		Pegar parafusos depositos x6	3,2	3,4								3,2	3,4	0,2	3,3
VW		Aperter 1º deposito	6,6	6,6								6,6	6,6	0	6,6
VW		Aperter 2º deposito	5,4	5,2								5,2	5,4	0,2	5,3
AW		pousar maquina electrica	1,8	1								1	1,8	0,8	1,4
AW		Pegar tampas dos depositos	2,2	2								2	2,2	0,2	2,1
VW		Aperter tampas dos depositos	9,6	10,2								9,6	10,2	0,6	9,9
AW		Pegar tubo	1,72	1,8								1,72	1,8	0,08	1,76
AW		Borrifar alcool no tubo superior	3,2	3								3	3,2	0,2	3,1
AW		Borrifar alcool no tubo superior de retorno do 1º deposito	2,4	3,8								2,4	3,8	1,4	3,1
AW		pegar abraçadeiras	3,8	3								3	3,8	0,8	3,4
VW		Montar tubo superior de admissão no radiador	11,6	6								6	11,6	5,6	8,8
VW		Montar tubo superior de retorno do 1ºdeposito	4,8	5,2								4,8	5,2	0,4	5
AW		Pegar alicata	2	2,2								2	2,2	0,2	2,1
AW		Posicionar abraçadeiras	14	14,2								14	14,2	0,2	14,1
AW		Pousar alicata	1	1,2								1	1,2	0,2	1,1
AW		sellar abraçadeiras	7	6,2								6,2	7	0,8	6,6
AW		ajustar mesa	3,4	2,2								2,2	3,4	1,2	2,8
AW		pegar abraçadeiras na caixa	4,6	7,8								4,6	7,8	3,2	6,2
AW		Pousar abraçadeiras no dolly	1,4	1,2								1,2	1,4	0,2	1,3
AW		borrifar tubo inferior 1º deposito	5	5								5	5	0	5
AW		pegar abraçadeira no dolly	0,6									0,6	0,6	0	0,6
VW		Montar tubo inferior do 1º deposito no radiador	6,4	5								5	6,4	0,4	5,2
AW		pegar alicata	1,4	1,6								1,4	1,8	0,4	1,6
VW		Posicionar abraçadeira	6,8	26,8								6,8	26,8	20	16,8
AW		pousar alicata	1	1								1	1	0	1
AW		sellar abraçadeira	5,4	4,4								4,4	5,4	1	4,9
AW		Ajustar mesa	2,2	2								2	2,2	0,2	2,1
AW		Pegar tubos do dolly e posicionar abraçadeiras	15,4	15								15	15,4	0,4	15,2
AW		borrifar tubos	9,2	8,8								8,8	9,2	0,4	9
VW		Montar tubos no radiador (x6)	36,4	33,6								33,8	35,4	1,6	34,6
AW		pegar alicata	1,2	1,2								1,2	1,2	0	1,2
VW		posicionar abraçadeiras (x6)	54,6	43,4								43,4	54,6	11,2	49
AW		Pousar alicata	1	1								1	1	0	1
AW		Sellar abraçadeiras	13,2	15								13,2	15	1,8	14,1
AW		Confirmar montagem	15,8	17,8								15,8	17,8	2	16,8
AW		pegar abraçadeiras na caixa	4,4	5								4,4	5	0,6	4,7
VW		Inserir nos tubos	9,2	9								9	9,2	0,2	9,1
			3,4	0,72								0,72	3,4	2,68	2,06
												0	0	0	0
												0	0	0	0
			330,1	335,1	0	0	0	0	0	0	0	0	335,1	335,1	628,34

MODA

4,72

AW

273,88

VW

347,66

Figure C.3: SWRS Radiator pre-assy, 2

	Crealiti Hi 3D Printer	439 €
	Original Prusa MK4S Kit	819 €
Filamentos, por 1kg		
	Prusament PLA Jet Black 1kg	29,99 €
	eSUNePLA-SS Fire Engine Red, 1,75 mm / 1000 g	13,39 €
custo por grama de PLA		0,03 €
		0,01 €
Interno	Proteções Centralina: 1º mês	
	nº de proteções	30
	Dimensões aproximadas	
	comprimento	16 cm
	largura	6 cm
	profundidade	4 cm
	Volume	384 cm ³
	espessura da proteção	2,5 mm
	densidade do preenchimento (infill)	15%
	Volume do material	57,6 cm ³
	Peso em PLA	55 g
	custo em PLA	1,64945 €
	tempo de impressão	6 h (~)
	Peso total	1650 g
	custo total peças	49 €
	poupança	136 €
		73%
Outras impressões mensal		
Gasto de PLA previsto	650 g (~)	
Custo associado	19 €	
% do custo em relação a ser num fornecedor externo	30%	
Custo se fosse forn.	65 €	
poupança	45 €	
	70%	

Figure C.4: Analysis assumptions/conditions - 3D printing, 1

externo	Fornecedor de impressão 3D	custo da impressão 1 un	10 € (min)	6 € (min)	várias un
			20 €(max)	9 €(max)	
		custos de transporte	5 € (min)		
			10 €(max)		
		custo total	185 € (min)		
			280 €(max)		

abatimento do custo da impressora	31%
	17%

Figure C.5: Analysis assumptions/conditions - 3D printing, 2

Mês	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Gastos PLA (g)		1650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
Custo impressão interna (€)		49	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Custo impressão externa (€)		185	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
Abatimento custo imp 3D (1)		31%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Abatimento custo imp 3D (2)		17%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Abatimento acumulado (1)	0%	31%	41%	52%	62%	72%	83%	93%	103%	114%	124%	134%	145%	155%	166%	176%	186%	197%
Abatimento acumulado (2)	0%	17%	22%	28%	33%	39%	44%	50%	55%	61%	67%	72%	78%	83%	89%	94%	100%	105%
Savings (€)	0	136	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Cumulative Savings	0	136	181	226	272	317	363	408	454	499	545	590	636	681	727	772	818	863
Custo da impressora em falta (1)	439	303	258	213	167	122	76	31	-	-	-	-	-	-	-	-	-	-
Custo da impressora em falta (2)	819	683	638	593	547	502	456	411	365	320	274	229	183	138	92	47	1	-44
Pinter Investment (Creality)	-439	-303	-258	-213	-167	-122	-76	-31	15	60	106	151	197	242	288	333	379	424
Pinter Investment (Prusa)	-819	-683	-638	-593	-547	-502	-456	-411	-365	-320	-274	-229	-183	-138	-92	-47	-1	44

Figure C.6: Financial analysis for printers – ROI

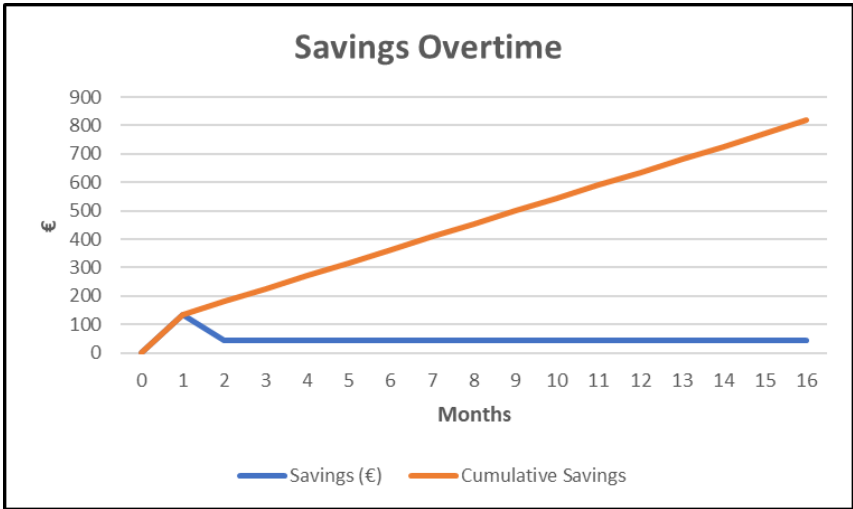


Figure C.7: Savings Over time - 3D printer solution

TOYOTA CAETANO PORTUGAL, SA
OVAR PLANT

Folha Detalhe da Operação
ELEMENTO EWS - 945

PRODUTO: T0005 4600-05 / 02
PROCESSO: Parking brake cable support bracket assembly
M.FINAL: S6

Ordem de operação	Operação	E. Descrição	Material	Quantidade	Tempo (seg)
1	MONTAR TRAVÃO DE MÃO	90 s			
11	APONTAR FÊMEA	Apontar primeira fêmea no cabo do travão de mão		1	
12	Posicionar gabarit de afinação do travão	Posicionar Gabarit de afinação do travão entre a cabine e a alavanca		1	
13	APERTAR FÊMEA	Apertar primeira fêmea no cabo do travão de mão até atingir o valor tabelado no manómetro (0,2000~0,2100 Mpa)		1	

Atenção:
1º - Posicionar Gabarit entre cabine e alavanca (manómetro para cima)
2º - Desbloquear Travão (pressionar botão)
3º - Acondicionar alavanca no gabarit

Cálculo valor Manómetro
Força: 192 N
Área de contato: 962,1128 mm²
(D=35mm; A=π*(35/2)²)
Pressão: 0,200 MPa (F/A)

Atenção:
Valor de Pressão a Observar no Manómetro:
0,2000 ~ 0,2100 MPa

1~3 fios de rosca

APONTAR FÊMEA

POSICIONAR GABARIT

APERTAR FÊMEA

Atenção:
90°

Segurança
Risco: ...
Medidas: ...
Quilómetros: ...
Formação: ...
Data: ...
Assinatura: ...

Revisão
1. Emissão do documento: 05/05/2018
2. Atualização Documento (Quick POKA YOB): 22/04/2023

Figure C.8: Updated EWS for handbrake assembly

C.2 Figures



Figure C.9: Controller contact, 1



Figure C.10: Controller contact, 2



Figure C.11: Controller contact, 2



Figure C.12: Controller contact, 4

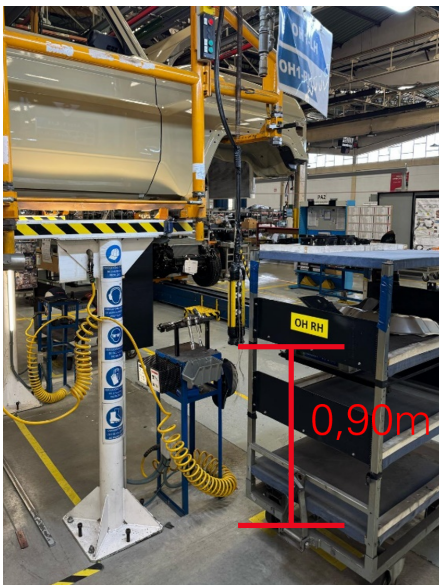


Figure C.13: Minimum height - controller position



Figure C.14: Maximum height - controller position



Figure C.15: Controller and cable weight

FLEX TYPE B

Model B1 / Modello B1

Model Modello	Loading capacity kg Capacità di carico kg	Weight kg Peso kg	Length mm Lunghezza mm	Size/Dimensioni Width mm Larghezza mm	Thickness mm Spessore mm	Cord length mt Lunghezza fune mt
FLEX 0,5-1	0,5-1	0,6	165	110	56	2,3
FLEX 0,5-1,5	0,5-1,8	0,6	165	110	56	2,3
FLEX 1-2	1-2	0,65	165	110	56	2,3
FLEX 2-3,5	2-3,5	0,65	165	110	56	2,3

Steel wire / Cavo in acciaio

Model Modello	Loading capacity kg Capacità di carico kg	Weight kg Peso kg	Length mm Lunghezza mm	Size/Dimensioni Width mm Larghezza mm	Thickness mm Spessore mm	Cord length mt Lunghezza fune mt
FLEX 0,5-1A	0,5-1	0,6	165	110	56	2,3
FLEX 0,5-1,5A	0,5-1,5	0,6	165	110	56	2,3
FLEX 1-2A	1-2	0,65	165	110	56	2,3
FLEX 2-3,5A	2-3,5	0,65	165	110	56	2,3

Model B2 / Modello B2

Model Modello	Loading capacity kg Capacità di carico kg	Weight kg Peso kg	Length mm Lunghezza mm	Size/Dimensioni Width mm Larghezza mm	Thickness mm Spessore mm	Cord length mt Lunghezza fune mt
FLEX 3-6A	3-6	1,64	230	160	76	2,3
FLEX 5-8,5A	5-8,5	1,7	230	160	76	2,3
FLEX 8-11A	8-11	1,75	230	160	76	2,3

Nylon rope (only on demand) / Con cavo in nylon (solo su richiesta)

Model Modello	Loading capacity kg Capacità di carico kg	Weight kg Peso kg	Length mm Lunghezza mm	Size/Dimensioni Width mm Larghezza mm	Thickness mm Spessore mm	Cord length mt Lunghezza fune mt
FLEX 3-6	3-6	1,64	230	160	76	2,3
FLEX 5-8,5	5-8,5	1,7	230	160	76	2,3
FLEX 8-11	8-11	1,75	230	160	76	2,3

FEATURES

- Metal housing
- 14 models selected for a load range from 0,1 to 11 kg
- Adjustable spring load through out a safety removable andle
- Adjustable rope stroke
- Available with nylon braided rope or steel braided nylon coated wire
- Tools in conformity with CE directives

CARATTERISTICHE

- Scocca in metallo
- 14 modelli per coprire un campo di carico tra 0,1 e 11 kg
- Carico della molla regolabile mediante leva di sicurezza removibile
- Corsa del cavo regolabile
- Disponibili con corda in nylon intrecciato o cavo in acciaio rivestito in nylon
- Conforme alle normative CE

Figure C.16: Balancer - flex type B

FLEX TYPE C

Model Modello	Leading capacity kg Capacità di carico kg	Weight kg Peso kg	Length mm Lunghezza mm	Size/Dimensioni Width mm Larghezza mm	Thickness mm Spessore mm	Cord length mt Lunghezza fune mt
FLEX-3	1-3	1,4	290	148	69	1,5
FLEX-5	3-5	1,5	290	148	69	1,5
FLEX-9	5-9	3,4	340	174	136	1,5
FLEX-15	9-15	3,8	340	174	136	1,5
FLEX-22	15-22	7,2	428	218	158	1,5
FLEX-30	22-30	8,5	428	218	158	1,5
FLEX-40	30-40	9,8	428	220	188	1,5
FLEX-50	40-50	10,4	428	220	188	1,5
FLEX-60	50-60	11,6	428	220	188	1,5
FLEX-70	60-70	11,8	428	220	188	1,5
FLEX-90	70-90	27	571	264	305,5	2,1
FLEX-105	85-105	29	571	264	305,5	2,1
FLEX-120	100-120	30	571	264	305,5	2,1

FEATURES

- Metal housing
- 13 models selected for a load range from 1 to 120 kg
- Adjustable spring load
- Adjustable rope stroke
- Steel rope
- Safety device against spring break off
- Tools in conformity with CE related directives

CARATTERISTICHE

- Scocca in metallo
- 13 modelli per coprire un campo di carico tra 1 e 120 kg
- Carico della molla regolabile
- Corsa del cavo regolabile
- Cavo in acciaio
- Dispositivo di sicurezza contro la rottura della molla
- Conforme alle normative CE



Figure C.17: Balancer, flex type c



Figure C.18: Balancer System installation



Figure C.19: Spring Balancer System installed

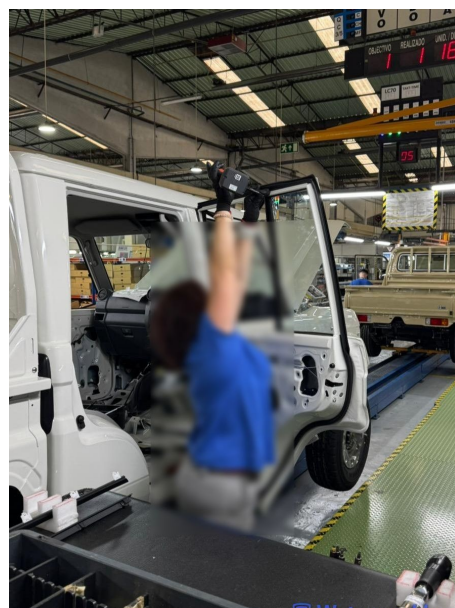


Figure C.20: Operator struggle to reach higher positions

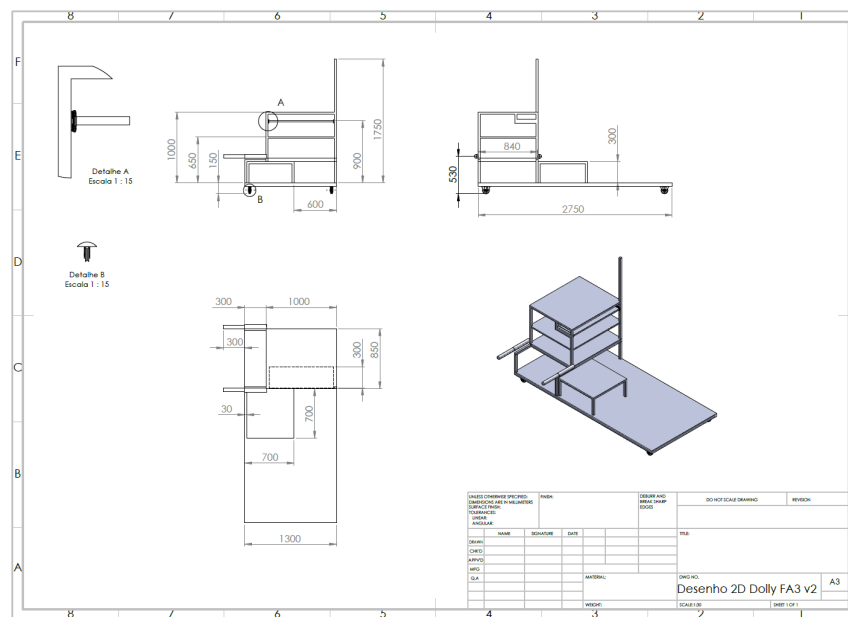




Figure C.24: Locking pin

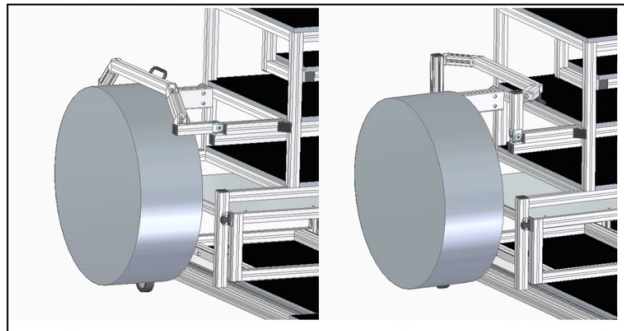


Figure C.25: New coupling mechanism



Figure C.26: Buffer installation



Figure C.27: Step locking system, before - Ergonomic risk



Figure C.28: Wheel support for side step



Figure C.29: Operator safety risk, when close to the car – need for additional step

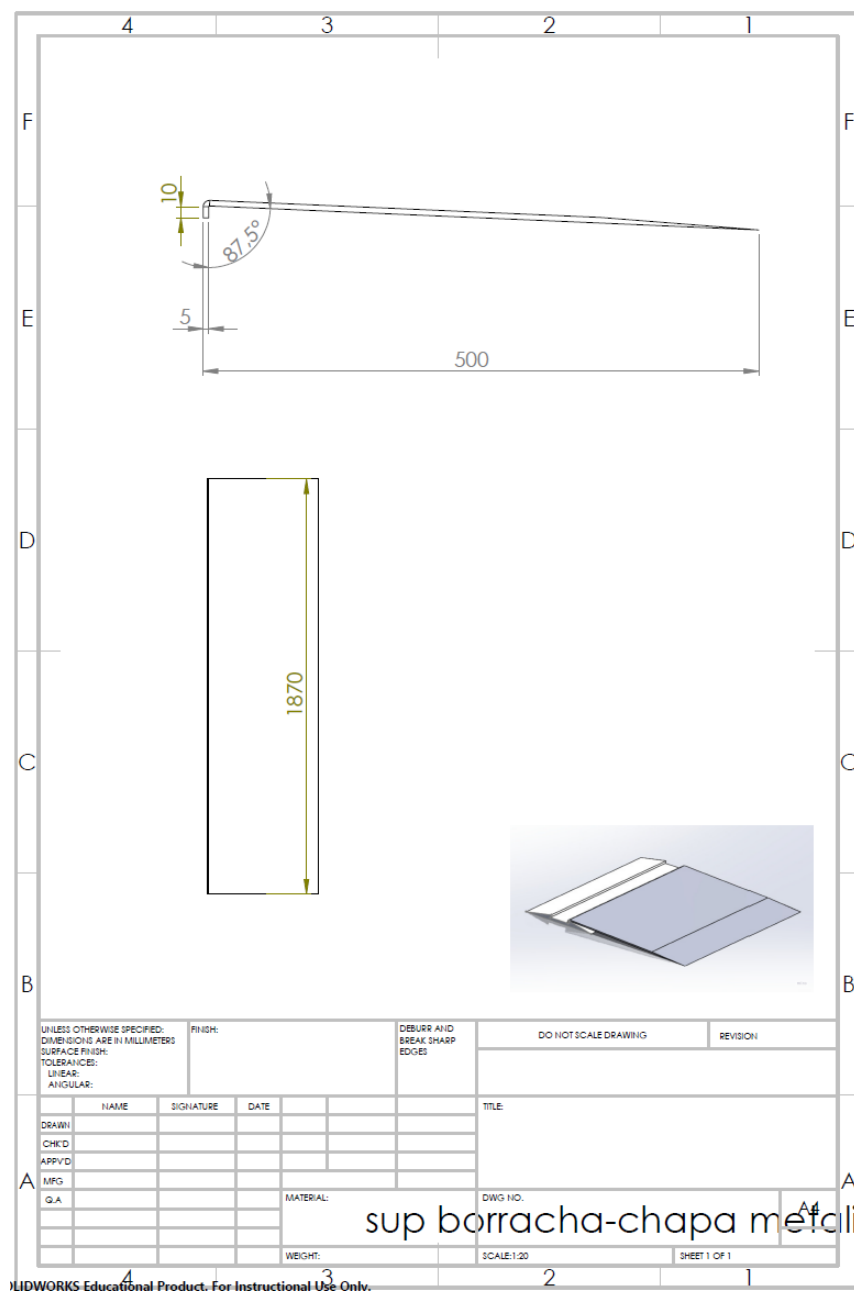


Figure C.30: Mizu ramp, technical drawing

Toyota Caetano Portugal, S.A.

[illegible]

Figure C.31: Defect sheet - fallen parts from mizu

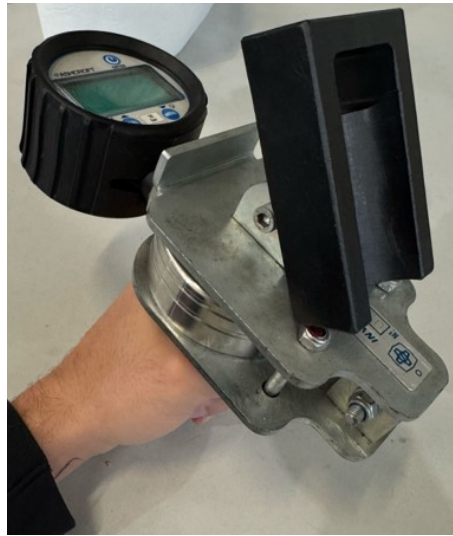


Figure C.32: Instrument based on a load cell - handbrake assembly