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Logística Interna e Otimização de Estratégias para Abastecimento de Linhas de Produção

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Internal Logistics and Optimization of Strategies for Supplying Production Lines

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Abstract

This dissertation addresses the optimization of internal logistics within an automotive production environment through the development and evaluation of two integrated digital solutions: a Pick-to-Light system for material picking and a mobile *Andon* system for real-time anomaly escalation and recording. The study was conducted at a vehicle assembly plant and guided by the Design Science Research methodology, which supported a structured process of problem identification, artifact conceptualization, prototyping, and evaluation. The research began with the mapping and analysis of current logistics operations, revealing inefficiencies such as picking errors, inconsistent part documentation, and the absence of a structured anomaly management system. To respond to these challenges, a prototype was developed using commercially available software tools, simulating the functional logic of the envisioned systems. The Pick-to-Light prototype aimed to enhance accuracy, reduce operator cognitive load, and support line balancing through visual guidance, while the mobile *Andon* mechanism enabled immediate support requests and structured anomaly registration. Evaluation of the prototype demonstrated the practical feasibility of the proposed solutions, although several technological limitations were identified. Overall, the work validates the potential of lean-aligned digital tools to improve logistics traceability, responsiveness, and standardization, laying the foundation for future industrial implementation and broader digital transformation.

KEYWORDS: Toyota Production System, Internal Logistics, Pick-to-Light, *Andon* System, Picking Optimization, Automotive Sector

Resumo

Esta dissertação tem como objetivo a otimização dos processos logísticos internos numa linha de montagem automóvel, através do desenvolvimento e avaliação de duas soluções digitais: um sistema *Pick-to-Light* para apoio ao abastecimento de peças à linha de montagem, e um sistema *Andon* que permita aos operadores logísticos chamar por auxílio em tempo real e o registo estruturado de anomalias. O estudo decorreu na fábrica da Toyota Caetano Portugal, em Ovar, no contexto da produção do modelo *Land Cruiser* Série 70, e foi conduzido segundo os princípios da metodologia de *Design Science Research*, que se foca em criar soluções para melhorar processos industriais já existentes.

A primeira fase da investigação consistiu na caracterização da realidade operacional logística da empresa, com foco na área de montagem final. Foram identificadas várias ineficiências nos processos, destacando-se: atrasos e erros de *picking*, documentação standard desatualizada e ausência de mecanismos estruturados para a deteção, escala e registo de anomalias. Estas falhas não só comprometem a fluidez do processo produtivo como também resultam em paragens da linha, com impacto direto na eficiência global da produção.

Face a este cenário, foi proposta a conceção de uma solução digital integrada, alinhada com os princípios do Sistema de Produção *Toyota* e da filosofia *Lean*. A solução idealizada compreende dois componentes principais: um sistema *Pick-to-Light*, que visa digitalizar o processo de *picking* de peças, eliminando listas em papel e orientando os operadores através de sinais visuais e sensores de confirmação; e um sistema *Andon* adaptado à realidade dos operadores logísticos, que permite sinalizar rapidamente problemas e garantir o registo das intervenções realizadas pelos supervisores.

Dado o tempo limitado do estágio e a impossibilidade de implementar uma solução completa com recursos externos, optou-se pelo desenvolvimento de um protótipo funcional, capaz de simular as principais funcionalidades pretendidas. O protótipo foi desenvolvido com recurso a ferramentas do *Microsoft Office (Power BI* e *Power Apps*), já disponíveis na infraestrutura digital da empresa, e concentrou-se na área da estação FA4, selecionada com base numa análise de *Pareto* que identificou esta zona como uma das mais críticas em termos de anomalias logísticas. O processo de desenvolvimento envolveu o mapeamento da localização de peças nas prateleiras e *dollies* do supermercado FA4, bem como a construção de bases de dados estruturadas e interfaces gráficas interativas.

O sistema *Pick-to-Light* foi simulado através de *dashboards* que reproduzem visualmente as localizações de peças e validam as escolhas feitas pelos operadores. O sistema *Andon* foi implementado em duas *Power Apps* distintas, uma para o pedido de suporte por parte do operador e outra para o registo da anomalia por parte do supervisor, ambas integradas numa base de dados central. Apesar de não incluir sensores físicos nem integração com sistemas de produção em tempo real, o protótipo demonstrou a lógica funcional e validou a viabilidade prática da solução proposta.

A avaliação foi conduzida com base na comparação entre os cenários *"as-is"* e *"to-be"*, tanto no que diz respeito ao *picking* de materiais como à gestão de anomalias. A análise mostrou que, no estado atual, os processos dependem fortemente de documentação em papel, verificações manuais e comunicação informal, fatores que contribuem para erros recorrentes e baixa rastreabilidade. Por contraste, o cenário futuro idealizado permitirá reduzir a carga cognitiva dos operadores, melhorar a padronização de tarefas, acelerar a resposta a anomalias e garantir a existência de registos históricos completos e fiáveis. Embora o protótipo ainda não permita recolher dados empíricos para aferir os objetivos quantitativos definidos, a avaliação qualitativa confirmou a pertinência das funcionalidades desenvolvidas e o alinhamento com os princípios da filosofia *Lean*.

As limitações do protótipo (ausência de sensores, a falta de integração em tempo real com o sistema de sequenciamento de produção e a separação entre as interfaces de alerta e registo de anomalias) refletem os constrangimentos tecnológicos e orçamentais do projeto. No entanto, estas lacunas não comprometem a validade do conceito proposto, servindo antes como guias para melhorias futuras. Entre os desenvolvimentos recomendados incluem-se: a integração do sistema com o *software* de gestão da empresa, a substituição dos cliques manuais por sensores de movimento, a fusão das aplicações *Power Apps* numa única plataforma e o desenvolvimento de painéis de controlo para análise de dados e apoio à decisão.

Conclui-se, assim, que a aplicação de ferramentas digitais simples, concebidas com base nos princípios da filosofia *Lean*, e adaptadas ao contexto real das operações, pode gerar ganhos significativos em termos de fiabilidade, rastreabilidade e eficiência dos processos logísticos internos. O protótipo desenvolvido constitui uma base sólida para evoluções futuras dos processos em vigor e representa uma contribuição prática e académica relevante para a digitalização de processos da logística na indústria automóvel.

PALAVRAS-CHAVE: Sistema de Produção *Toyota*, Logística Interna, *Pick-to-Light*, Sistema *Andon*, Otimização do *Picking*, Setor Automóvel

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Acronyms

Acronyms

AGV	Automated Guided Vehicle
AT	Automatic Transmission
BoL	Border of Line
BOM	Bill of Materials
CH	Chassis
CKD	Complete Knock Down
D/C	Double Cab
DSR	Design Science Research
EWS	Element Work Sheet
FA	Final Assembly
FIFO	First In, First Out
GSC	Salvador Caetano Group
JIS	Just-In-Sequence
JIT	Just-In-Time
LC70	Land Cruiser Series 70
LH	Left-Hand Side
MT	Manual Transmission
OH	Overhead
PA	Pre-Assembly
PTL	Pick-To-Light
RH	Right-Hand Side
S/C	Single Cab
SVG	Scalable Vector Graphics
T	Pre-Assembly Table
TCAP	Toyota Caetano Portugal S.A.
TMC	Toyota Motor Company
TPS	Toyota Production System
TR	Trimming
VSM	Value Stream Mapping

1. Introduction

This chapter presents the framework and relevance of the dissertation, outlining the problem under investigation and the circumstances that led to its emergence. It then introduces the research primary and specific objectives, followed by a description of the methodological approach adopted, next, a summary of the hosting company, Toyota Caetano Portugal, S.A. (TCAP), is provided. Finally, the thesis structure is presented.

1.1. Framework and Relevance

The automotive industry stands as one of the most complex and competitive manufacturing sectors in the global economy. Characterized by high product variability, intricate supply chains, demanding quality standards, and ever-tightening cost margins, the industry continuously seeks ways to enhance efficiency and responsiveness while maintaining profitability and customer satisfaction. This dynamic environment places significant pressure on manufacturers to optimize every aspect of their production systems.

Among this context, the Toyota Production System (TPS) has emerged as a foundational model for achieving operational excellence. Developed and refined over decades, TPS integrates lean manufacturing principles with a strong emphasis on waste elimination, continuous improvement, and employee empowerment. Its influence extends well beyond Toyota itself, serving as a benchmark for automotive companies worldwide that aspire to streamline operations, reduce lead times, and improve product quality without incurring excessive costs.

As a company guided by the principles of the TPS, TCAP continuously strives to maintain its competitiveness through increasingly efficient and standardized processes. TPS serves not only as a production philosophy but also as a strategic framework for eliminating waste, optimizing workflows, and ensuring high levels of responsiveness throughout the value chain. In such an environment, the logistics function plays a pivotal role, particularly in supporting production by ensuring that the right parts arrive at the right place, in the right quantity, and at the right time.

This academic research contributes directly to these objectives by focusing on the optimization of supply strategies within the logistics area. Through the analysis and redesign of part-feeding methods this study aims to enhance material flow, reduce operational inefficiencies, and support the broader goals of TPS implementation at TCAP. In doing so, it bridges academic inquiry with industrial application, reinforcing the relevance of logistics process improvement as a key enabler of production system performance.

Therefore, this research holds both practical and theoretical relevance: it contributes to the academic literature on lean logistics and production system design, while also addressing real-world challenges faced by automotive manufacturers striving for greater efficiency and adaptability in the picking processes. In doing so, it aligns with the dual objective of deepening scholarly understanding and supporting industry efforts to build cost-effective and high-performance production systems.

1.2. Objectives

The primary objective of this research is to analyze and optimize the supply strategy within the logistics operations of an automotive production environment, in alignment with the principles of the TPS. The study seeks to contribute to the continuous improvement of internal logistics processes by identifying inefficiencies, evaluating current material feeding methods, and proposing targeted solutions that support cost control, process standardization, and overall operational efficiency.

This academic work focuses on the specific context of TCAP, where logistics performance is critical to maintain a stable production flow and support Just-In-Time (JIT) delivery. By applying a structured and evidence-based approach, the research aims to provide actionable insights that reinforce the company's commitment to lean principles and competitiveness.

To achieve the primary objective, the study is guided by the following specific objectives:

- To map and characterize the current logistics processes, with an emphasis on part-feeding strategies used on the production line.
- To identify critical inefficiencies or anomalies in the current system, particularly those that compromise supply flow or trigger production delays.
- To design and propose an optimized feeding solution tailored to the operational constraints and goals of the selected case within the plant.
- To evaluate the feasibility and expected impact of the proposed solution, considering its alignment with TPS principles, digital integration opportunities, and potential gains in productivity, traceability, and responsiveness.

1.3. Methodology

Design Science Research (DSR) (Peffers et al., 2007) was the research method used in this thesis developed as case study in an industrial context. After the literature review to support the work develop options, the selection of DSR as the methodological framework for this study is justified by the nature and objectives of the work, which involves the improvement of existing operational processes in a real industrial context through the design of an artifact, a purposefully designed solution created to address a specific problem or need (Brocke et al., 2020).

1.4. Presentation of the Hosting Company

The work supporting this thesis was conducted in Ovar at Toyota Caetano Portugal S.A. (TCAP), a company part of the Salvador Caetano Group (GSC). TCAP is a benchmark company in the automotive sector in Portugal, with a consolidated track record and a history of success (Toyota Caetano Portugal, 2023a).

The partnership between GSC and Toyota started in 1968, when the group began importing and distributing Toyota vehicles in the Portuguese market. Over the years, a relationship of trust was established with Toyota Motor Corporation (TMC) in Japan, which recognized GSC as a strategic partner for representing and marketing the brand in the country. In 1970, TCAP began TMC's strategy of producing Toyota vehicles in Europe, with the start of vehicle production operations at the Ovar plant. In addition to importing and distributing Toyota vehicles, TCAP plays a key role in providing after-sales services, including maintenance, repair and the sale of Toyota spare parts. The company has a comprehensive network of dealers and authorized workshops throughout Portugal, guaranteeing complete support for Toyota customers (Toyota Caetano Portugal, 2023a).

More information on TCAP's positioning, vision and values can be found in Table 1.

Table 1 - TCAP's Positioning, Vision and Values (Toyota Caetano Portugal, 2023b)

Positioning	Vision	Values
Toyota Caetano Portugal adopts a leadership position in all its areas of activity, underpinned by the values of the GSC. The company is guided by its commitment to its employees and customers, respect for the environment and economic growth.	To be a benchmark in the mobility market, with a focus on the customer, standing out for its ability to innovate, respond to challenges and diversify its offer of quality products and services.	Customer satisfaction Respect Ambition Collaboration

1.5. Thesis Structure

This thesis is structured according to the principles of the DSR methodology, which guides the work through a systematic process of problem identification, artifact conceptualization, design, demonstration, and evaluation. The ultimate objective is to design an integrated solution, comprising a Pick-to-Light (PTL) system and an *Andon* system, to address key inefficiencies in internal logistics operations. Due to limitations in time and company resources, the research resulted in the development of a digital prototype that shows the intended functionality of the envisioned system.

The structure of the thesis is organized into six main chapters:

The first chapter – Introduction - provides the contextual foundation for the thesis. It introduces the relevance of optimizing internal logistics in the automotive industry, emphasizing the role of the TPS in driving efficiency and competitiveness. It establishes the main and specific objectives of the research, presents the adopted methodology, describes the structure of the thesis, and does a short presentation of the hosting company.

The second chapter - State of the Art - presents a review of relevant literature on internal logistics systems in automotive assembly plants. It begins by detailing the activities that comprise inbound logistics, with particular emphasis on the delivery of parts to the production line. The three main part-feeding strategies are analyzed and compared. In the second part of the chapter, the fundamentals of Lean Manufacturing and the Toyota Production System are explored. This review establishes the academic foundation for the study.

The third chapter - Research Context and Problem Identification - introduces the operational reality of Toyota Caetano Portugal, detailing its internal logistics structure and the challenges currently faced on the shop floor. This chapter identifies the logistics inefficiencies, particularly in part feeding execution and anomaly traceability, which motivated this research. It also justifies the selection of the research problem - excessive logistics related anomalies at the assembly line - as a relevant and high impact area for intervention.

The Chapter 4 - Objectives, Design and Development of the Artifact – is divided in two parts. The first part of the chapter defines the conceptual artifact proposed by this study: a Pick-to-Light system, to streamline parts feeding to the assembly line, and an *Andon* mechanism, for real-time digital anomaly reporting and recording. Based on the previously defined problem, this chapter outlines the functional and performance objectives of the solution. It explains how the system is expected to improve logistics operations, and align with Lean principles, thereby forming the foundation for the prototype’s design. The second part portrays the development of a digital prototype that simulates the core functionalities of the proposed integrated solution. Due to time and resource constraints, the full implementation of the system was not feasible within the scope of this research. Instead, a representative prototype was created to demonstrate the intended behavior and value of the solution. This chapter describes how it was made and then the structure, features, and use cases addressed by the prototype and explains how it serves as a proof of concept for the envisioned PTL and *Andon* system.

The Chapter 5 - Demonstration - compares the current (as-is) logistics processes with the improved (to-be) scenario enabled by the proposed systems. It evaluates the potential benefits of the full artifact through the prototype demonstration, considering dimensions such as process standardization, responsiveness, and traceability. This chapter also discusses the limitations of the prototype and its alignment with the original system goals.

Finally, Chapter 6 – Conclusion – summarizes and evaluates the main findings and contributions of the research. It reflects on the practical and academic value of the study, highlights its limitations, and proposes directions for future work, particularly regarding the full implementation and industrial validation of the designed PTL and *Andon* system.

2. State of the Art

This chapter explores the key concepts and strategies related to logistics in the automotive sector, with a particular focus on production line feeding policies and lean manufacturing principles.

The chapter begins by examining the complexity of internal logistics and supply chains in automotive assembly plants, highlighting the challenges posed by fluctuating production volumes, part variability, and the need for efficient material supply systems. It categorizes logistics operations into external logistics, internal logistics, and reverse logistics, with more attention being given to internal logistics.

Next, the chapter presents three primary production line feeding policies: line stocking, sequencing and kitting. The advantages and limitations of each approach are discussed, as well as hybrid strategies that combine elements of different policies to optimize efficiency.

The closing section delves into lean manufacturing principles, emphasizing the Toyota Production System and its fundamental pillars. It explains how lean manufacturing aims to eliminate waste and reduce process variability through continuous improvement, standardized processes, and production leveling.

By synthesizing these insights, this chapter provides the theoretical foundation for the research, supporting the development of optimized logistics strategies to improve the efficiency and reliability of automotive production line supply systems.

2.1. Logistics and Supply Chain Management in the Automotive Sector

The automotive industry has been shaped by decades of optimization efforts aimed at reducing costs and improving efficiency, all while grappling with demand volatility, process uncertainty, and the complexities of global supply chains. These developments have created a dynamic and competitive landscape, compelling companies to build resilient supply chains to navigate this challenging environment (Raaymann & Spinler, 2024).

This reorganization has also redefined the relationships between Original Equipment Manufacturers (OEM's) and suppliers, fundamentally altering the structure of the production process. A focus on fuel efficiency, rising commodity costs, the transition to electric and smart mobility, and shorter development cycles have all contributed to making the automotive sector one of the most competitive industries today. Furthermore, automotive manufacturers face growing pressure from intense global competition and increasingly demanding customers, further amplifying the challenges they must address (Ribeiro et al., 2019).

To gain a competitive edge, many adapt their assembly systems for mass customization, enabling them to offer the variety customers desire while controlling costs and maintaining profitability. Consequently, each vehicle produced is distinct from the one before and after it, equipped with specific options tailored to individual customer requests (Limère et al., 2012).

This has led to mixed-model assembly lines being implemented in most car manufacturing companies. These lines allow to produce different vehicle models in a flexible sequence, as the models share enough commonalities to be processed on the same line. As a result, production orders vary in their Bill of Materials (BOM) based on specific order characteristics (Ostermeier et al., 2023).

This results in a growing number of parts moving through the assembly facility to be delivered to stations, complicating the material supply process compared to standard mass production. Mastering these new logistical and organizational requirements presents a strategic opportunity for companies to surpass their competitors (Limère et al., 2012).

An expanded catalog of options naturally increases the variety of parts that need to be managed. From a logistics perspective, this amplifies uncertainties about the necessary parts, significantly shortening the planning cycles for part logistics and the risk of a stock-out increases (Boysen et al., 2015).

A supply chain risk can be defined as the probability and impact of unforeseen macro and/or micro level events or circumstances that negatively affect any part of a supply chain, resulting in failures or disruptions at the operational, tactical, or strategic levels (Ho et al., 2015). Risks can be categorized in five types as shown in Table 2.

Table 2 - Risk Types and Mitigation Strategies (adapted from Ho et al., 2015; Saad et al.,2024)

<table>
<tr><th>Factor</th><th>Risk Type</th><th>Risk Definition</th><th>Risk Mitigation Strategies</th></tr>
<tr><td rowspan="4">Micro</td><td>Demand</td><td rowspan="4">Recurrent events originated directly from internal activities of companies and/or relationships within partners in the entire supply chain</td><td rowspan="5">Diversifying suppliers, creating contingency plans, establishing strong relationships with partners, using insurance and financial tools, real-time risk monitoring via advanced analytics, and proactive management</td></tr>
<tr><td>Supply</td></tr>
<tr><td>Operational</td></tr>
<tr><td>Financial</td></tr>
<tr><td>Macro</td><td>External</td><td>Adverse and relatively rare external events or situations which might have negative impact on companies (wars, pandemics, political instability, natural disasters)</td></tr>
</table>

2.1.1. Internal Logistics in Automotive Assembly Plants

Part logistics process begins upstream with the call order sent to a supplier and extends downstream to the final assembly line, where parts are consumed. Between these two stages, logistics operations can be categorized into three types (Boysen et al., 2015) as shown in Figure 1. An explanation of each operation included in internal logistics is provided on Table 3.

- **external logistics:** encompasses all activities involved in delivering parts from a supplier's facility to the OEM's plant. It relies on long-term supplier relationships and framework agreements, and the execution of short-term call orders. Within this contractual framework, call orders are regularly placed based on the final assembly's demand for specific parts within a defined time horizon, triggering the logistics process. External transportation is then arranged to deliver the parts to the OEM's plant.
- **internal logistics:** the process begins with goods receipt, where parts are transferred from the supplier to the OEM's facilities. If not immediately delivered to the production line through a fully synchronized Just-In-Sequence (JIS) process, parts are temporarily stored in a warehouse. They are later sorted into bins according to the assembly sequence. These bins are then transported to the production line using automated guided vehicles (AGVs). Finally, the parts are unloaded and made accessible to assembly workers, typically by placing the bins on racks within easy reach.
- **reverse logistics:** after the final assembly, several reverse logistics activities take place, including the return of empty bins and the handling of defective parts or components disassembled from returned vehicles. Similar to the forward chain, reverse logistics can be divided into internal and external processes.

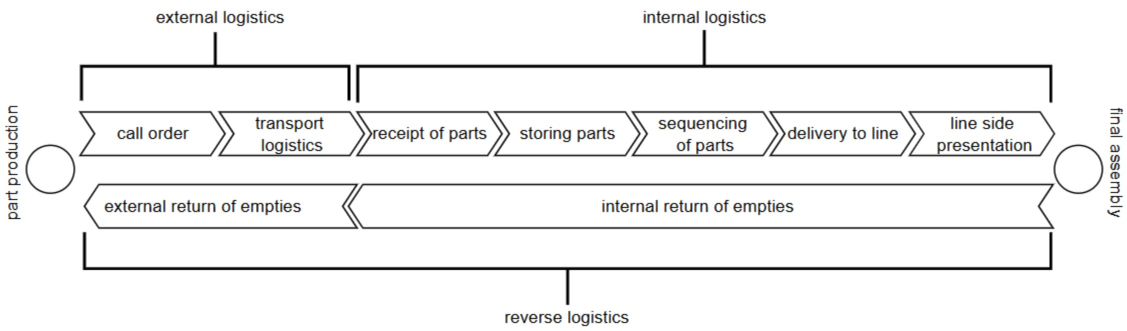

Figure 1 - Process steps of part logistics (adapted from Boysen et al., 2015)

Automotive companies utilize either centralized or decentralized storage areas for temporary parts storage, and the literature has extensively explored challenges such as layout design, storage assignment, routing, and order batching. Among these, decentralized storage areas - commonly referred to as supermarkets - have garnered particular attention due to their advantages (Thanou & Matopoulos, 2021).

The supermarket concept, aligned with JIT principles, is increasingly adopted by manufacturers to streamline part delivery on the shop floor. These decentralized storage areas serve as intermediate warehouses for parts needed by nearby assembly lines. Operators deliver parts in standardized containers and retrieve empty ones using in-house transportation vehicles along predefined routes and schedules. This system enables frequent, small-lot deliveries, reducing inventory at the Border of Line (BoL) and avoiding long-distance transportation from central warehouses. Supermarkets often use ergonomic storage solutions like gravity shelves and modular pipes to ensure fast and efficient handling (Faccio et al., 2013). However, prior research has also identified key logistical issues regarding their use such as location planning, vehicle routing, scheduling, and transport loading (Thanou & Matopoulos, 2021).

The production process in the assembly plant involves a wide range of products, fluctuating production volumes, and numerous vehicle components. These factors, combined with the extensive resources required for part supply, make internal logistics overly complex and susceptible to disruptions (Montoya-Zapata et al., 2024).

Table 3 - Internal Logistics Operations Explained (Boysen et al., 2015)

Receipt of parts	When a truck delivery arrives at the OEM's plant, the receipt of parts must be systematically organized. Inbound trucks are first registered at the gate and assigned to a loading dock. Once docked, the containers are unloaded, and the received parts are recorded in the OEM's information system. Finally, the parts are directed to their next destination, either intermediate storage for JIT and LOT parts or directly to final assembly for JIS parts.
Storing parts	Parts storage refers to holding items in a designated logistics area to bridge the time gap between their receipt and delivery to the production line. Despite the efficiency-driven principles of the Toyota Production System, eliminating intermediate warehousing remains impossible in the automotive industry. Parts can be stored in centralized locations, such as the receiving store or they can be moved closer to the production line and stored in supermarkets.
Sequencing of parts	Part sequencing is a specialized retrieval process in which selected JIT/LOT parts are picked from storage and arranged into bins in the exact order of their assembly. In the automotive industry, different part variants serving the same function are packed into bins or kits according to the sequence in which they will be used at the assembly station. This approach enables assembly workers to quickly access the required parts without wasting time on identification and searching, thereby improving efficiency and reducing assembly delays.
Delivery to line	Before the assembly of cars, the transport of parts to the consumptive workstations is mandatory. In the automotive sector the milkrun is a logistics strategy used to accomplish that. The process begins at supermarkets, where logistics workers load the wagons with parts or kits based on the part requirements of different assembly stations according to the production sequence. The tow train then follows a fixed schedule and route, making sequential stops at multiple stations to deliver the required parts and collect empty bins. For safety reasons or due to takt time requirements, the number of wagons per train is often limited and there can be multiple milk runs for the same end product. By consolidating deliveries and returns in a single trip, the milk run minimizes transportation waste, optimizes resource utilization, and ensures a continuous and timely supply of parts to the production line.
Line side presentation	In this process, material bins delivered by transport vehicles must be placed in appropriate storage spaces at BoL. A key challenge is the placement problem, which involves determining whether each bin should be positioned on the ground or in a rack while optimizing the use of limited station space. In modern assembly lines, a vehicle typically remains at each workstation for 60 to 90 seconds. Since walking can consume a sizable portion of this cycle time, minimizing unnecessary movement is essential to improving efficiency.
Internal return of empties	The internal return of empty bins follows the route from the assembly line back to a designated logistics area. Upon arrival, the bins are either loaded onto trucks for external return to the supplier or refilled during the sequencing process for immediate re-supply to the final assembly line.

2.2. Production Line Feeding Policies

Automotive assembly manufacturers need the parts from suppliers to reach the production line to complete the production order. When selecting a specific line feeding policy, the decision typically depends on the specific circumstances and characteristics of the policy (Baller et al., 2020). Three distinguished main feeding policies decide how these parts are fed to the assembly line, namely line stocking, kitting, and sequencing. Figure 2 provides an overview of the line feeding systems, illustrating the process from the warehouse stage through to the arrival of parts at the BoL. Although other line-feeding policies are discussed in the literature, they are often hybrids of these three policies or adaptations of one of them (Müllerklein et al., 2022).

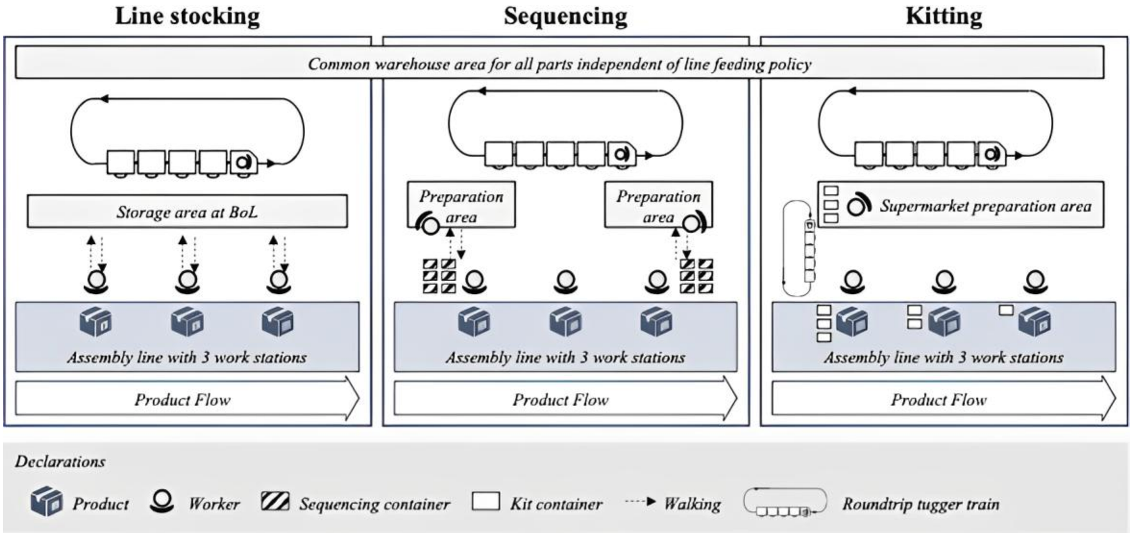

Figure 2 - The 3 Main Assembly Line Supply Strategies (Müllerklein et al., 2022)

- **Line Stocking:** In the automotive industry, line stocking is the most widely used parts supply strategy, favored for its simplicity and low material handling requirements (Ostermeier et al., 2023). In this policy, parts that arrive at the factory are stored in a central warehouse and then picked up and transported in boxes or containers to the BoL. The picking and transportation are done by an operator or, to speed up the process, by an in-house transport vehicle. This occurs when a reorder point is reached or the previous box at the BoL empties.

  The major advantage of this approach is the permanent availability of materials next to the assembly line. If an issue occurs with a part, a similar one can be quickly retrieved from the containers. Yet, when assembling complex or large products, substantial stock can take up significant space on the assembly line, and workers may spend additional time locating and picking the required parts, an inefficiency that is undesirable (Kilic & Durmusoglu, 2015).

- **Sequencing:** Sequencing involves organizing different variants of the same component (part family) within a container, arranged in the exact order they will be used on the assembly line. Each component type has its own container, where its variants are sequentially placed to match the production order (Zangaro et al., 2021).

A part variant group can be defined as a set of parts that differ slightly per component while maintaining the same functionality and equivalent size and weight. If one part within a variant group is sequenced, all parts within that group are sequenced as well. Sequence boxes are prepared in the supermarket and then transported to a specific workstation on the assembly line. Each workstation has its own sequencing preparation area (Müllerklein et al., 2022).

This setup reduces picking times, saves space at the BoL and improves process conformity as the check for the appropriate part was previously made in the supermarket. Nonetheless, this approach requires additional planning and handling steps, which can increase operational complexity (Ostermeier et al., 2023).

- **Kitting:** A kit is a specific set of components and subassemblies that collectively support the assembly operations for a single final product (Kilic & Durmusoglu, 2015). There are two types of kits: stationary kits and traveling kits. A stationary kit is delivered to a specific workstation and remains there until all its contents are used. In contrast, a traveling kit moves along with the end product, supplying multiple workstations as needed until its contents are fully depleted (Limère et al., 2012).

  A kit order includes at least the parts needed for a single production job, though it may also batch parts for multiple jobs, particularly if these jobs are grouped together within the production sequence. Kits are transported from the warehouse to a supermarket where a picking operator sets up the kitting parts in racks at the right containers, pairing with the production plan. Depending on the number of kit containers required and the capacity of the transporter, the operator may need to make multiple roundtrips between the supermarket and the central warehouse to gather all required kits. Those kit containers are then unloaded at the workstations at the BoL by a distinct vehicle. On the return trip, the vehicle stops at the workstations, collects the empty kit containers, and transports them back to the supermarket (Ostermeier et al., 2023).

  Kitting provides several benefits, including a reduction in stock levels, decreased operator travel time to retrieve parts, and less time spent searching for the necessary items. Additionally, kitting simplifies the scheduling of replenishments compared to bulk restocking and can improve ergonomic conditions, allowing line operators easier access to parts if kits are designed with ergonomics in mind. However, these advantages are offset by certain drawbacks, notably the added cost associated with kit preparation, which requires additional parts handling. Moreover, errors in kit preparation or defective parts within kits can disrupt production or compromise quality (Kilic & Durmusoglu, 2015).

- **Hybrid Policies:** Hybrid line feeding policies are also an option, where distinct groups of parts are simultaneously assigned to distinct supply strategies (Müllerklein et al., 2022). This approach is common in industrial practice, as the advantages and disadvantages of various strategies often necessitate a combination of methods to supply different part families to an assembly line. Consequently, companies typically cannot rely on a single part supply strategy but must implement and manage multiple strategies in parallel (Ostermeier et al., 2023).

2.3. Lean Manufacturing

Lean Manufacturing is a methodology that gained widespread recognition following the publication of Womack *"The Machine That Changed the World"* in 1990 (Bortolotti et al., 2015). Manufacturing in the twenty-first century is defined by the demand for customized products, leading to complex production planning and control systems that challenge traditional mass production methods. Many organizations, especially in the automotive sector, have struggled to adapt to customer-driven and globally competitive markets. These challenges have pushed organizations to seek new tools and methods to remain competitive in a rapidly changing market landscape. While some companies thrived by leveraging economic stability, others failed due to lack of understanding of the shifting customer preferences and cost management practices. To address these challenges and enhance profitability, many producers adopted lean manufacturing as a solution (Bhamu & Singh Sangwan, 2014).

Rooted in the principles of JIT and TPS, lean manufacturing represents their core characteristics via two interconnected perspectives: a strategic and philosophical, and an operational and technical. The strategic perspective views lean manufacturing as a philosophy based on five guiding principles aimed at eliminating all forms of waste (muda) in a production process. The operational perspective, on the other hand, translates this philosophy into actionable practices. From this viewpoint, lean manufacturing is seen as a managerial system that employs specific tools and techniques to minimize variability in processes, both internal and external. This variability, referred to as mura, is recognized in lean thinking as a primary source of production challenges. Together, these perspectives underscore lean manufacturing's dual role as both a guiding philosophy and a practical framework for improving efficiency and reducing waste (Bortolotti et al., 2015).

2.3.1. The Toyota Philosophy

The TPS, as defined by Taiichi Ohno, is a quantity control system with the primary objective of cost reduction through quality improvement (Sunmola et al., 2024). At the core of this approach lies the concept of continuous improvement "*Kaizen*" which is the most effective way to enhance productivity and sustain competitiveness in any manufacturing system. Toyota has consistently implemented Kaizen through its manufacturing, engineering, and business processes. This continuous improvement mindset is not only a critical element of TPS but also represents the essence of lean manufacturing (Li, 2013). The TPS can be metaphorically described as a house, as shown in Figure 3.

The house of TPS is built on two pillars: JIT and *Jidoka*. JIT is implemented through practices such as *Kanban*, short setup times, and multi-skilled workers, all designed to eliminate waste and boost productivity. Under the JIT framework, production is strictly governed by Kanban cards, preventing early or late production. This decentralized production control system ensures a smooth flow of parts and components through a lean facility. By reducing overproduction, *Kanban* minimizes inventory costs and enhances on-time performance by enabling short cycle times. Jidoka emphasizes that all physical movements by workers should add value to the product; otherwise, they are considered waste. Workers are entrusted with broader responsibilities, including addressing quality issues themselves, granting them greater authority and engagement in the production processes (Thun et al., 2010).

The house foundation is built on the need for standardized, stable, and reliable processes, supported by the concept of *Heijunka* (leveling), which ensures stability and minimizes inventory. Every element of the TPS house is essential, but its strength lies in how these elements reinforce each other.

The JIT approach aims to minimize inventory and minimal inventory safeguards. That said, avoiding quality issues or giving rapid responses when they occur is essential to prevent production disruptions. This constant urgency fosters teamwork, compelling employees to collaborate to address problems efficiently. Such group synergy depends on workforce stability and expertise, highlighting people as the cornerstone of the TPS and the enablers of continuous improvement (Kehr & Proctor, 2017).

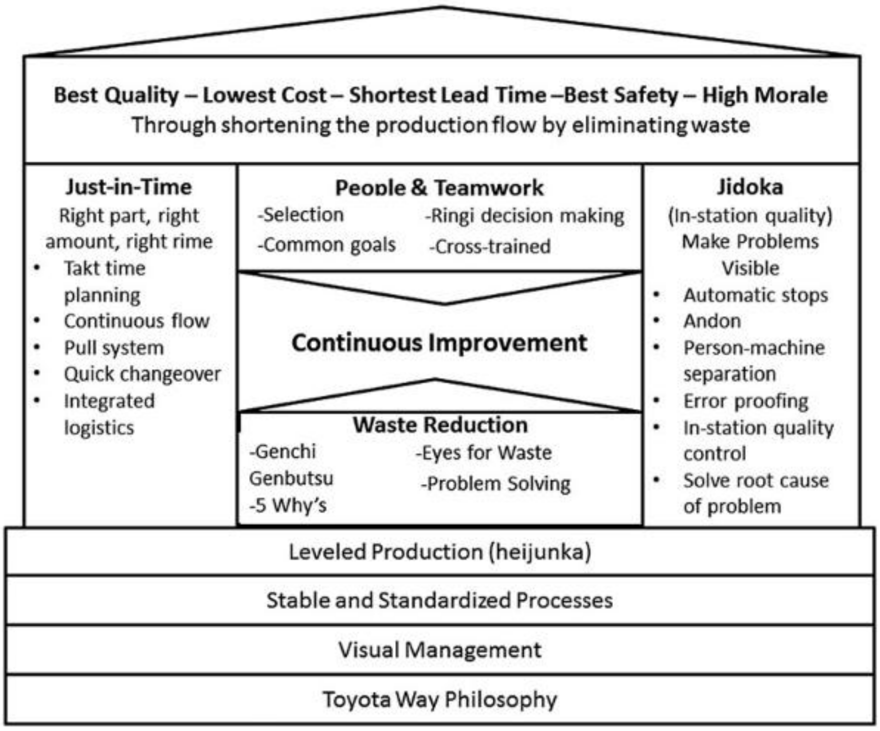

Figure 3 - House of TPS (Kehr & Proctor, 2017)

Womack and Jones distilled Toyota's philosophy into a concise framework for operational excellence in their book "*Lean Thinking*", where they outlined the five fundamental principles of lean manufacturing (Kumar et al., 2022). By adapting Toyota's practical strategies into a universal approach, they made lean principles applicable across industries and organizations, extending its benefits well beyond the automotive sector. A summary of each of the five principles is given below:

1) **Value:** Customer satisfaction is the goal. Value is defined as anything the customer is willing to pay for. It involves identifying which features of a product or service are essential to meet the customer's needs and expectations.

2) **Flow:** Flow ensures smooth and uninterrupted progression of products from the planning stage until the production stage until the customer. By eliminating bottlenecks and delays, flow creates a continuous and efficient production process.
3) **Pull:** In a pull system, production begins only in response to customer demand, preventing overproduction and excess inventory. Customers "pull" the products they need, driving the process.
4) **Perfection:** The ultimate objective is to achieve perfection by continuously refining processes, eliminating waste, and improving quality. This pursuit of excellence distinguishes top-performing producers from their competitors.
5) **Value Stream Mapping (VSM):** VSM involves visualizing and analyzing the material and information flows necessary to bring a product from scratch to the customer. VSM evaluates all operations and logistics between manufacturers, suppliers, and distributors. It connects various processes to create an efficient working environment and identifies areas of waste to optimize the value delivery.

The core objective of TPS is the elimination of all forms of waste, which includes any activity that fails to add value from the customer’s perspective (Thun et al., 2010). Waste can also be defined as an unimportant action that creates an unnecessary result (Kumar et al., 2022) or as any use of materials, machines, space, worker time, or parts beyond the minimum necessary to produce a product (Sunmola et al., 2024).

Taichi Ohno classified seven forms of waste. Sivaraman et al. (2020) provided a detailed description of each waste type and its consequences based on Ohno classification, as outlined below:

1) **Overproduction:** Producing more than what the customer needs or making products too early creates waste. It leads to storage issues, higher risks of obsolescence, and longer lead and storage times. Manufacturing in advance or in excess disrupts the balance of supply and demand.
2) **Waiting:** Studies indicate that much time of a product's production time can be wasted in waiting. Idle time occurs when workers or machines are stalled due to bottlenecks or inefficiencies. Waiting wastes time and affects both workers and goods that aren’t actively progressing through production. Waiting disrupts the continuous flow of operations, making processes inefficient and ineffective.
3) **Transportation:** The unnecessary movement of materials from one location to another adds no value to the product. Excessive transportation extends production times, wastes labor and space, and increases the risk of damage during handling.
4) **Overprocessing:** Overprocessing refers to performing more work or adding features beyond what the customer requires. This includes unnecessary cleaning, finishing, or overly complex solutions to simple problems, leading to wasted time and resources.
5) **Excessive Inventory:** Excessive levels of raw materials, work-in-process, or finished goods result in higher storage costs, financing expenses, defect rates and potential obsolescence. Extra inventory increases lead times, hides production issues, and demands more storage space, complicating problem identification.

6) **Defects:** Defects in production lead to poor-quality products, customer dissatisfaction, and reduced market value and reliability. These issues decrease sales and can harm a company's reputation. Defects also disrupt schedules, cause material shortages, and extend lead times, slowing down production. Defects include physical flaws, paperwork errors, late deliveries, or incorrect specifications.
7) **Unnecessary Motion:** Any movement by individuals or equipment that does not directly add value to the product or service is considered motion waste. Efficient workplace planning and ergonomics are crucial to minimizing unnecessary motion and increasing productivity.

3. Research Context and Problem Identification

This chapter defines and connects the methodology adopted with the thesis structure. Then, it examines the operational environment of TCAP, focusing on the internal logistics processes that support assembly operations. It provides an overview of the company's production structure, the principles guiding its manufacturing strategy, and the logistics flows that ensure material availability at the point of use.

Within this context, the chapter identifies key inefficiencies and recurring anomalies that compromise the performance of part-feeding activities and hinder effective anomaly traceability. These issues not only affect operational stability but also highlight the need for more standardized, digitized, and responsive systems to support internal logistics. By analyzing these challenges, this chapter lays the foundation for the development of an improved logistics solution.

3.1. DSR Methodology

This thesis seeks to contribute to the continuous improvement of internal logistics processes by identifying inefficiencies, evaluating current material feeding methods, and proposing targeted solutions that support cost control, process standardization, and overall operational efficiency. Design Science Research (DSR) methodology is used to accomplish that.

DSR is fundamentally a problem-solving paradigm, focused not only on understanding existing phenomena but on creating purposeful artifacts that provide effective solutions to identified problems (Brocke et al., 2020). Rather than merely explaining or observing reality, DSR seeks to develop solutions that embody knowledge of how things can and should be constructed to achieve specific goals, enunciated in Chapter 1, section 1.2. It is especially suitable for applications involving interfaces, design methods, and industrial systems, and it proves particularly effective for the design and improvement of existing processes (Peffers et al., 2007).

The methodology, formalized by Peffers et al. (2007), is structured into six steps:

1) Problem identification and motivation
2) Define the objectives for a solution
3) Design and development
4) Demonstration
5) Evaluation
6) Communication

By structuring the succeeding chapters according to the six steps of the methodology, as illustrated in Figure 4, this study aims to deliver a validated and integrated artifact that enhances efficiency, traceability, responsiveness, and data quality within the logistics operations at TCAP. This effort directly responds to the primary objective of the thesis, as it addresses logistics inefficiencies and improves anomaly management through the design and evaluation of a digital system that supports both the part-picking process and the structured recording of anomalies.

To support the initiation of DSR's first step, a preliminary Diagnosis Phase was conducted at the beginning of the research, during which TCAP's production system and logistics operations were thoroughly analyzed to identify existing challenges.

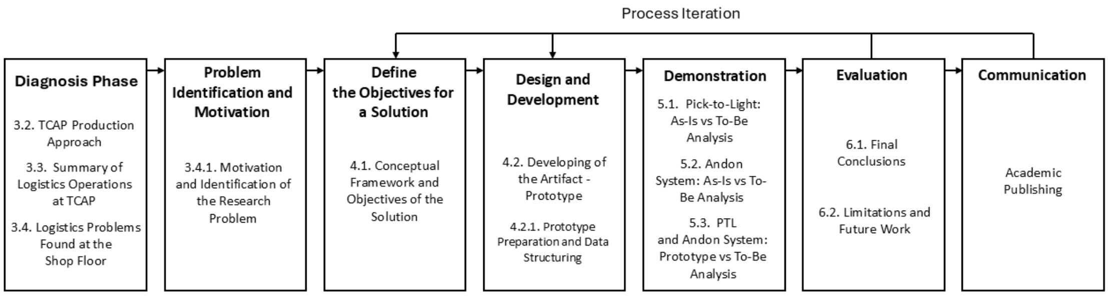

Figure 4 - Link between DSR Methodology and Thesis Chapters

3.2. TCAP Production Approach

Currently, the TCAP plant in Ovar is dedicated to producing a single vehicle model, which is the Land Cruiser Series 70 (LC70), as shown in Figure 5. The model is available in two variants: single cab (S/C) and double cab (D/C) and both variants can be produced in the color white or beige. There are also different engine and transmission types, either automatic (AT) or manual (MT). Each combination of cab type, engine, transmission and color is identified by a specific suffix, as detailed in Table 4. In total, there are 9 different LC70 suffixes that can enter the production sequence.

Figure 5 - LC70 S/C (Source: TCAP 2025)

Table 4 - LC70' Versions with Color Scheme and Suffix (Source: TCAP 2025)

Motorization	Cab	Full Designation	Suffix
GR #FF0000	S/C #FFC000	LC 70 Simple Cab V6 4.0 GASOLINE White (MT)	AP #EEECAA
		LC 70 Simple Cab V6 4.0 GASOLINE Beije (MT)	
	D/C #0070C0	LC 70 Double Cab V6 4.0 GASOLINE White (MT)	AN #FFCCFF
		LC 70 Double Cab V6 4.0 GASOLINE Beije (MT)	
GD #7030A0	S/C #FFC000	LC 70 Simple Cab L4 2.8 DIESEL White (AT)	AM #ED7D31
		LC 70 Simple Cab L4 2.8 DIESEL Beije (AT)	
	S/C #FFC000	LC 70 Simple Cab L4 2.8 DIESEL White (MT)	AK #33CC33
		LC70 Simple Cab L4 2.8 DIESEL Beije (MT)	
	D/C #0070C0	LC 70 Double Cab L4 2.8 DIESEL White (AT)	AC #5B9BD5
		LC 70 Double Cab L4 2.8 DIESEL Beije (AT)	
HZ #757171	S/C #FFC000	LC 70 Simple Cab V6 4.0 DIESEL White (MT)	AR #9966FF
		LC 70 Simple Cab V6 4.0 DIESEL Beije (MT)	
	D/C #0070C0	LC 70 Double Cab V6 4.0 DIESEL White (MT)	AQ #D9D9D9
		LC 70 Double Cab V6 4.0 DIESEL Beije (MT)	
VD #663300	S/C #FFC000	LC 70 Simple Cab V8 4.5 DIESEL White (MT)	AT #996633
		LC 70 Simple Cab V8 4.5 DIESEL Beije (MT)	
	D/C #0070C0	LC 70 Double Cab V8 4.5 DIESEL White (MT)	AS #FFFFFF
		LC 70 Double Cab V8 4.5 DIESEL Beije (MT)	

The production of vehicles is based on a Complete Knock Down (CKD) process. This means that all parts and components needed to assemble the LC70 are shipped from TMC directly from Japan. No parts are produced in-house.

TCAP is responsible for the call order, which is conducted according to a pull system driven by customer demand and according to JIT principles, with no LC70 production for stock. However, due to delays in transporting CKD lots, a process which can take up to 4 months, safety stock is usually ordered.

TMC ships CKD material in modules (lots) of 5 units and each one is identified by a unique lot number. As shown in Table 5, each LC70 vehicle requires multiple CKD lots. Each lot contains a distinct number of parts, each with an internal part number associated. Currently the logistics department manages approximately 2730 part-numbers. It is important to note that parts with the same name can have different part numbers, as it may be shared across multiple suffixes, having minor changes across each one.

To meet customer demand, TCAP operates with a takt time of 31 minutes. The takt time, calculated using Equation 1, represents the production pace required to satisfy customer needs. To accommodate potential anomalies, the line is balanced to a target cycle time of 29 minutes. Although the workstations are balanced to meet this takt time, disruptions may prevent achieving it. Therefore, maintaining a reliable logistics chain is essential to minimize the risk of non-compliance.

$$Takt\ Time\ [min] = \frac{Availabe\ Production\ Time\ [min]}{Number\ of\ Ordered\ Units\ (Customer\ Demand)} \qquad \text{(Equation 1)}$$

Table 5 - CKD Modules Characteristics

CKD Lot Nº	Unique Part-Numbers	Destiny Shop	Unpacking Workstation	Cab Type
10	87	Welding Shop	Deck	(S/C) and (D/C)
11	26	Welding Shop	Body	(S/C) and (D/C)
12	54	Welding Shop	Body	(S/C) and (D/C)
13	4	Welding Shop	Body	(D/C)
15	14	Welding Shop	Body	(S/C) and (D/C)
16	4	Welding Shop	Body	(S/C) and (D/C)
21	39	Assembly Shop	Chassis	(S/C) and (D/C)
22	67	Assembly Shop	Chassis	(S/C) and (D/C)
23	21	Assembly Shop	Chassis	(S/C) and (D/C)
25	736	Assembly Shop	Chassis	(S/C) and (D/C)
33	179	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)
36	277	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)
42	69	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)
43	31	Assembly Shop	Trimming and Final Assembly	(D/C)
52	163	Assembly Shop	Chassis	(S/C) and (D/C)
53	103	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)
54	86	Welding Shop	Frame	(S/C) and (D/C)
55	73	Assembly Shop	Chassis	(S/C) and (D/C)
56	624	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)
57	73	Assembly Shop	Trimming and Final Assembly	(S/C) and (D/C)

3.3. Summary of Logistics Operations at TCAP

The flow of the distinct parts that make up the LC70 is shown in a simplified manner in Figure 6. A clearer and more detailed version of this flow diagram, where individual elements are more easily identifiable, can be consulted in the Appendix A.

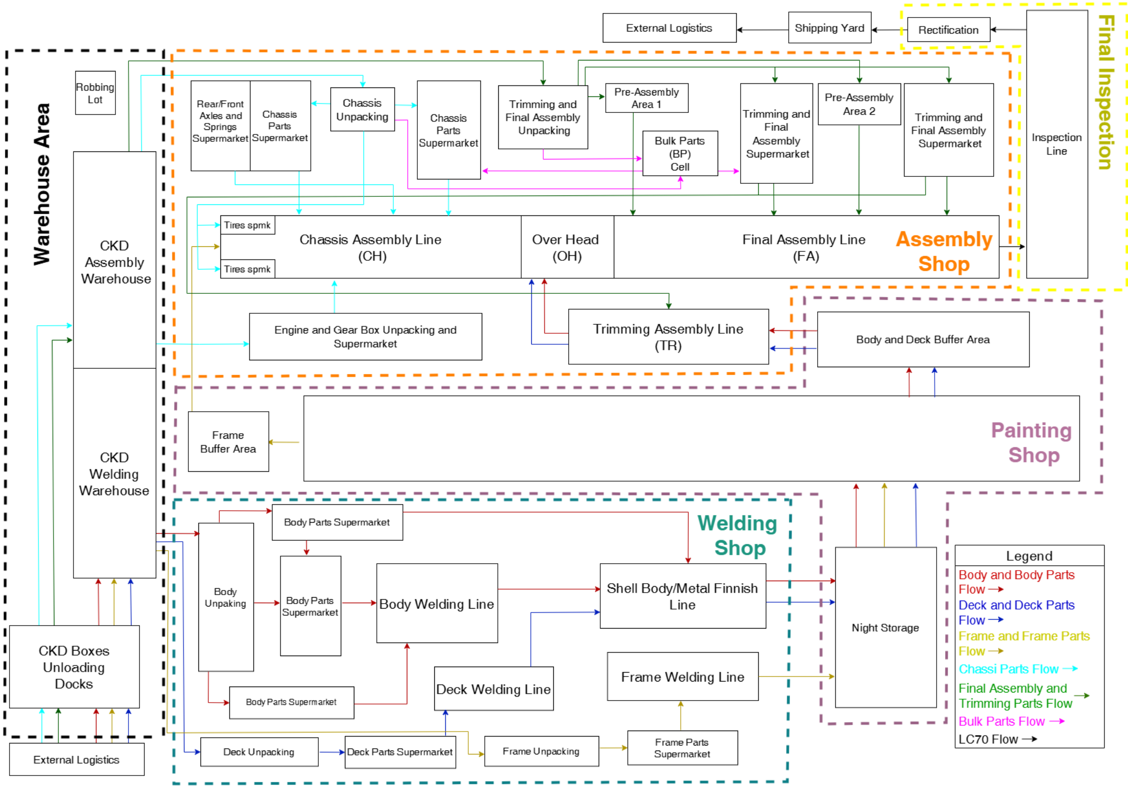

Figure 6 - Internal Logistics Parts Flow at TCAP

The flow begins in the Warehouse Area, where parts are received and stored. From there, they are sent either to the Assembly Shop or the Welding Shop, depending on which assembly line will need them first.

The three main parts — body, deck, and frame — are assembled in the Welding Shop. The frame is the structural base that supports the vehicle's components. The body is the vehicle's main cabin structure where passengers sit, and the deck refers to the rear cargo area.

Once they're assembled, they move to the Paint Shop, where they undergo an electrophoretic deposition treatment and are painted. Then, they are sent to the Assembly Shop. At this stage, the frame is referred to as the chassis. Here, all remaining exterior components and the vehicle's entire interior are assembled. Finally, each vehicle goes through the Final Inspection. If no issues are found, it is ready to be shipped to the customer.

This thesis focuses on logistics in the Assembly Shop, which consists of three main assembly lines: the Chassis Line (CH), the Trimming Line (TR), and the Final Assembly Line (FA). These lines meet at the Overhead (OH) workstation, where the chassis, body, and deck are joined, and the LC70 begins to take its final shape.

The main operations on the CH line include laser engraving the Vehicle Identification Number, a unique 17-character code that identifies each vehicle worldwide, and assembling the axles, engine, transmission, exhaust system, fuel tank, and tires onto the chassis. The TR line involves installing the instrument panel, air conditioner, glass panels, and brake and clutch pedals. The FA line is where components such as the front bumper, battery, seats, headlights, steering wheel, and spare tire are installed. Additionally, the FA3 segment of this line is activated only when assembling D/C vehicles. Here, extra tasks specific to D/C models (such as installing rear doors and rear seats) are conducted. Every line encompasses a quality gate workstation at the end, where operators from the respective line are responsible for checking whether any errors were made in the previous assembly tasks.

The first step in logistics within the Assembly Shop is opening the CKD modules in their designated areas. Afterward, the corresponding supermarkets must be stocked with the correct parts. The parts are transported between the opening area, the supermarkets and the pre-assembly tables using dollies - trolleys on which the material needed for assembly is placed. The logistics operators are responsible for this transportation, using support dollies that don't go to BoL.

Figure 7 and Figure 8 illustrate the arrangement of parts on the racks, organized according to cab type and suffix. The legend for interpreting these figures is provided in Table 6. Clearer and more detailed versions of Figures 7 and 8, where specific elements are more visible, can be found in Appendix B. Both figures show that the CH supermarket is arranged mostly by suffix, while the TR and the FA supermarket is set according to cab type and workstation.

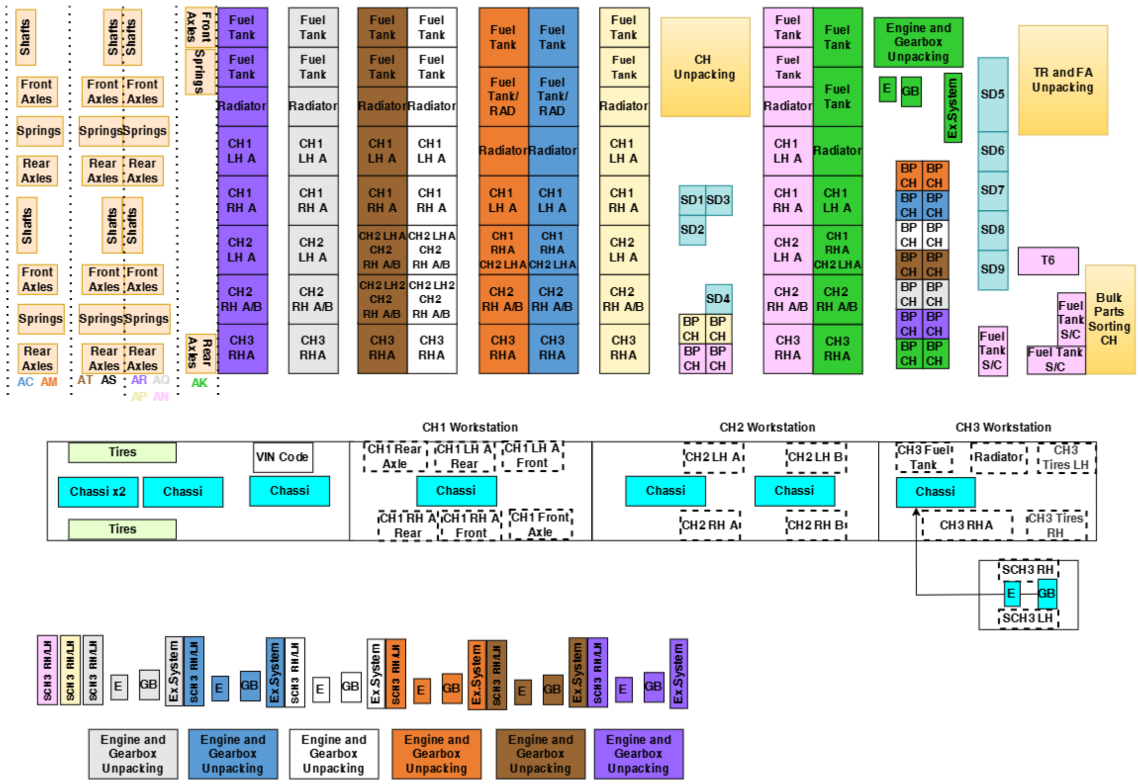

Figure 7 - Chassi Assembly Layout and Supermarket

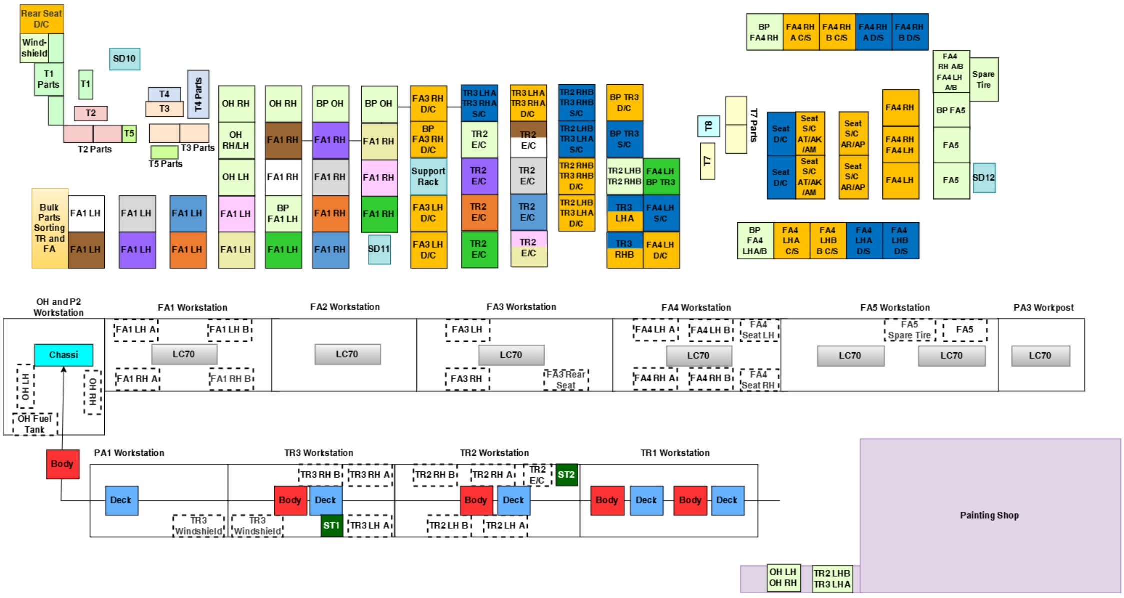

Figure 8 - Final Assembly Line and Trimming Line Layout and Supermarket

Table 6 - Legend of Figure 7 and Figure 8

	AC parts rack		AT parts rack	ST#	Stove#
	AK parts rack		D/C parts rack	E	Engine
	AM parts rack		S/C parts rack	GB	Gear Box
	AN parts rack		All suffixes parts rack	E/C	Engine Compartment
	AP parts rack	X	Space at BoL for the X Dollie	SCH	Side Chassis
	AQ parts rack	SD #	Support Dolly#	RH	Right-Hand Side
	AR parts rack	T#	Pre-Assembly Table#	LH	Left-Hand Side
	AS parts rack		Dollie for Axles/Springs/ Shafts		

Table 7 shows which Pre-Assemblies (PA) are conducted at each Pre-Assembly Table (T) and the dolly in which they will be presented at BoL. Regarding PA's there are nuances that should be considered:

– PA29 and PA30 are done by the picking operator in the moment he prepares D34 and D46;

– PA24 is only made for S/C vehicles;
– PA6 and P17 are only made for HZ and VD motorization vehicles, respectively.

Table 7 - PA List for LC70 by Worktable

Table	PA	Pre Assembly	Dolly	
1	1	Dashboard	D24	TR2 RH B
1	2	Dashboard Reinforcement	D23	TR2 RH A
1	3	Brake Pedal	D23	TR2 RH A
2	4	Clutch Master Cylinder	D22	TR2 E/C
2	5	ABS Actuator	D22	TR2 E/C
2	6	Accelerator Pedal Cable	D23	TR2 RH A
2	7	Heater Radiator	D25	TR2 LH A
2	8	Heater Motor	D25	TR2 LH A
2	9	E/C Wiring	D22	TR2 E/C
2	10	Main Wiring	D23	TR2 RH A
3	11	Upper Right Dashboard Trim	D34	FA1 RH A
3	12	Radio Lower Trim	D28	TR3 RH B
3	13	Radio Upper Trim	D28	TR3 RH B
3	14	Radio Drawer	D28	TR3 RH B
3	15	RH Wheel Arch Support	D43	FA4 RH B
3	16	Steering Column Lower Trim	D43	FA4 RH B
3	17	Accelerator Pedal	D34	FA1 RH A
3	18	Steering Wheel	D43	FA4 RH B
3	19	Passenger Airbag	D32	FA1 LH A
3	20	Sound Column Trim	D32	FA1 LH A
3	21	Battery Support	D33	FA1 LH B
4	22	Bumper Reinforcement	D42	FA4 RH A
5	23	Rear Window Glass	D24	TR2 RH B
6	24	Fuel Tank S/C	D22	OH (FT S/C)
7	25	Bumper	D39	FA4 LH A
8	26	Airbag Sensor	D40	FA4 LH B
8	27	LH Wheel Arch Support	D40	FA4 LH B
8	28	Control Unit /ECU	D36	FA3 LH
-	29	Combination Switch	D34	FA1 RH A
-	30	Front Grille	D46	FA5

The assembly line is mostly supplied by the unit, so only the material needed is supplied in the exact quantity and at the right time. To avoid downtime on the assembly line, the picking process must always be one takt time ahead of assembly. However, the Unpacking and Bulk Sorting work by lots. To ensure that there is no shortage of material in the supermarkets or in the Bulk Cell, daily planning is required to define which lots should be opened.

The line feeding system used is kitting, with each dolly corresponding to a single kit. This system operates on two alternating cycles (A and B), each lasting 14.5 minutes (half of the takt time). While the line operator assembles the parts for Cycle A, the picking operator prepares the parts for Cycle B, and vice versa. This strategy, combined with pre-assembly, reduces set-up time and minimizes the need to increase the number of workstations. All parts are properly identified with labels, and each employee is provided with picking lists, which are adapted to the suffix being produced. Also, each vehicle assembled has a unique Renban, a sequential number that identifies its position in production order. The picking lists are prepared according to the Renban of the vehicle being assembled, ensuring that the correct parts are delivered in the exact sequence required by the assembly line.

The CH LH and FA LH workstations are fed manually, with the operators taking the dollies by hand from the supermarket to BoL. The remaining sections of the Assembly Shop are supplied via milkrun by the mizusumashi. A mizusumashi is a dedicated operator responsible for continuously supplying parts and materials to the assembly lines. Moving between supermarkets and workstations in a predefined route, the mizusumashi ensures that each station receives the right parts at the right time, without interruption to the production flow. There are two identical units of the same dolly and while one dolly is in use at the BoL the other is being loaded by the picking operator. The mizusumashi operator switches the empty dolly at the BoL with the full dolly prepared in the picking area.

The arrangement of parts on the racks, organized according to the workstations they supply, is illustrated in Figures C.1 and C.3, located in Appendix C. Each dolly is labeled according to the corresponding workstation it serves. The legend for interpreting these figures is provided in Table C.5. Additional information regarding the mizusumashi routes is presented in Tables C.2 and C.4 in Appendix C.

3.4. Logistics Problems Found on the Shop Floor

Throughout the operation of the Assembly Shop, several logistical issues have been observed that negatively impact efficiency, safety, and reliability. These problems can be categorized into three main groups: space constraints, excessive anomalies, and ergonomic challenges.

1) Space constraints

One of the most pressing logistical challenges at TCAP relates to limited space, which affects various stages of the supply process.

The first issue occurs when opening a CKD lot. Every time a lot is opened all parts are stored in the supermarket, regardless of whether they are immediately required. As a result, even if only one vehicle for a given suffix is scheduled for production, the remaining 4 parts stay stored in the supermarket. This leads to overstocking components that appear less frequently in the production sequence. As a result, parts with low turnover accumulate in storage areas, reducing available space and increasing clutter. For this reason, certain engine types such as AK are stored separately, while AN and AP engines and gearboxes are relocated to the welding shop. Ideally, all engines and gearboxes should be stored in the same designated supermarket zone to streamline access and handling.

Another related problem arises in the CH unpacking area, where there is only enough room for unpacking one lot at a time. This causes inefficiencies when operators complete unpacking before the forklift operator is ready to deliver the next lot, leading to downtime and setup delays. Expanding the unpacking space to accommodate two or more lots could mitigate these interruptions and increase flow continuity.

Space limitations also compromise the correct implementation of the FIFO (First In, First Out) principle. In some cases, due to the lack of access from both sides of the rack, replenishment and picking are often performed from the same aisle.

This causes newer parts to be placed in front of older ones, resulting in outdated components being pushed to the back of the rack and left unused. This not only increases the risk of part degradation but also undermines the traceability and sequencing integrity of the logistics flow. Ideally, picking should be carried out from one side of the aisle and replenishing from the opposite side, ensuring a continuous flow where the oldest parts on the rack are always picked first.

2) Excessive Anomalies

A huge portion of the inefficiencies observed in the assembly process stems from the excessive number of anomalies that cause stops and delays at the production line, many of which are logistics responsibility.

One of the key contributors to this issue is the use of outdated documentation, particularly picking lists and Element Work Sheets (EWS) of logistics procedures. These documents often fail to reflect recent changes in workstation parts layouts caused by takt time adjustments. As workstations are rebalanced and materials relocated to optimize efficiency, the associated standardized documentation is not always updated accordingly. This gap increases the likelihood of human error, especially among newer operators who may rely heavily on these materials for guidance. As a result, errors such as delivering incorrect parts or even missing the supply of some parts become more frequent, directly impacting the reliability of the logistics flow.

Another critical shortcoming is the absence of an *Andon* system for the logistic area. An *Andon* system is a visual management tool used to signal problems or abnormalities in real time. Just as *Kanban* serves as a signal for the need to supply or produce, *Andon* functions as a signal for assistance or intervention, enabling immediate response to operational issues. Without this visual aid and structured stop-call-wait mechanism, logistics-related anomalies are often addressed slowly and without systemic visibility. This lack of immediate escalation reduces the responsiveness of support teams and increases the risk of recurring issues being resolved informally or incompletely.

Additionally, the logistics section lacks a structured anomaly recording system. In the assembly lines, all anomalies are systematically recorded and monitored. However, the logistics team does not consistently follow this good practice.

Issues that arise during unpacking and line feeding operations are often not documented, and when they are, the records are only temporary. Problems are usually written on a whiteboard and erased at the beginning of the following week, preventing any long-term tracking or analysis. This absence of a digital or historical record means that recurring issues can go undetected for extended periods, as there is no data available to analyze trends or identify root causes. The result is a reactive environment, where efforts are focused on short-term fixes rather than continuous improvement.

3) Ergonomic Challenges

The third group of issues pertains to ergonomic risks and physical strain on logistics operators, particularly during material handling tasks.

Heavy components - including tires, radiators, batteries, and chassis - are transferred between supermarkets and workstations and between shops without any mechanical lifting assistance. This manual handling of bulky and heavy items increases the risk of musculoskeletal injuries among operators. In addition to manual handling issues, some of the dollies used in the logistics process are in poor condition due to continuous use over time. Worn-out dollies can be harder to maneuver, reduce the stability of transported materials, and increase the physical effort required by operators.

Given the repetitive nature of these operations and the significant weight of the components involved, this practice poses a serious occupational health concern.

3.4.1. Motivation and Identification of the Research Problem

Given the range of issues identified, this thesis will focus specifically on addressing the problem of recurring logistics-related anomalies. Among the three categories of problems outlined in the previous chapter, this issue was selected as the primary focus for two main reasons.

Firstly, while space limitations are critical, expanding the warehouse or reorganizing supermarkets and opening areas would require significant infrastructure changes and potentially halt the assembly line, which is not desirable by TCAP. Secondly, ergonomics and safety concerns are already being monitored by specialized teams at TCAP, such as the safety and ergonomics departments, which are better positioned to implement long-term solutions in those areas.

In contrast, the logistics anomalies problem can be addressed through procedural and digital improvements, without interrupting production. Reducing the number of anomalies has a direct impact on assembly line efficiency and aligns with the principles of lean manufacturing and continuous improvement. For these reasons, solving this issue was deemed the most practical and impactful approach within the scope of this thesis.

Between the beginning of 2024 and the end of March 2025, a total of 7,091 anomalies were recorded by the assembly section across the TR, CH, and FA lines. Since the logistics area does not consistently track its own errors, the data used in this analysis comes exclusively from the assembly line section. In this context, an anomaly refers to any action or event that deviates from the standard procedures for assembling the LC70, leading to unintended consequences. In most cases, it prevents the vehicle from being assembled at the affected workstation. For this reason, team leaders and group leaders must respond quickly to resolve the issue and avoid a line stoppage. In many cases, due to response time limitations or the complexity of the issue, it is impossible to prevent stoppages.

The assembly section defined that logistics errors were personally responsible for 2739 anomalies, accounting for 38.6% of the total recorded. Among these, 144 anomalies (10.4% of the total) resulted in line stoppages, as shown in Figure 9. This discrepancy can be explained because most logistic anomalies are related to missing or wrong parts being delivered at BoL and, in most cases, the correct part can be quickly retrieved from the supermarket. To better understand logistics related anomalies, they were categorized into six groups, as illustrated in Figure 10.

The most common issue was supplying delays or missing parts at the dollies presented at BoL, representing 45.3% of all logistics anomalies. The second most frequent problem was the feeding of incorrect parts or parts from the wrong suffix to the lines (28.6%). Dirty or damaged parts ranked third (10.6%), typically caused by poor handling by operators or non-compliance with FIFO, which leads to dust accumulation and dirt build up on certain components. Bulk-related anomalies accounted for 10.4% of the total. These issues mirror the previous categories but specifically concern bulk parts, which are prepared in a separate section of the supermarket known as Bulk Cell. The next 3.8% fell under miscellaneous issues, including missing or outdated picking lists, a lack of available dollies for picking, and operators late for work. Lastly, problems regarding incorrect pre-assemblies were responsible for 2.2% of anomalies.

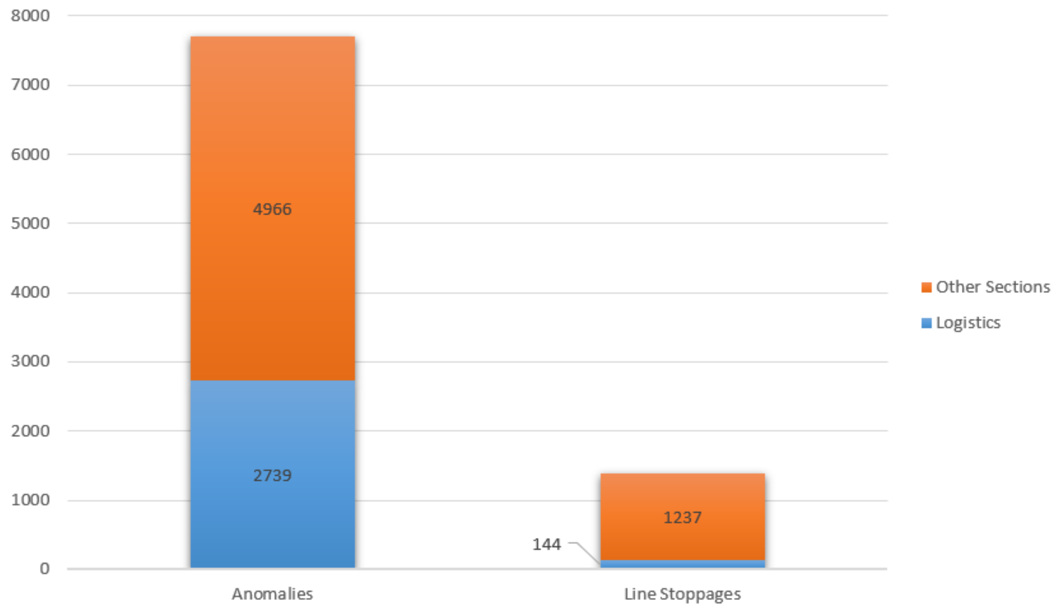

Figure 9 - Anomalies vs Line Stoppages

When translating these anomalies into lost production time, a total of 18 088 minutes were lost due to stoppages. Of those minutes, 1 451 were linked to logistics issues.

Additionally, 1 395 minutes were lost but did not translate into production time losses, as most workstations have some buffer time. Workstations are balanced with tasks that collectively take less time than the takt time, allowing operators to absorb minor delays. In some cases, an extra operator, known as the absentee, helps regular operators meet takt time requirements when anomalies occur. Of these absorbed minutes, 236 were attributed to logistics, as shown in Figure 11. It is also important to note that in most cases, when one workstation is stopped, the others continue operating. Therefore, the value of one car is not entirely lost for every full takt time minutes lost, because there's multiple ways to recover down time.

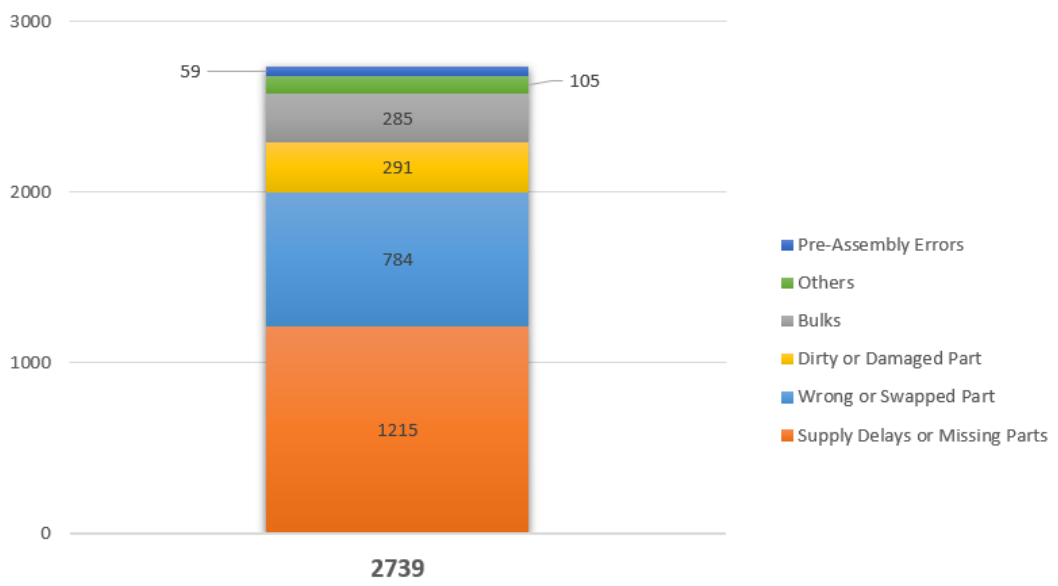

Figure 10 - Types of Anomalies Caused by Logistics

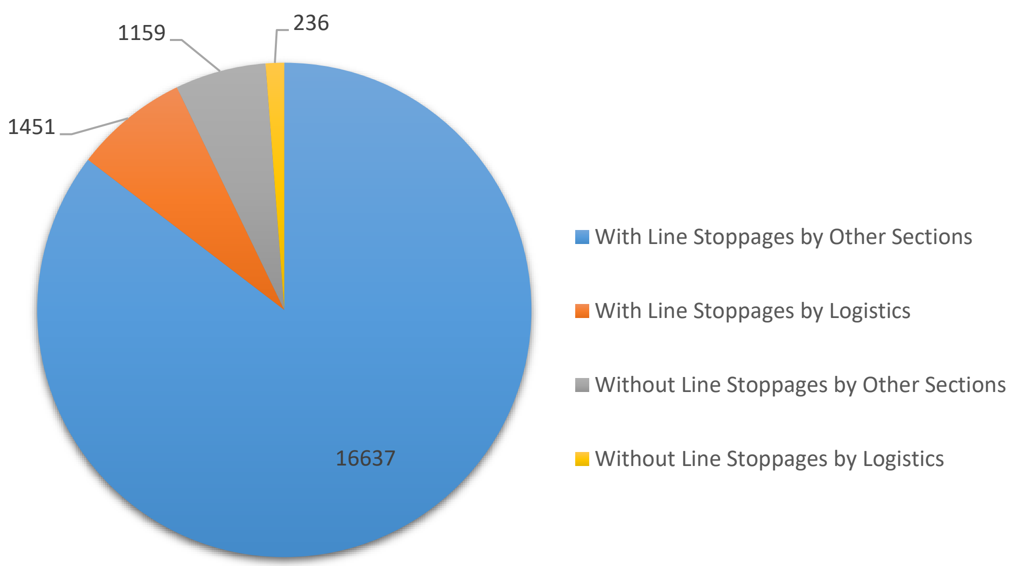

Figure 11 - Lost Time Due to Anomalies [min]

4. Objectives, Design and Development of the Artifact

The analysis of anomalies and lost time in the production process highlights that logistics related issues have a significant impact on efficiency, particularly due to supply delays, missing parts, and incorrect or swapped parts being delivered at BoL.

Implementing a more digital picking system in place of traditional paper-based lists can help mitigate these problems by improving accuracy, reducing human error, and speeding up material handling.

However, no system is entirely error-proof, even with digital tools in place. For this reason, it is equally important to implement an *Andon* system within the logistics area. This visual and structured alert mechanism ensures that when errors do occur, they are detected and addressed in real time, preventing them from escalating into production stoppages.

4.1. Conceptual Framework and Objectives of the Solution

This subchapter presents the conceptual framework and corresponding objectives that guide the development of the proposed solutions for improving logistics performance at TCAP. Based on the limitations identified in the current processes two digital solutions were conceptualized: a Pick-to-Light system to optimize part picking accuracy and efficiency, and a Digital *Andon* system tailored for the dynamic context of logistics operations.

The conceptual models for both systems are designed to align with lean principles, leveraging real-time feedback, standardization, and digital traceability. Additionally, a set of qualitative and quantitative objectives has been defined to support the evaluation of the proposed solutions. These objectives serve to validate the expected improvements and provide measurable indicators for assessing the impact of the solution and future full-scale implementations.

The conceptual models for the PTL solution and the *Andon* solution are presented in Table 8 and in Table 9, respectively. The qualitative and quantitative objectives of each solution are displayed in Table 10 and Table 11, respectively.

Table 8 - Conceptual Framework of the PTL solution

PTL Main Objective
Eliminate paper-based picking, reduce errors, and improve material flow between supermarket and assembly line
Key components
→ Light modules on racks and dollies indicating part location and quantity

→ Motion sensors for automatic confirmation → Software integration with production sequence → Real-time supervision dashboard → Digital reprogramming capability for line rebalancing
Operator Flow
1. PTL system highlights picking locations based on production sequence 2. Operator picks the part; sensor detects action 3. PTL confirms pick; part is placed in predefined dolly slot 4. Dashboard provides real-time picking status and alerts

Table 9 - Conceptual Framework of the *Andon* solution

***Andon* Main Objective**
Create a structured anomaly escalation and recording system for logistic operators
Key components
→ Handheld mobile devices for operators and supervisors → Simple UI to report identity, location, and anomaly type → Real-time alerting system for supervisors → Supervisor interface to register and classify resolved anomalies → Instant data sync with anomaly database
Operator Flow
1. Operator detects anomaly and reports it via handheld device 2. Supervisor is alerted and attends the site 3. Supervisor resolves the issue and logs anomaly via predefined parameters 4. Record is linked to the original call ID and saved instantly in database

Table 10 - Quantitative Objectives of the Proposed Solutions

Metric	Objective	Current	Target	System
Picking Error Rate	80% reduction	1 in 200 picks (estimated)	1 in 1000 picks	PTL
Picking Time (per cab type)	20% reduction	58,98 min (S/C) 69,85 min (D/C)	47,19 min (S/C) 55,88 min (D/C)	PTL
Anomaly Response Time (from detection to support intervention)	< 3 min	No data	< 3 min	*Andon*
Anomaly Documentation (on database)	100 %	0%	100%	*Andon*

Table 11 - Qualitative Objectives of the Proposed Solutions

System	Objective	Description
PTL	Improve picking accuracy	Reduce the occurrence of human errors (picking wrong parts, incorrect quantities, or placing items in the wrong dolly slots)
PTL	Reduce operator cognitive load	Simplify decision-making by replacing paper lists with intuitive visual indicators that guide part selection

PTL	Enhance standardization	Enforce consistent part placement on dollies, aligned with predefined configurations that optimize assembly ergonomics
PTL	Support easier reconfiguration during line balancing	Allow flexible reprogramming of part locations without the need for physical label changes
PTL	Promote operator autonomy	Enable workers to execute tasks with minimal verbal instructions or supervision by following system prompts
PTL	Improve training efficiency	Simplify the onboarding of new employees through a visually guided system that reduces reliance on prior experience
PTL	Increase process transparency	Providing supervisors with real-time visibility into the picking process via dashboards, enabling proactive support
PTL	Reduce dependency on printed materials	Eliminate paper-based instructions, contributing to sustainable practices and reducing waste
Andon	Enable real-time anomaly escalation	Allow logistics operators to immediately signal issues regardless of their location in the plant
Andon	Adapt *Andon* principles to mobile workflows	Customize the traditional *Andon* logic to suit the non-fixed, mobile nature of logistics operators
Andon	Reduce communication delays	Replace informal communication (verbal alerts) with a digital interface that ensures immediate delivery of support requests
Andon	Standardize anomaly reporting	Ensure all anomalies are documented using predefined categories and input fields to improve consistency
Andon	Improve traceability of logistics problems	Link each alert with its resolution using unique IDs, making it easier to track issue history and recurrence
Andon	Promote data-driven problem solving	Store anomalies in a structured database that supports trend analysis and process improvement initiatives
Andon	Enhance team coordination	Improve response coordination by notifying the correct support team or supervisor automatically
Andon	Ensure immediate data availability	Eliminate delays caused by manual transcription of records, allowing data to be instantly available for analysis

4.2. Developing of the Artifact - Prototype

Given the extensive scale of the factory and the time constraints of this research, implementing a fully developed digital picking solution across the entire assembly shop supermarket is not feasible within the scope of this thesis. Implementing a fully integrated system at this stage would require considerable time and resources - including coordination with external suppliers, internal approval processes, and substantial setup time - that could potentially disrupt ongoing operations, which is not viable under current production constraints.

Therefore, this research adopts a prototyping approach. Given the significant extent of the supermarket area, a Pareto Diagram was developed to compare the number of anomalies per workstation, with the aim of prioritizing which section of the supermarket should be evaluated with the prototype. The Pareto diagram, shown in Figure 12, indicates that the supermarket areas requiring the most attention are those corresponding to the TR2, FA4, and TR3 workstations.

FA4 was selected as the representative area for the prototype implementation, as it encompasses a larger supermarket coverage and handles a higher variety of part-numbers, as illustrated in Table 12.

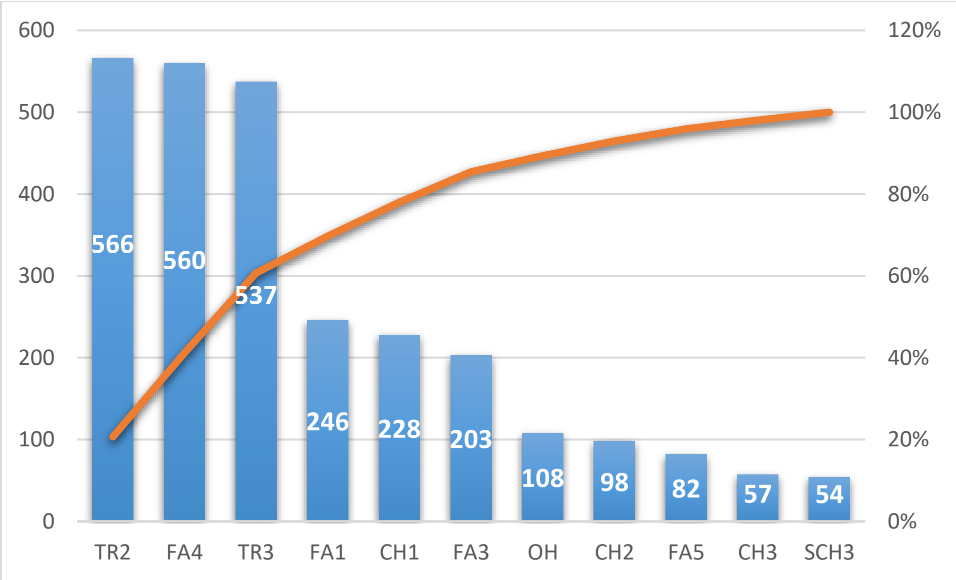

Figure 12 - Distribution of Anomalies per Workstation

Table 12 - Supermarket Coverage and Distinct Part-Numbers of TR2, TR3 and FA4 Supermarket

Workstation	Supermarket Coverage	Unique Part-Numbers
TR2	6,31%	134
TR3	5,34%	49
FA4	12,62%	139

Rather than representing a definitive deployment, the prototype serves as an initial proof of concept - a preliminary model to explore the feasibility and potential impact of the proposed solution. This prototype offers a limited but focused glimpse of the envisioned system. If successful, the insights gained from FA4 can inform future discussions with technicians and administration board, and support a more robust, supplier-led implementation in the broader logistics environment.

The prototype consists of a digital interactive dashboard designed to support logistics operators in their daily activities in a user-friendly and mobile-accessible interface. The aim is to assess, in a controlled environment, the potential of digitalizing logistics processes in a way that reduces inefficiencies, enhances traceability, and accelerates support during anomalies.

4.2.1. Prototype Preparation and Data Structuring

Before the prototype can be implemented at workstation FA4, it was necessary to undertake a series of preparatory steps to ensure that the solution would be both functional and aligned with the operational reality of the logistics area. These preliminary activities were essential to define the system's scope, structure its internal logic, and enable the development of a prototype that could be effectively assessed within the factory environment. These activities included:

1) Selection of Software Platform

To ensure the feasibility of the prototype within the constraints of this academic research, it was essential to adopt a cost-effective solution that could also align with the technological environment already in place at the company. In this context, the decision was made to utilize tools from the Microsoft Office suite, to which all factory employees already have access. This approach allowed for the development of the prototype without requiring additional licenses, external software, or complex system integrations, thereby optimizing company resources and minimizing future implementation costs.

Microsoft Power BI was selected as the central platform for simulating the Pick-to-Light system due to its user-friendly interface, dynamic data visualization capabilities, and seamless connectivity with multiple data sources. Its flexibility in dashboard creation made it an ideal tool for testing interactive logic and visual feedback within a digital picking environment.

To simulate the *Andon* system, two applications were developed using Microsoft Power Apps: one representing the call-for-support mechanism and the other dedicated to anomaly registration. Power Apps was chosen for its ability to create customized data entry forms that can be directly integrated with SharePoint lists, enabling submitted data to be structured, centralized, and immediately available for analysis.

Furthermore, Power BI supports native integration with Power Apps, allowing both functionalities to coexist within the same Power BI report. This integration enhances the prototype's interactivity and usability by enabling users to trigger *Andon* calls or register anomalies directly from the dashboard interface, without leaving the report environment.

This software selection ensured that the prototype remained low-cost, scalable, and compatible with the company’s existing digital ecosystem, while also delivering the essential functionalities required to evaluate the core concepts of the proposed solution.

2) Mapping of Part Locations in the FA4 Supermarket and Dollies

As previously mentioned, the existing documentation regarding part locations within the supermarket was outdated and inconsistent. Therefore, a complete and up-to-date mapping process was necessary to ensure the accuracy and reliability of the prototype.

The mapping task began with the physical identification and cataloguing of all parts stored in the FA4 supermarket. Each of the 26 racks that make up the supermarket area was thoroughly inspected, and the position of every item was recorded. The rack identification system adopted in this study is visually represented in Figure 13, with each rack labeled using the corresponding letter code.

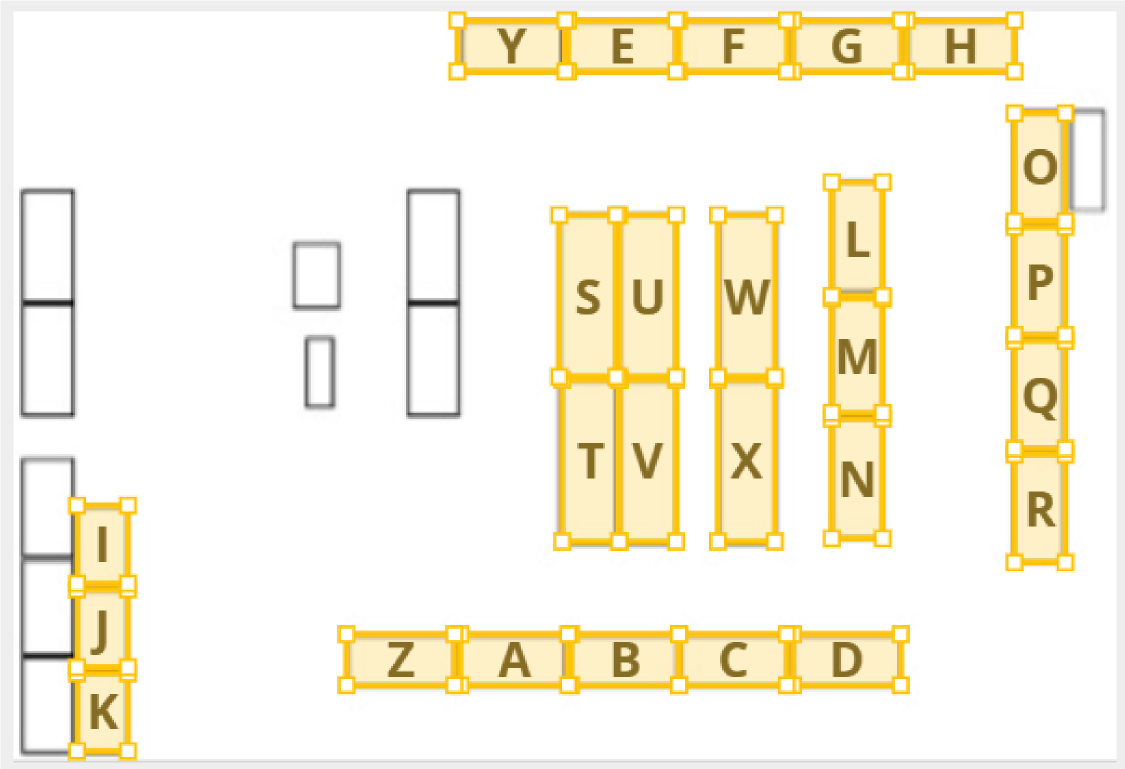

Figure 13 - Racks Spatial Organization and Nomenclature of FA4 Supermarket

A total of 656 storage positions were documented. Although there are only 139 unique part-numbers, many of them appear across multiple suffixes, which resulted in multiple positions being assigned to the same part-number. The positions of parts inside the 7 dollies used to feed the FA4 workstation were also catalogued. To enhance traceability and visual reference, high-resolution photographs were taken of each rack and dolly in its entirety.

These images were subsequently converted into Scalable Vector Graphics (SVG) format. This format was chosen due to its compatibility with interactive features and its ability to be integrated within Power BI dashboards. Within each SVG image, individual storage locations were manually assigned the corresponding part-number, enabling precise mapping of every item's physical position.

An example of an SVG image of a rack and a dolly is presented in Figure 14 and Figure 15, respectively. Each rack has all its slots assigned to specific part numbers. However, the same does not apply to the dollies, as some of the components they carry originate from pre-assembly tables or the Bulk Cell and those areas were not mapped.

The use of SVGs allowed for a visual and interactive representation of the supermarket layout, which could later be connected to the data structures in Power BI. This integration enabled the development of a functionality within the prototype that allows operators to search for a specific part and instantly identify its exact location within the supermarket, thus reducing search time and improving operational efficiency.

This mapping phase was critical for ensuring that the prototype accurately reflected the real-world configuration of the FA4 supermarket and could support the functionalities intended for testing.

Figure 14 - SVG of Rack B

Figure 15 - SVG of Dolly FA4 RH A

3) Data Modeling and Integration

To support the functionality of the prototype, it was necessary to structure the collected data in a way that ensured compatibility with the software tools adopted. This process included the development of a dedicated Excel database to manage part-related information, as well as the creation of SharePoint lists to handle anomaly data and supervisor support calls. Even though TCAP already maintains an internal parts database, it was not suitable for direct integration into Power BI. Specifically, the existing system did not assign unique identifiers to each part number according to its suffix, which is a critical requirement for Power BI, where each row (entry) must be distinct and associated with a unique column ID. As a result, the original dataset could not be directly updated or reused.

To overcome this limitation, a new database for FA4 part-numbers was created, in which each part-number and suffix combination was assigned a distinct identifier. This structure ensured proper indexing and data manipulation within Power BI. Consequently, as illustrated in Figure 16, a single part-number may appear multiple times (up to nine entries) if it is used across the nine different suffixes.

In addition, two SharePoint lists were developed to support the simulation of the *Andon* system:

- The first list is used to register supervisor call requests, initiated by the operator when an anomaly occurs (Figure 17);
- The second list is used to record the anomaly resolution, filled out by the supervisor once the situation has been addressed (Figure 18).

To ensure traceability and enable connection between both records, the unique ID generated during the support call can later be inserted into one of the parameters of the anomaly registration. This linking mechanism enables cross-referencing of the two events within the database, facilitating analysis of response time, frequency, and anomaly patterns. This step was fundamental to ensuring data consistency, enabling relational integration between system components, and supporting the analytical capabilities of the prototype within a fully digital environment.

Part Number	Part ID	Nome	Sufixo	Rack	Qt.	Fila	Lugar	Lista de Picking	Ordem	Imagem
01999-60W93-00	2	MANUAL, OWNERS	AC	C	1	1	2	FA4 LH A	2	
01999-60W93-00	24	MANUAL, OWNERS	AK	A	1	1	2	FA4 LH A	3	
01999-60W93-00	41	MANUAL, OWNERS	AM	A	1	1	2	FA4 LH A	3	
01999-60W93-00	57	MANUAL, OWNERS	AN	C	1	1	2	FA4 LH A	2	
01999-60W93-00	79	MANUAL, OWNERS	AP	A	1	1	2	FA4 LH A	3	
01999-60W93-00	95	MANUAL, OWNERS	AQ	C	1	1	2	FA4 LH A	2	
01999-60W93-00	117	MANUAL, OWNERS	AR	A	1	1	2	FA4 LH A	3	
01999-60W93-00	133	MANUAL, OWNERS	AS	C	1	1	2	FA4 LH A	2	
01999-60W93-00	154	MANUAL, OWNERS	AT	A	1	1	2	FA4 LH A	3	
09101-60670-00	243	TOOL SET, STD L/JACK	AN	D	1	3	3	FA4 LH B	14	
09101-60670-00	264	TOOL SET, STD L/JACK	AP	B	1	3	3	FA4 LH B	15	
09101-60690-00	181	TOOL SET, STD L/JACK	AC	D	1	3	2	FA4 LH B	14	
09101-60690-00	203	TOOL SET, STD L/JACK	AK	B	1	3	2	FA4 LH B	15	
09101-60690-00	223	TOOL SET, STD L/JACK	AM	B	1	3	2	FA4 LH B	15	
09101-60690-00	283	TOOL SET, STD L/JACK	AQ	D	1	3	2	FA4 LH B	14	
09101-60690-00	304	TOOL SET, STD L/JACK	AR	B	1	3	2	FA4 LH B	15	
09101-60690-00	323	TOOL SET, STD L/JACK	AS	D	1	3	2	FA4 LH B	14	
09101-60690-00	344	TOOL SET, STD L/JACK	AT	B	1	3	2	FA4 LH B	15	
09111-60180-00	187	JACK SUB-ASSY, SCREW	AC	D	1	3	9	FA4 LH B	20	
09111-60180-00	207	JACK SUB-ASSY, SCREW	AK	B	1	3	8	FA4 LH B	19	

Figure 16 - Excerpt from the Database Created

ID	Posto	Observações	Criado
1	Picking MF1		05 de maio
2	Outro (Observaç...	Preciso dum Escape	05 de maio
3	Picking MF3		06 de maio
4	Picking MF2	Falta peça 326364-1642598	06 de maio
5	Picking MF1	Sem stock na rack	06 de maio
6	Picking MF3	falta peça x	07 de maio
7	Picking MF2	FAlta rda	08 de maio
8	Picking MF3	Falta Pneus	08 de maio
9	Picking MF2	Dollie avariou	08 de maio
11	Picking MF3		09 de maio
12	Picking MF1	Falta peça XXXXX-YYYYY-00 na rack F	09 de maio

Figure 17 - Excerpt from the Supervisor Call Registration List

ID	Criado	Tipo de Anomalia	Part Number Afeto	Posto	Sufixo	Renban	Paragem d...	Tempo de ...	Observações	ID Pedido Ajuda
4	05 de maio	Falta Stock na Rack	215151	Picking MF2	AM	65		0	Stock 0	1
5	05 de maio	Peça Suja/Danificada	25415	Picking MF3	AM	36		2		
6	06 de maio	Outro (Inserir nas Observações)	58585	Picking MF2	AM	96			colaborador adormeceu	
7	06 de maio	Falta Stock na Rack	511215-5485	Picking MF1	AK	56			resolvido	4
8	06 de maio	Falta Stock na Rack	8585	Picking MF1	AK	56	✓	5	8778687	6
9	07 de maio	Dificuldade em Localizar Peça	651515	Picking MF2	AK	525				6
11	08 de maio	Outro (Inserir nas Observações)		Picking MF2					resolvido	8
12	09 de maio	Falta Stock na Rack	488455-512984-00	Picking MF2	AM	89	✓	2	Resolvido	10
13	09 de maio	Falta Stock na Rack	XXXXX-YYYYY-00	Picking MF1	AK	14	✓	1	Resolvido.	12
14	12 de maio	Falta Stock na Rack	12345-12345-00	Picking MF3	AQ	34	✓	4	Peça reposta.	13

Figure 18 - Excerpt from the Anomaly Registration List

4) Dashboard Structure Design

Once the data was properly mapped and organized, the next step involved defining the structure of the digital dashboard. The primary objective in this phase was to develop a layout that would be both intuitive and functional for logistics operators, ensuring ease of use while maintaining alignment with the operational needs of the FA4 area.

The dashboard was designed to centralize key logistical functions into a single interactive interface, allowing users to access essential tools quickly and efficiently. Its structure was guided by usability principles, aiming to reduce complexity, facilitate navigation, and support decision-making on the shop floor.

The final prototype integrates four core functionalities, as confirmed by Figure 19, each represented by a distinct icon and accessible through the same report interface. When an icon is selected on the front page, the operator is automatically redirected to the corresponding page within the dashboard, allowing for intuitive and efficient navigation between functionalities. The upright corner of the dashboard front page also displays the most recent update/modification time of the dashboard or dashboard data, ensuring that operators and supervisors are aware of the last system's changes. These functionalities are as follows:

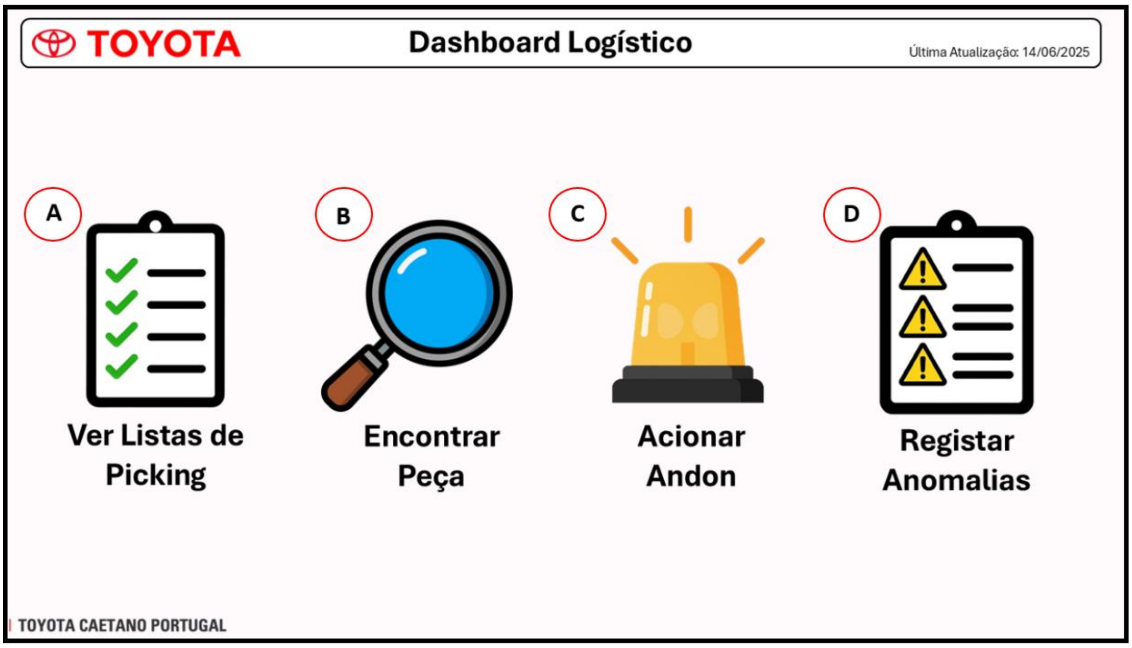

Figure 19 - Prototype Dashboard Front Page

A) View Picking Lists

This functionality provides access to digital picking lists based on the principles of PTL systems. It was developed to offer operators an interactive and structured interface through which digital picking instructions can be followed in a guided and visual manner, supporting more efficient and accurate part retrieval.

The process begins with the operator selecting the suffix and the target dolly/workstation for which the picking task is to be performed. Upon selection, the dashboard immediately displays the total number of distinct part-numbers required, along with the racks in which each part is stored. The central table updates and provides additional support, displaying the relevant information for each part, including part-number, assigned rack, and required quantity, as shown by Figure 20. This provides a clear overview of the workload and allows the operator to plan an optimized picking route.

The operator can switch between rack view and dolly view depending on the current picking phase. In rack view, the operator must input the specific rack they intend to pick from, using the field located in the upper-right corner of the dashboard. This step is mandatory, as the SVG-based layout must match the correct rack to ensure accurate visual representation and part highlighting. Once the rack is selected, the layout updates accordingly. The operator begins by clicking on the part-numbers one by one. Each correctly selected part is highlighted in green, simulating the confirmation light of a PTL system. If a part that is not on the current picking list is selected, its position is highlighted in red, signaling a mismatch and helping to prevent picking errors. To assist further in part identification, the image of the last selected part is shown within the dashboard, as shown in Figure 21.

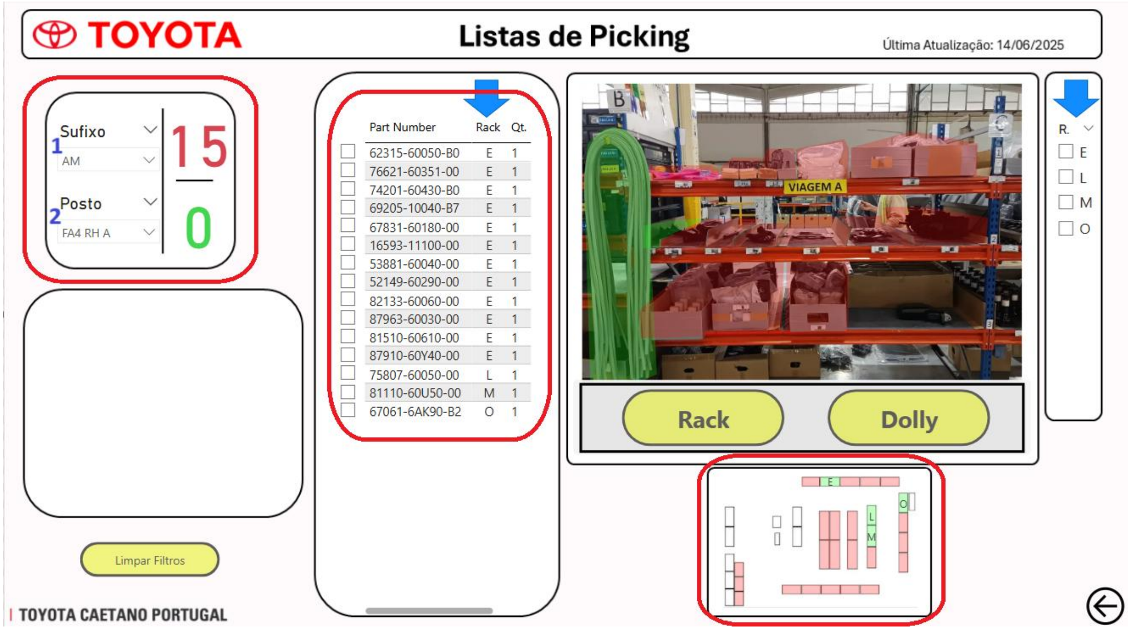

Figure 20 - Picking List Dashboard – Rack View Example 1

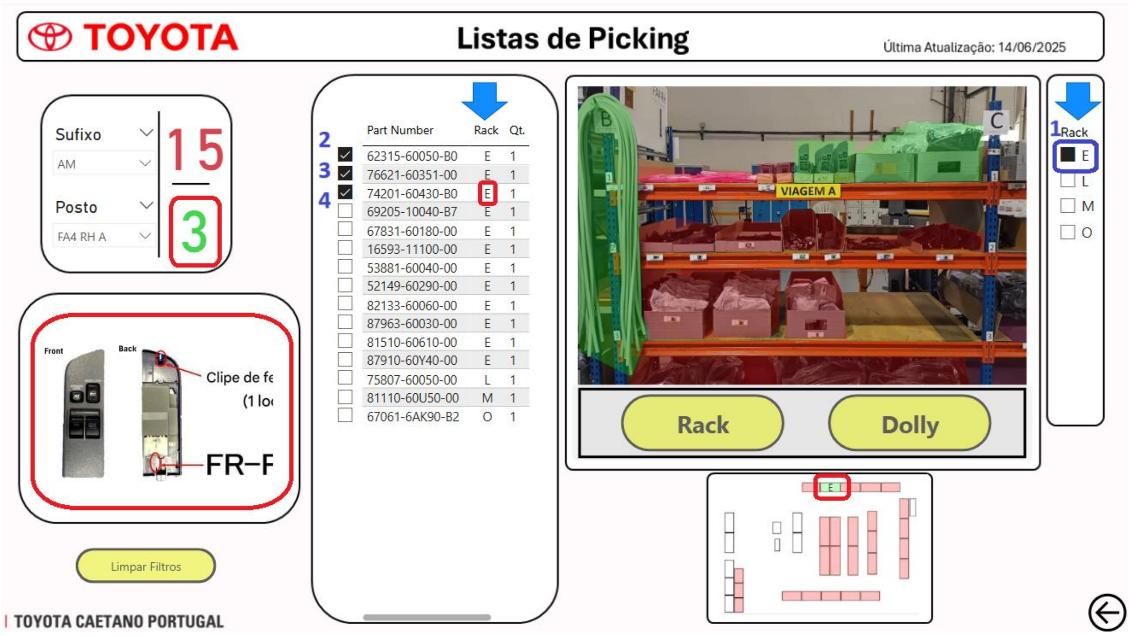

Figure 21 - Picking List Dashboard – Rack View Example 2

Once picking from racks is completed, the operator is expected to clear the selections and switch to dolly view to confirm part placement, as shown in Figure 22.

In this mode, no additional inputs are required since each dolly is associated with a single predefined picking list, and its layout is automatically loaded. The same visual logic applies. Parts correct locations are highlighted in green upon selection while incorrect locations are shown in red. The operator manually confirms placement by clicking each part individually, reinforcing the visual alignment of the digital process with the physical flow, as illustrated in Figure 23.

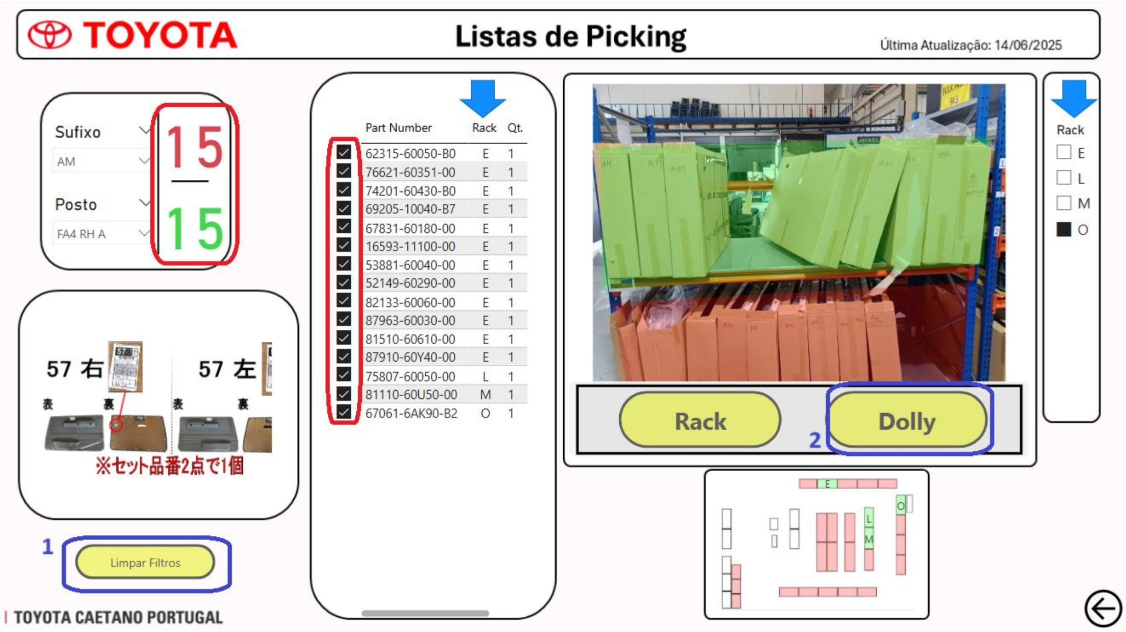

Figure 22 - Picking List Dashboard – Rack View Example 3

Figure 23 - Picking List Dashboard – Dolly View Example

Despite effectively simulating the logic of a PTL system, the prototype has certain limitations. The picking sequence is not automated. The operator must manually confirm each picked item and move to the next one, which may increase process time and introduce variability. In the last version of the system, it is intended that this confirmation step will be replaced by sensor-based automation, allowing the system to detect part removal in real time and automatically highlight the next part to be picked, streamlining the entire process.

Additionally, once a part is selected, its position remains highlighted in green to provide a visual record of progress. While this supports operator awareness of which items have already been collected, as more parts are picked and more locations turn green, visual clarity may decline, making it more difficult to locate remaining parts.

Nonetheless, this functionality successfully validates the interaction model and demonstrates the potential benefits of digital picking systems. It provides a practical, low-cost approach for simulating PTL logic and serves as a foundation for more advanced, automated solutions to be developed in future implementations.

B) Locate Part

This module was developed to support logistics operators in quickly identifying the physical location of any individual component stored in the FA4 supermarket. Unlike the previous feature, which is structured around production-driven part retrieval, this function is not tied to a specific suffix or picking list. Instead, it serves as a flexible and on-demand tool for locating any part-number within the storage area. This functionality is particularly useful in several operational scenarios, such as:

- When a part is damaged during handling or transport and needs to be urgently replaced at the assembly line;
- When a supplier identifies a defective batch and requests the immediate removal of affected parts from the supermarket;
- During internal audits or quality checks, where specific parts need to be located for inspection;
- When operators need to verify the physical stock position of a component not currently included in a scheduled picking list.

To use the tool, the operator can search for the desired part number by scrolling through the sidebar, where part numbers are listed in numerical order. To reduce the search scope, the operator may also filter the results by entering the suffix and/or the workstation in which the part is used. The dashboard then highlights the locations in which the selected part is stored using the SVG layout of the FA4 supermarket, as shown in Figure 24. The SVG layout is interactive: the operator begins by clicking on a rack in the overview layout, after which a zoomed-in version of the selected rack appears, displaying the internal structure and highlighting the position of the searched part. If the part is stored in more than one rack, the operator can zoom out and click on another rack, repeating the process to view all instances where the part is located. Figure 25 displays the location of the part-number selected on Figure 24. The part-number is present in two different racks.

Each valid location is highlighted in green, offering immediate visual confirmation and replicating the feedback logic of a PTL system. If the part-number is not found in the mapped database or does not exist in the selected rack, no highlight is shown.

This feature significantly improves the efficiency of unplanned or exception-driven retrieval tasks by providing real-time access to accurate spatial data. It eliminates the need for manual searches through physical storage or spreadsheets and supports a more responsive and autonomous logistics workflow. By integrating this functionality into the same platform used for picking operations, the system ensures consistency in user experience and maximizes the utility of the digital supermarket representation.

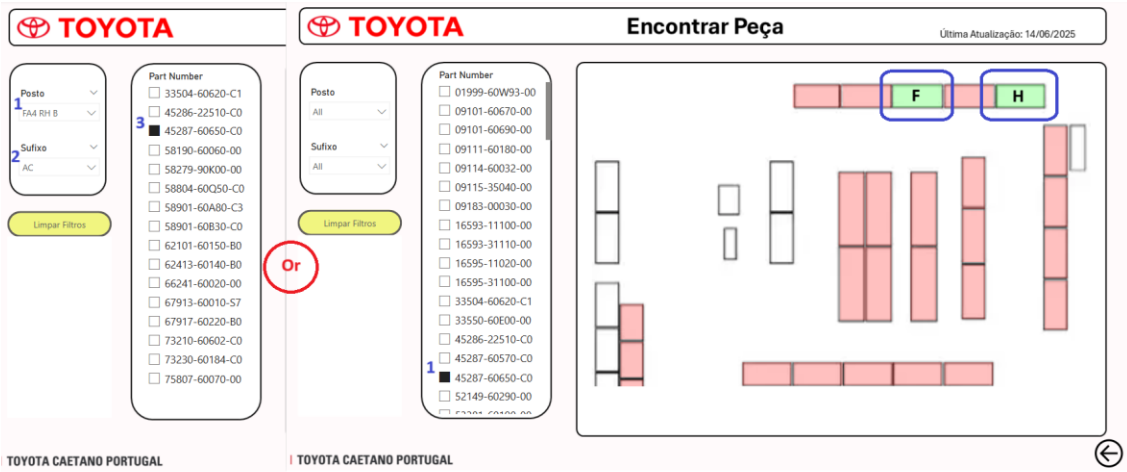

Figure 24 - Locate Part Dashboard – Example 1

Figure 25 - Locate Part Dashboard – Example 2

C) Trigger *Andon*

This feature was developed to simulate the process of requesting immediate support when an anomaly occurs in the logistics section. Unlike traditional *Andon* systems in fixed places, this version is adapted for mobile use, considering that logistics operators do not work at static positions.

To initiate a call, the operator accesses the dedicated Power App embedded within the dashboard and clicks on the "Add" symbol, as shown in Figure 26. The operator then identifies themselves and, if deemed useful, may include a brief note for the supervisor. To submit the request, the "arrow" symbol is pressed; alternatively, the request can be discarded by clicking the "cross" symbol, as illustrated in Figure 27.

Upon submission, a unique identifier (ID) is automatically generated, and the date and time of the request are recorded. Recent calls for assistance are displayed in a panel on the left side of the application, providing visibility of active alerts, as Figure 28 shows. Simultaneously, the call is automatically registered in a SharePoint list, and a notification is sent to the supervisor with the relevant details, enabling immediate action (see Figure 29).

This ensures traceability and provides a real-time alert to the supervisor or team leader, allowing for prompt reaction and logging of the anomaly. The interface was designed for simplicity and speed, enabling the operator to send the alert with minimal disruption to ongoing tasks. This mechanism replicates the real-time signaling concept of traditional *Andon* systems and enhances communication flow within the logistics area.

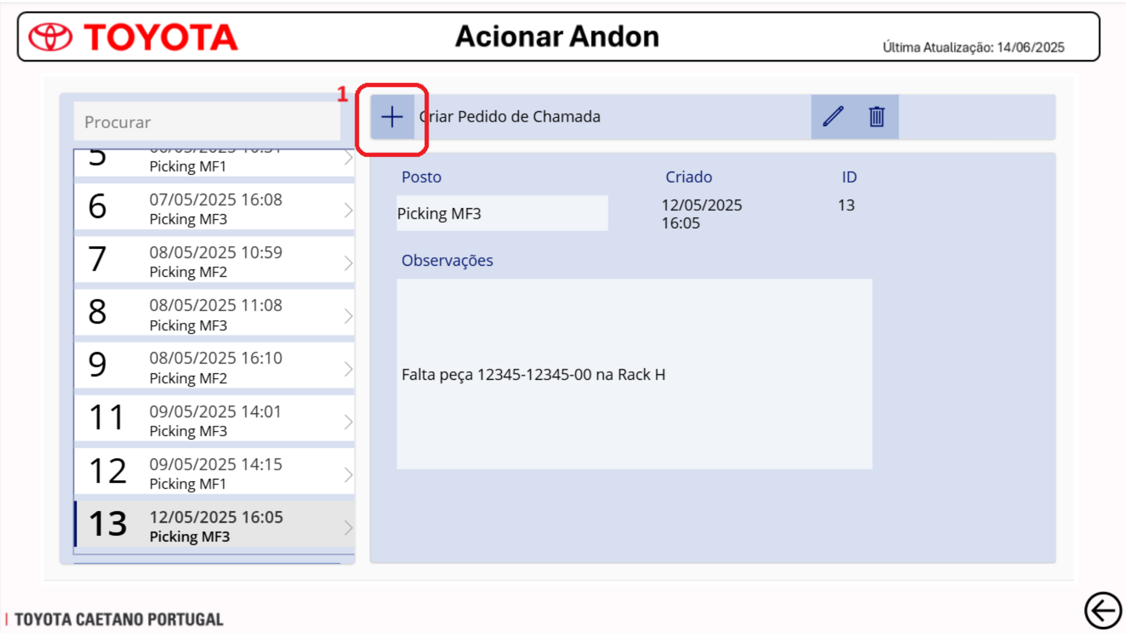

Figure 26 - Trigger *Andon* Dashboard – Example 1

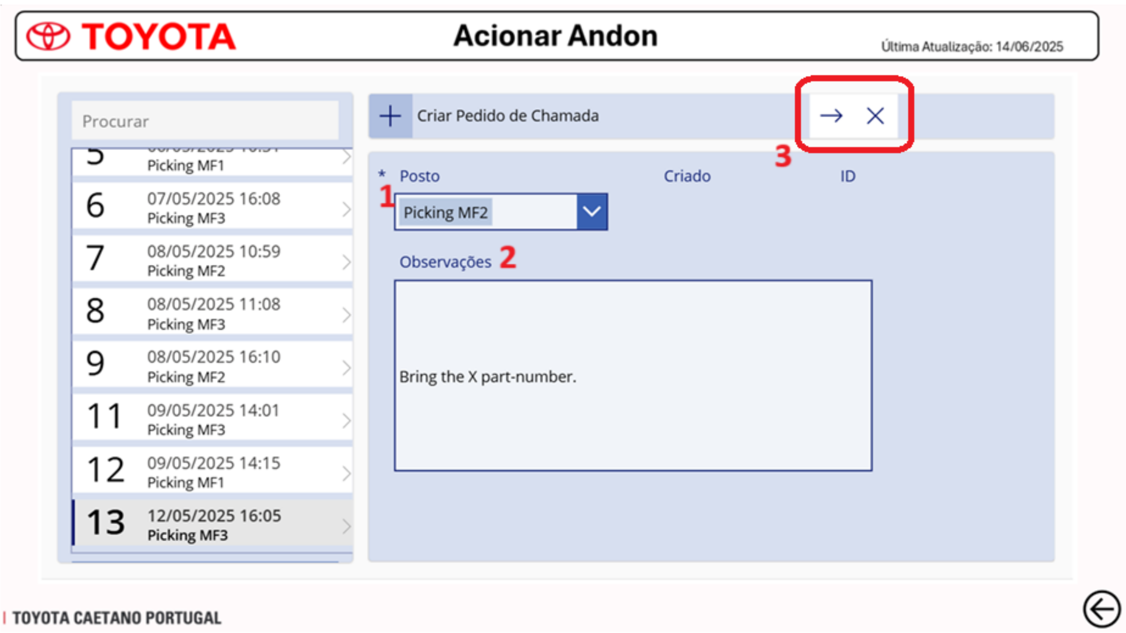

Figure 27 - Trigger *Andon* Dashboard – Example 2

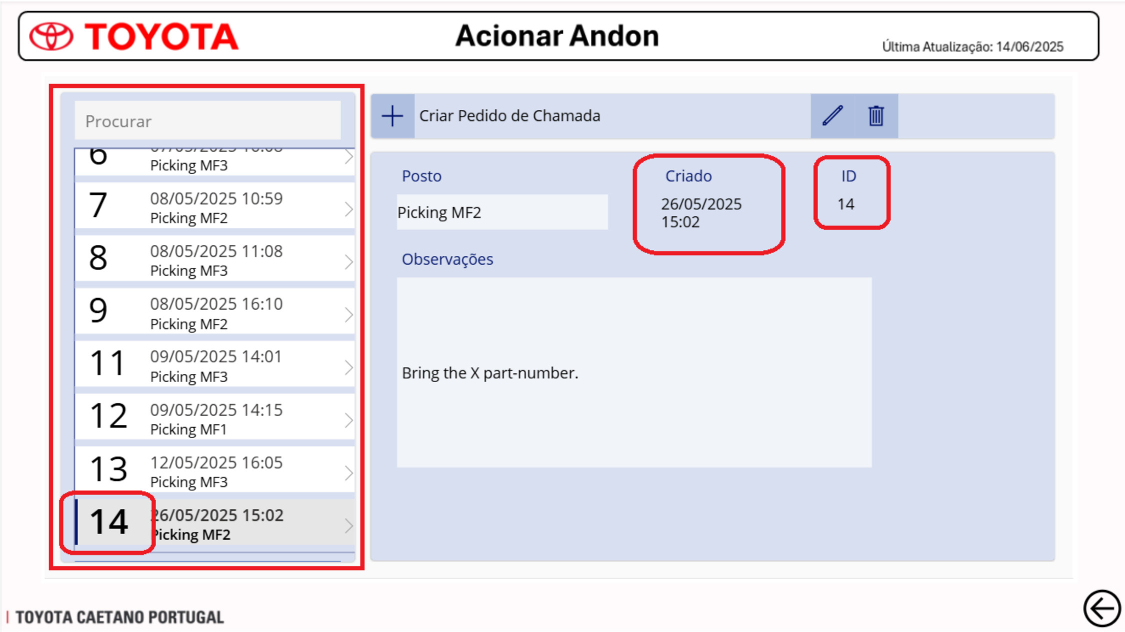

Figure 28 - Trigger *Andon* Dashboard – Example 3

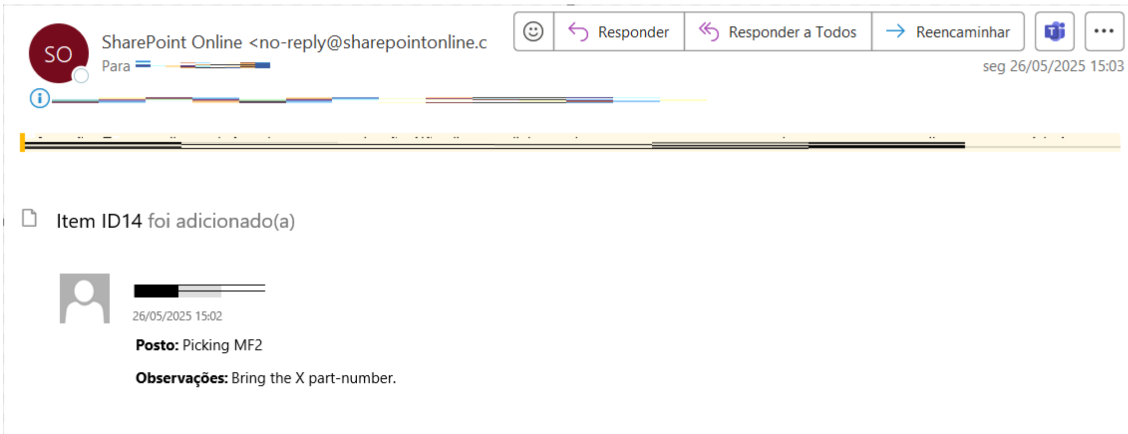

Figure 29 - Supervisor Alert

Despite fulfilling its intended purpose within the prototype, the *Andon* call system presents certain limitations that constrain its effectiveness in an operational context.

Currently, once a call is submitted, the supervisor is notified via email, which may result in delays in response due to limited visibility or attention to incoming messages during work. This notification method lacks the immediacy and visibility required in fast-paced production environments.

The *Andon* system at the assembly that relies on visual (signal lights) and auditory (buzzers) alerts, which are far more effective in ensuring real-time awareness and prompt response. To achieve similar performance in logistics applications, future implementations should incorporate integrated visual and audible alerts, ensuring that supervisors are instantly and unmistakably informed of the latest support requests, even in the absence of direct interaction with digital devices.

D) Register Anomalies

This final functionality enables the structured recording of anomalies by supervisors after the intervention has taken place. Once the supervisor arrives at the scene and addresses the issue, they access a second Power App, also embedded within the dashboard, to formally document the anomaly using a standardized set of parameters.

The interface follows a structure like the previously explained Power App, including options to add or delete entries and to view recent records. By clicking the "Add" symbol, a form is displayed, as illustrated in Figure 30, allowing the supervisor to input the necessary information. Once the form is submitted, the data is saved in a separate SharePoint list and can also be consulted through the Power Bi report as presented in Figure 31.

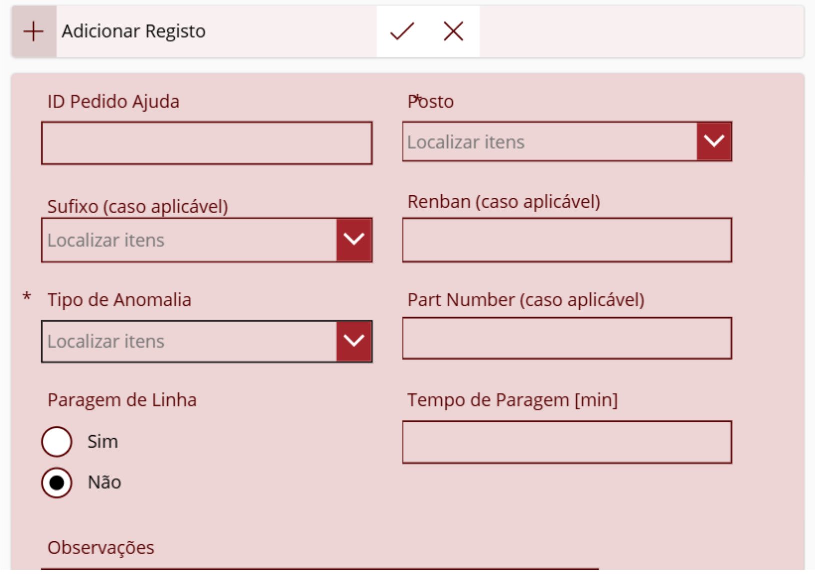

Figure 30 - Register Anomalies Dashboard – Example 1

Figure 31 - Register Anomalies Dashboard – Example 2

Both records can be linked using the ID created in the request for help, allowing full traceability from the initial alert to the final resolution. The goal of this functionality is to build a structured anomaly database that supports analysis, continuous improvement, and performance monitoring. It ensures that all incidents are recorded with sufficient detail to identify patterns, root causes, and recurring issues.

Together, these two functionalities simulate an integrated *Andon* and anomaly management system adapted to the specific needs of internal logistics, demonstrating the feasibility of digitalizing these processes through simple, scalable tools.

5. Demonstration

This chapter presents the demonstration and critical discussion of the solutions developed throughout the project using the DRS methodology. The analysis is structured around a comparative framework that contrasts the *as-is* and *to-be* states, enabling a deeper understanding of the value and impact of the proposed interventions.

The *to-be* scenario refers to the idealized or optimal solution that was originally envisioned - incorporating the full integration of the Pick-to-Light system with a digital *Andon* platform, supported by real-time anomaly traceability, supervisor feedback loops, and seamless data integration. This version represents the target state the project sought to achieve under ideal conditions, unconstrained by time or resource limitations. The *as-is* refers to the current operational reality, prior to any intervention, where logistics activities are conducted without digital support systems.

The evaluation proceeds by comparing the performance, functionalities, and feasibility of the prototype against the envisioned optimal solution. This analysis is essential for identifying the gaps between what was designed and what can be achieved with the prototype, assessing its practical effectiveness, and outlining future improvement opportunities. The discussion also reflects on qualitative and quantitative aspects, offering insights into the practical value of the system within the logistics context of TCAP.

5.1. Pick-to-Light: As-Is vs To-Be Analysis

- **Picking As-Is**

At present, all picking activities at TCAP are conducted using paper-based instructions. Each dolly that goes to the assembly line is associated with nine different picking lists, corresponding to the nine suffixes that can enter the production sequence. These lists are stored on a support bench (see Figure 32), and the picking operator is responsible for manually updating the displayed list on each dolly at every takt time. As part of this process, the operator writes the Renban number of the vehicle on the header of the selected list to ensure alignment with the current production order.

Each picking list is identified according to the workstation, line side (LH or RH), takt time cycle (A or B), and suffix, and includes a breakdown of all the parts to be picked for the respective job at the line. Within the list, each part is specified by its image, name, part-number, and its designated rack and dolly address. The list also includes the quantity to be picked and a checkbox that the operator is expected to mark once the part has been placed on the dolly.

However, as previously mentioned, many of these addresses are outdated. A clear picking list example is shown on Figure 33. At the supermarket, parts are identified through standardized labels, which serve as quick-reference guides for the picking operator, as Figure 34 illustrates. These labels display the part image, part number, and the suffixes in which the part can be used.

Figure 32 - Picking Lists on the CH1 Support Bench

Figure 33 - Excerpt of FA4 RH A Picking List for an AM Suffix

Figure 34 - Label Example

The current picking process presents operational limitations that compromise efficiency and accuracy. While the list includes checkboxes for verification, operators often bypass this step due to time pressure or repetitive strain, leading to unverified picks and a higher risk of errors. Also, operators tend to avoid carrying the list during the picking route, instead relying on memory to recall part numbers and positions. This practice increases the likelihood of omissions or misplacements, particularly when dealing with suffix specific variations. Figure 35 shows an example of a picking list displayed on the dolly ready to feed the assembly line.

Figure 35 - FA4 RH B Picking List at Dolly

Another major challenge lies in the identification of parts on the racks, as Figure 36 illustrates. Although racks are labeled with part images and codes, the labels are often small, worn, or visually similar, making it difficult for operators to quickly and accurately locate the correct item. This issue is intensified by the outdated positional information on the picking lists, which no longer reflects the actual supermarket layout. Furthermore, the absence of real-time validation or error-proofing mechanisms means that mistakes, such as picking incorrect parts or insufficient quantities, may go unnoticed until the dolly reaches the assembly line, potentially leading to production delays or rework. Overall, the system’s heavy reliance on manual inputs, memory, and paper documentation hinders its ability to feed the line in a consistent and structured way.

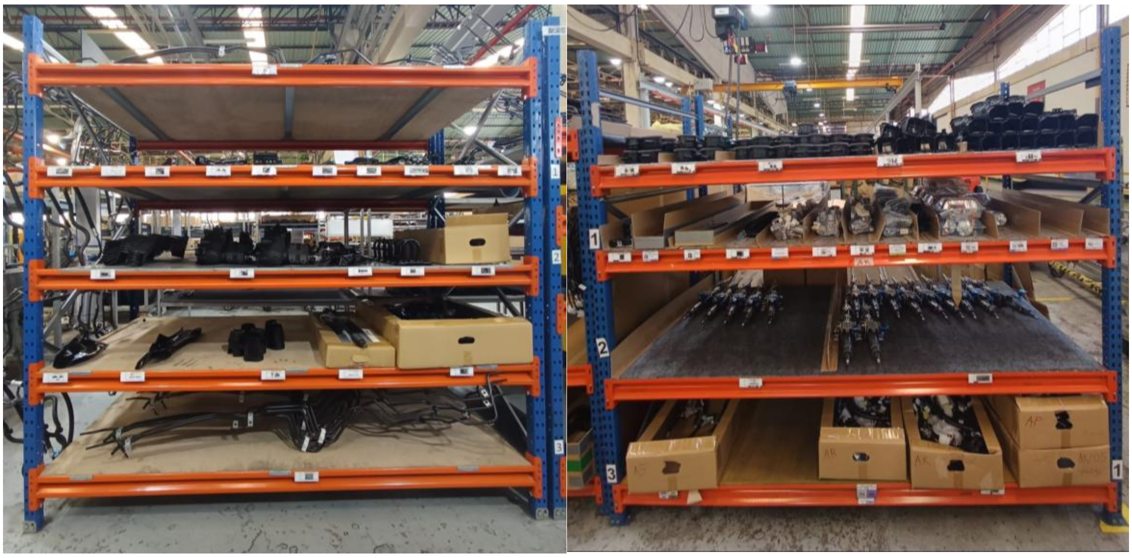

Figure 36 - Example of Labels on Two Distinct Racks

- **Picking To-Be**

The implementation of a Pick-to-Light system introduces a structured and technologically advanced approach to the picking process that can mitigate common logistics anomalies. By providing visual signals directly at the picking locations through illuminated indicators and digital displays, the system guides operators with precision, enabling faster and more accurate part retrieval. This targeted guidance reduces time spent searching for materials, minimizes supply delays, and supports a more consistent and uninterrupted production flow. A sketch of a PTL system on a rack is presented at Figure 37.

One of the key advantages of the PTL system is its integrated confirmation mechanism based on motion-detection sensors. Instead of requiring manual input, the system automatically registers the picking action when the operator removes a part from the designated location. This hands-free mechanism is crucial, as operators most times have both hands occupied while working. This sensor-based confirmation ensures that each part is accounted for in real time, significantly reducing the likelihood of missing components. In addition, PTL systems can also be combined with barcode scanning or visual recognition technologies to validate the identity of the item, which is useful when restocking the supermarket by the unpacking team. These verification layers are particularly effective in preventing swapped or incorrect parts, which remain among the most frequent and disruptive anomalies in logistics operations.

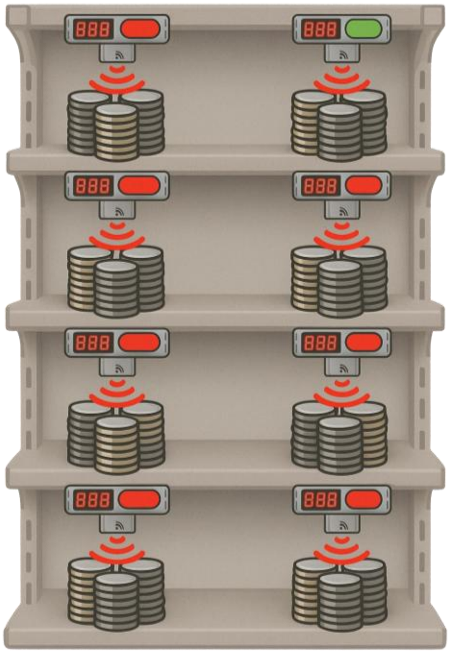

Figure 37 - Sketch Sample of the PTL Solution Desired

Beyond its application at static picking locations, PTL technology can also be integrated into dollies used to deliver parts from the supermarket to the line. In this setup, each compartment on the dolly is equipped with a light indicator corresponding to the correct location for each part, like how it is used on racks. The parts layout on the dolly is predefined based on assembly ergonomics and sequence of use, ensuring that parts are positioned in a way that facilitates easy and efficient retrieval by the assembly operator, so respecting this configuration is mandatory. By guiding the picking operator to place each item in its designated slot, the PTL system ensures that this optimal configuration is consistently respected. This not only eliminates misplacements but also contributes to a more streamlined assembly process, improving overall workflow efficiency at the line.

PTL also offers increased flexibility during line rebalancing activities. In conventional systems, changes to the position of parts on racks or dollies require manual relabeling and physical reorganization, which is both time-consuming and prone to error. With PTL, part locations are digitally managed, allowing the light indicators to be quickly reprogrammed through software to reflect updated layouts. This enables the logistics team to adapt the part configuration in response to changes in takt time or workstation assignments without disrupting the picking process. By ensuring that operators always receive accurate visual guidance, even after layout modifications, PTL supports a smoother transition during line balancing and reinforces the standardization of part presentation, contributing to a more agile and responsive production system.

Outside reducing errors, PTL systems improve operational efficiency by enabling real-time monitoring. Supervisors can oversee the picking progress through system dashboards, allowing for rapid intervention if deviations occur. The shift away from paper-based picking lists also contributes to environmental sustainability by reducing paper waste. In addition, the intuitive visual interface enhances operator confidence and speed, promoting a more reliable and traceable process overall. Figure 38 resumes the *as-is* vs *to-be* scenario of the picking process.

Picking As-Is
→ Paper-based picking lists updated manually at each takt time
→ Operators rely on memory or printed lists to locate parts
→ Checkboxes used for manual verification (often skipped)
→ Part labels on racks are small and sometimes outdated
→ Difficulty keeping part positions up to date in the database
→ System relies heavily on manual inputs
→ Part positioning on dollies not consistently followed
→ No real-time visibility for supervisors

Picking To-Be
→ Visual light indicators guide operators to correct part locations
→ Motion sensors confirm part removal automatically
→ Dolly compartments are validated to ensure correct placement
→ System is easily reconfigurable during line balancing
→ Real-time dashboard provides picking status to supervisors
→ Eliminates paper use and reduces cognitive load on operators
→ System relies on digital and automated information

Figure 38 - Picking *as-is* vs *to-be* Resume

5.2. *Andon* System: As-Is vs To-Be Analysis

- ***Andon* As-Is**

Currently, the logistics area at TCAP does not have a dedicated *Andon* system to manage anomalies that occur during the unpacking and picking processes. When issues arise, operators rely on informal communication methods, such as calling out to or physically walking over to a supervisor or support team. This reactive and manual approach introduces limitations.

Response times are often delayed, as problems may not be reported immediately or communicated with sufficient clarity. Furthermore, there is no traceability or formal record-keeping, which hinders the ability to conduct systematic analysis or identify recurring issues over time. The absence of a structured escalation process makes it difficult to prioritize or track critical anomalies that could potentially affect downstream assembly operations. In addition, without a consistent feedback loop, the causes and resolutions of anomalies are rarely shared or documented in a standardized way.

This results in a high degree of operator dependence, where the effectiveness of anomaly handling relies heavily on individual initiative rather than formal procedures. As a result, the overall process lacks structure and visibility, increasing the risk of delays, particularly during takt time changeovers or high-pressure moments in the production cycle.

Although the logistics area does not have an *Andon* system, one is already in place on the assembly line, allowing operators to signal anomalies using two overhead pull cords that run along the entire assembly line. When a problem is detected, the operator pulls one of the cords, see Figure 39, triggering a visual and audible alert.

Figure 39 - *Andon* System in FA1 LH Workstation

The system distinguishes between two levels of severity:

1) Pulling the white cord activates a yellow light above the workstation and a corresponding warning sound. In this case, only the affected workstation stops, allowing support teams to intervene without interrupting the entire line.
2) If the anomaly is critical and cannot be resolved locally, the operator pulls the red cord, which activates a red light above the workstation and a different and more urgent sound is hearable. This action causes the entire assembly line to stop immediately, prompting intervention from team leaders and supervisors.

Once the problem is addressed, supervisors manually record the anomaly on a physical board located at the site, as presented in Figure 40. At the end of each day or week, these entries are manually transferred to a digital database, which serves as the central repository for tracking and analyzing anomalies that occur at the line.

While this system ensures structured escalation and maintains a historical record of events, the manual data transfer process results in duplicated effort. Additionally, because the recorded data is not standardized, inconsistencies in how anomalies are documented limit the quality and reliability of subsequent analysis. As shown in Figure 40, anomaly-related parameters are either left blank or indicated with question marks which is not desired.

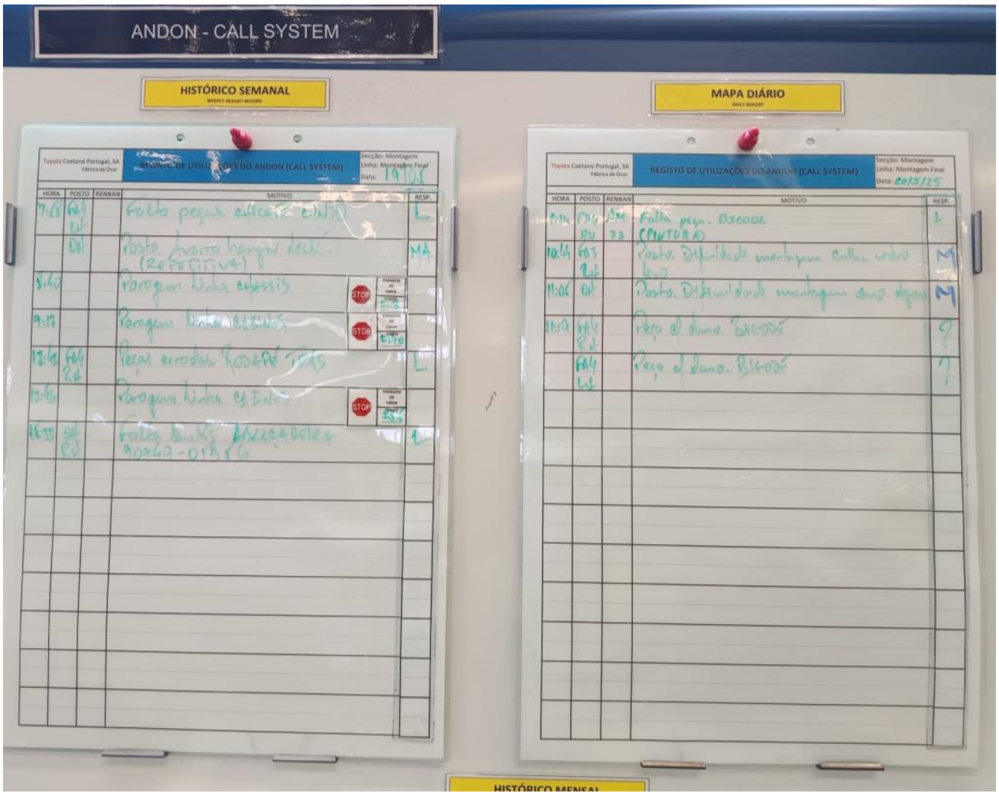

Figure 40 - Anomalies Record at Assembly Line

- ***Andon* To-Be**

The proposed *Andon* system for the logistics area aims to follow the same fundamental principles already established on the assembly line - namely, real-time anomaly signaling, rapid response, and structured resolution - while introducing key adjustments to accommodate the specific nature of logistics work. Unlike assembly operators who perform tasks at fixed workstations, logistics operators move throughout the plant, making it necessary for the *Andon* system to be mobile and flexible.

To address this, each operator would carry a handheld device capable of sending an immediate support request when an anomaly is detected. This device would feature a simple and intuitive interface, enabling the operator to quickly communicate their identity, current location within the plant, and a brief description or categorization of the problem.

Once the call is issued, a supervisor is alerted in real time, arrives at the scene, and provides assistance. After resolving the issue, the supervisor uses their own device to register the anomaly, filling out a set of predefined parameters to ensure consistency and completeness of the record. Each support call would be assigned a unique identifier, which is linked to the corresponding anomaly record, ensuring accurate traceability between the call and the resolution.

Unlike the manual system currently used in the assembly line, this digital solution would allow the anomaly to be instantly entered into the database, enabling real-time tracking, immediate data availability for analysis, and full traceability throughout the logistics flow. Figure 41 resumes the *as-is* vs *to-be* scenario of the *Andon* system process.

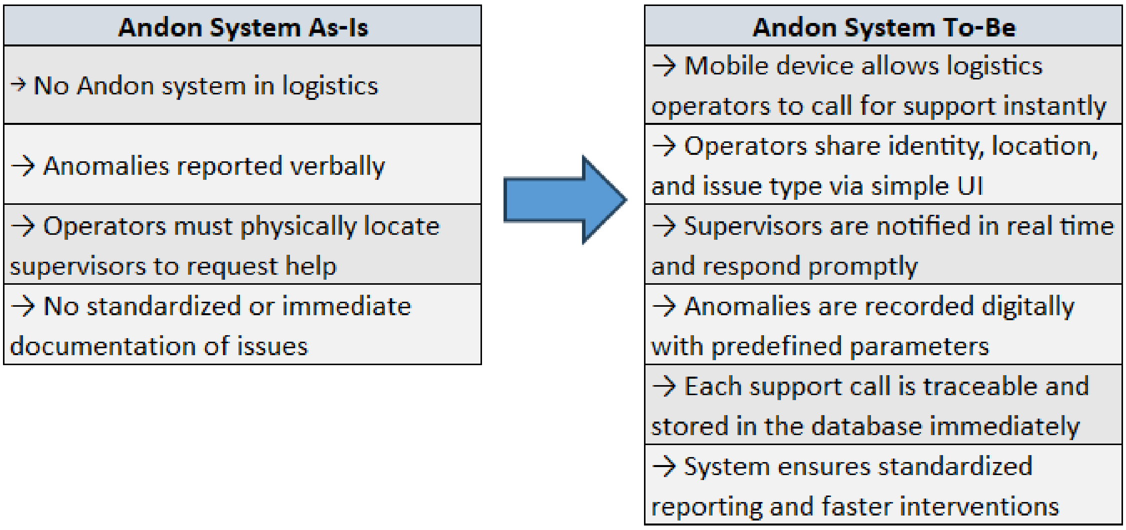

Figure 41 - *Andon* System as-is vs to-be Resume

5.3. PTL and *Andon* System: Prototype vs To-Be Analysis

This section conducts an evaluation of the developed prototype by comparing it directly with the *to-be* (ideal) solution. While the prototype reflects quick progress in digitizing part feeding and anomaly reporting in logistics, certain functionalities and levels of integration were constrained by available resources and time.

By isolating each system and examining their ideal and current states, this analysis provides a structured overview of what was achieved, what remains to be developed, and the implications of these gaps for system performance and logistics operations.

The functional comparison between the ideal system and the developed prototype, presented in Table 13 and

Table 14, reveals a clear distinction between envisioned and achieved capabilities. This analysis is guided by the qualitative objectives outlined in the conceptual framework present in the Chapter 4, section 4.1.

Although quantitative objectives were also defined in the conceptual model, these cannot yet be evaluated because the prototype has not been fully deployed in a live operational setting, and therefore, no empirical data is available to measure its impact against baseline performance indicators.

Regarding the PTL system, the *to-be* solution was designed to ensure prominent levels of standardization and error-proofing in the picking process through real-time enterprise systems integration, automatic light activation, and sensor-based confirmation. These features aim to reduce variability and promote consistent operator behavior.

However, the prototype, constrained by the lack of integration and automation, only partially supports this objective. Although it simulates the visual guidance concept, it does not yet ensure real-time validation or connectivity to production sequence data, limiting its ability to drive consistent standard work.

Table 13 - Qualitative Objectives Comparison between Envisioned PTL System and Prototype Capabilities

Qualitative Objective	To-Be Solution	Prototype Solution	Gap/Observation
Improve picking accuracy	Real-time light cues and sensor confirmation prevent picking errors	Manual light triggers, no validation mechanism	No feedback loop to confirm correct picks
Reduce operator cognitive load	Visual guidance reduces the need for memorization and searching	Visual guidance simulated manually	Requires more attention and manual input from operator
Enhance standardization	Consistent picking process via automatic logic and sequencing	Partially simulated; fixed light logic	Standardization not ensured due to manual setup
Support easier reconfiguration during line balancing	System updates picking logic based on task redistribution	No real-time reconfiguration	Lacks flexibility to support dynamic layout changes
Promote operator autonomy	Operator follows lights without needing instructions	Limited autonomy; relies on external triggers	Prototype does not allow operator-driven actions
Improve training efficiency	Intuitive light system accelerates learning curve	Demonstrated visually	Concept shown, but lacks dynamic interaction for full training support
Increase process transparency	Enterprise software connectivity enables data logging and process visibility	No data storage or tracking	Prototype operates offline
Reduce dependency on printed materials	Digital picking replaces printed lists	Paper still needed to guide process	No system linkage to task instructions or production sequence

Concerning the *Andon* system, the *to-be* model was envisioned as a mobile-enabled, fully digital solution capable of quickly alerting supervisors, capturing anomaly contexts, and enabling structured follow-up. The prototype captures this intent through separate Power Apps for operator calls and supervisor intervention records, both linked via unique IDs and stored in SharePoint.

While this configuration successfully enables structured anomaly registration and introduces a digital layer to the process, it exhibits limitations when evaluated against the full aspirations of the *to-be* model. Chief among these is the lack of real-time system responsiveness, as the architecture depends on manual data refreshes rather than live notifications or automated syncing. Additionally, the separation between the two applications introduces friction in user experience, particularly when compared to the streamlined interaction that a single, fully integrated app could provide.

Despite these constraints, the prototype fulfills its intended role within the scope of this research. It demonstrates the feasibility of extending *Andon* logic into the logistics domain and provides a functional base for future developments.

Table 14 - Qualitative Objectives Comparison between Envisioned *Andon* System and Prototype

Qualitative Objective	To-Be Solution	Prototype Solution	Gap/Observation
Enable real-time anomaly escalation	Operator alerts supervisor instantly via mobile device	Operator alerts supervisor instantly via mobile device	Functional but may involve slight delays due to backend
Adapt *Andon* to mobile workflows	Tablet or phone used to trigger and track anomalies	Power App accessed on tablet	Fully aligned in form, though interface could be more unified
Reduce communication delays	Automatic messaging and notifications	SharePoint triggered messages	Slight lag, dependent on platform refresh cycles
Standardize anomaly reporting	Structured form with predefined categories and timestamps	Supervisor fills form in separate Power App	Logic respected, but split app affects fluidity
Improve traceability of problems	Centralized database logs call ID, timestamp, user, and resolution	All data stored in SharePoint lists with ID linkage	Traceability achieved
Promote data-driven problem solving	Stored anomalies support historical analysis	Data stored but no dashboard or reports yet	Data not used for decision-making in current state
Enhance team coordination	Supervisors receive alerts and act based on system escalation	Alerts received and resolved manually	Relies on human follow-up, lacks task confirmation feedback
Ensure immediate data availability	Cloud-based database updates instantly after form submission	SharePoint forms auto-update on submission	Functional but could improve

In conclusion, while the prototype does not fully meet the envisioned technical specifications, it successfully validates the functional feasibility of both the Pick-to-Light and *Andon* systems. The core logic behind operator guidance, anomaly signaling, and structured data registration has been demonstrated effectively.

However, from a technological standpoint, limitations became evident during development, primarily due to constraints in time, budget, and available software. The absence of real-time integration with enterprise systems, the lack of automated confirmation mechanisms, and the separation between the call and logging interfaces represent critical gaps. These limitations underscore the need for further development and refinement before the prototype can be reliably deployed in a high-demand industrial environment. To make the current prototype more similar to the envisioned *to-be* solution, fundamental improvement areas are mandatory:

- Integrate digital picking lists and TCAP enterprise systems to trigger lights based on actual production orders;
- Replace simulation switches with real-time sensors to confirm pick events;
- Implement error-proofing logic to validate correct part selection before confirmation;
- Merge call-for-help and anomaly registration into a single, role-based Power App or mobile platform;
- Introduce geolocation or QR-based station scanning for precise location tracking;

– Build a live dashboard to monitor anomalies and response times in real time.

These improvements require further coordination with IT infrastructure, support from system integrators, and potential investment in hardware and cloud services. However, the existing prototype offers a strong foundational step, proving the feasibility and relevance of the proposed digitalization strategy.

6. Conclusion

This chapter presents the closing remarks of the research, providing a synthesis of the results achieved and reflecting on the broader implications of the work. It also acknowledges the project's limitations and outlines potential directions for future developments that may expand or deepen the contributions made.

6.1. Final Conclusions

This dissertation explored the continuous improvement of logistics processes within the internal supply system of an automotive assembly line. Guided by the Design Science Research methodology, the study supported the systematic development, prototyping, and evaluation of two integrated digital solutions: a Pick-to-Light system (PTL) to improve material picking accuracy and a mobile *Andon* system for real-time anomaly escalation – both representing de developed "artifact". These solutions were conceived as part of a broader strategy to reduce logistical inefficiencies, enhance process visibility, and increase operational responsiveness.

The research was rooted in the primary objective of analyzing and optimizing the supply strategy within the logistics operations of an automotive production environment, in alignment with the principles of the Toyota Production System. Specifically, the work aimed to contribute to the continuous improvement of internal logistics by mapping the current processes, identifying key inefficiencies, and proposing targeted digital solutions that promote process standardization, cost control, and efficiency. This primary objective was achieved.

The PTL system was idealized to digitalize and standardize the part-picking process, replacing traditional paper-based lists with a visually guided, intuitive interface. Its purpose was to reduce human error, minimize operator cognitive load, and increase process repeatability. By improving picking clarity and precision, the system helped address one of the most frequently observed sources of disruption in logistics: the recurrence of wrong or missing parts at the point of use.

In parallel, a mobile *Andon* system was planned to address the lack of a structured mechanism for managing logistics anomalies. Given that logistics operators do not work in fixed positions, a mobile-enabled solution allowed them to signal support needs in real time, including contextual information such as location and a short problem description. After resolving the issue, supervisors could register the anomaly using predefined categories and parameters, ensuring traceability, and enabling structured data analysis. The synchronization of these records into a centralized repository supports the long-term vision of data-driven continuous improvement.

Due to time and resource constraints (and considering that engaging external suppliers to implement a full solution would have required top management approval and entailed a lengthy and complex process, surpassing the timeframe of this thesis) a prototype (Artifact) was developed as a functional yet limited demonstration of the ideal solution. Nevertheless, it successfully validated the feasibility of the proposed systems. The results highlighted the relevance of combining lean principles with digital tools to address logistical pain points in a structured and practical manner. Furthermore, the integration of both systems represented a deliberate effort to extend lean thinking into the logistics domain, where such tools remain underutilized.

By simulating core functionalities through a working prototype, the research demonstrated that digital solutions can be effectively adapted to the specific needs and constraints of logistics activities. The combined focus on increasing picking accuracy and ensuring anomaly traceability reflected a comprehensive approach to quality, one where preventive and corrective mechanisms coexist to stabilize production support flows.

Concluding, this research succeeded in mapping and characterizing current logistics processes, identifying critical anomalies and inefficiencies, and designing and evaluating a prototype that reflects the core principles of TPS. While the proposed systems were not deployed at full scale, the functional prototype validated their conceptual soundness and operational relevance. The study also underscored the importance of combining functional simplicity with technological feasibility, ensuring that proposed solutions remain user-friendly, scalable, and aligned with actual production constraints. Finally, the findings demonstrate that even modest, well-targeted digital interventions, when guided by lean principles and contextual understanding, can generate significant process improvements and lay the groundwork for broader transformations in logistics performance.

6.2. Limitations and Future Work

Despite the successful validation of core functionalities, the dashboard presented limitations that must be addressed before possible full-scale implementation. It is important to note that the current solution remains a prototype. While it successfully demonstrates the functional viability of the proposed systems, its limitations result from necessary compromises due to technological, budgetary, and time constraints. The next logical step would be to design and implement the ideal solution - one that is robust, scalable, fully integrated with the company's digital infrastructure, and capable of sustaining long-term operational improvements. If considered opportune by decision-makers, the current prototype may be further developed to overcome some of its weaknesses. However, any solution built upon a prototype foundation will always carry certain structural limitations. Therefore, the most effective long-term strategy lies in the deployment of a dedicated Pick-to-Light system and a professionally developed *Andon* mechanism, both engineered for seamless integration and high operational reliability.

Additionally, the PTL concept itself offers scalable potential beyond the original application. For instance, it can be adapted into a Put-to-Light system to assist the unpacking team in sorting and allocating materials more efficiently. Similarly, Assemble-to-Light systems could be implemented at the logistics pre-assembly tables to guide operators through the picking of the necessary parts for the assemblies. These extensions illustrate the broader applicability of light-guided systems in supporting logistics operations across different workflows, contributing to enhanced standardization, reduced errors, and improved overall efficiency.

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Declaration of Integrity

I declare that I conducted this academic work with integrity. I did not plagiarize or apply any form of misuse of information or falsification of results throughout the process that led to its preparation. I declare that the work presented in this document is original and my own and has not previously been used for any other purpose. I further declare that I am fully aware of the Code of Ethical Conduct of P.PORTO, ISEP.

NAME: Francisco José Marinho Bastos

Porto, June 14, 2025

Declaration of Integrity

Appendices

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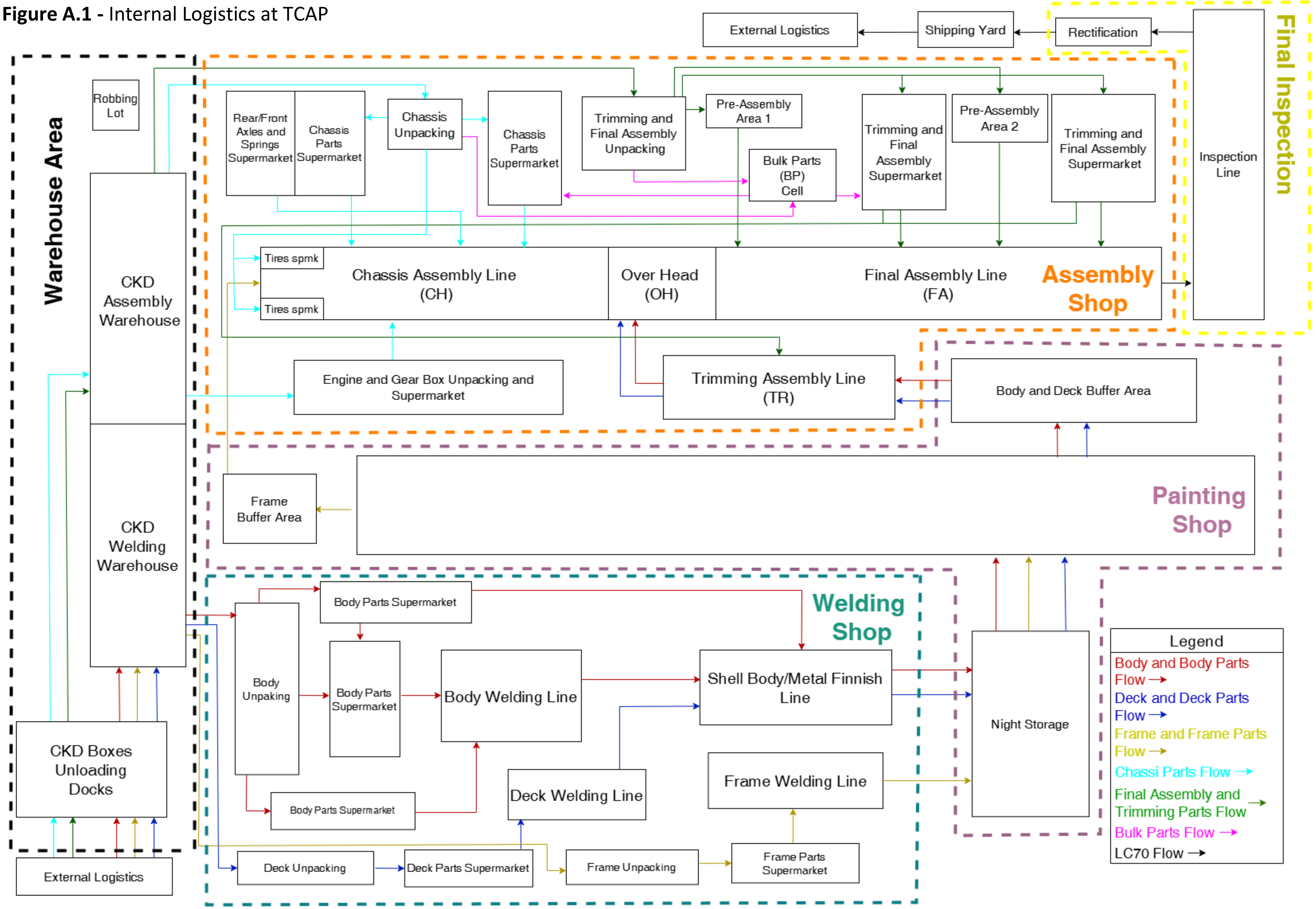
- **APPENDIX B –** Assembly Shop Layout
- **APPENDIX C –** Mizusumashi Stops

Appendices

Appendix A - INTERNAL LOGISTICS AT TCAP FLOWCHART

Figure A.1 - Internal Logistics at TCAP



Appendix B - ASSEMBLY SHOP LAYOUT

Figure B.1 - Chassi Assembly Layout and Supermarket

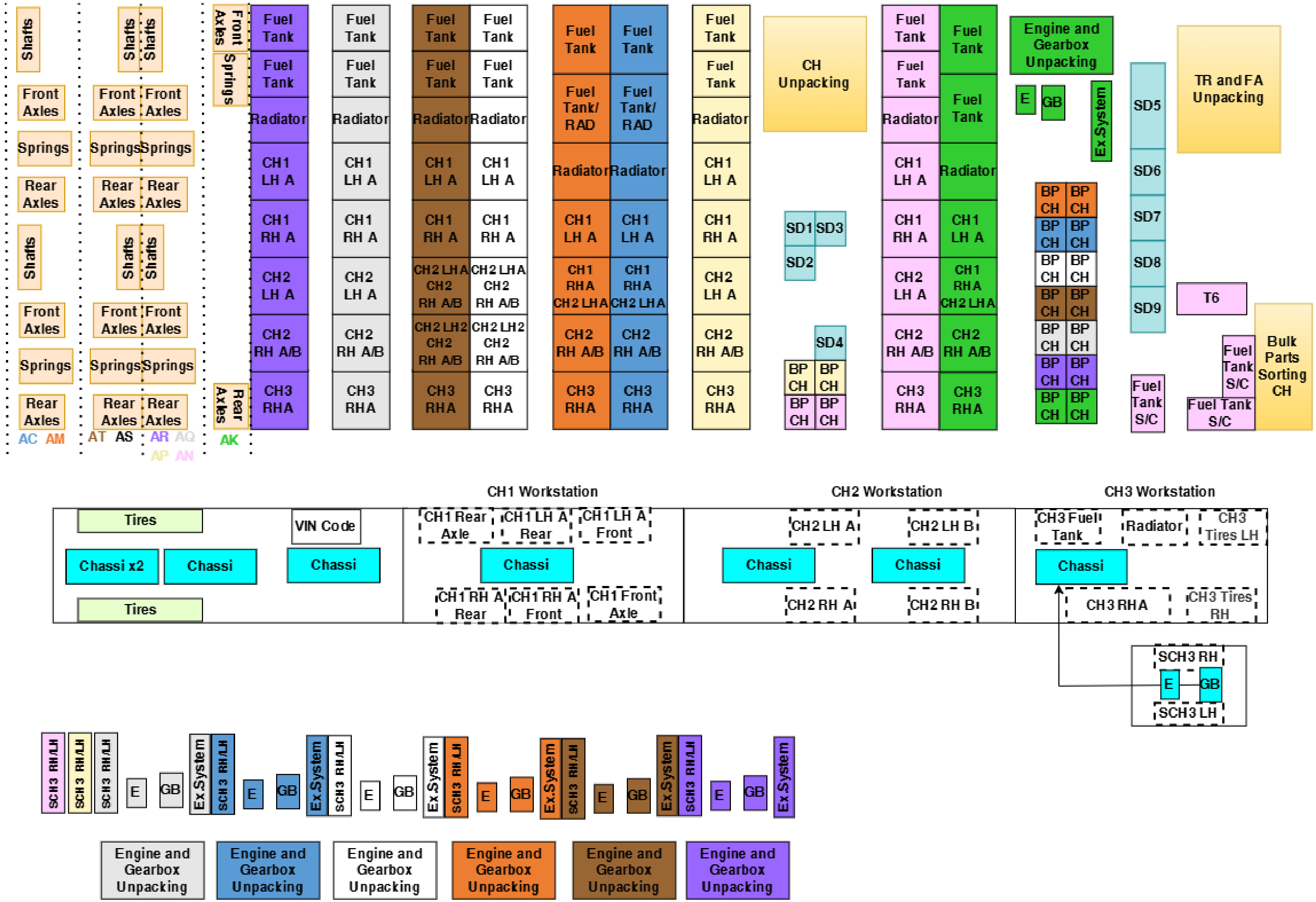
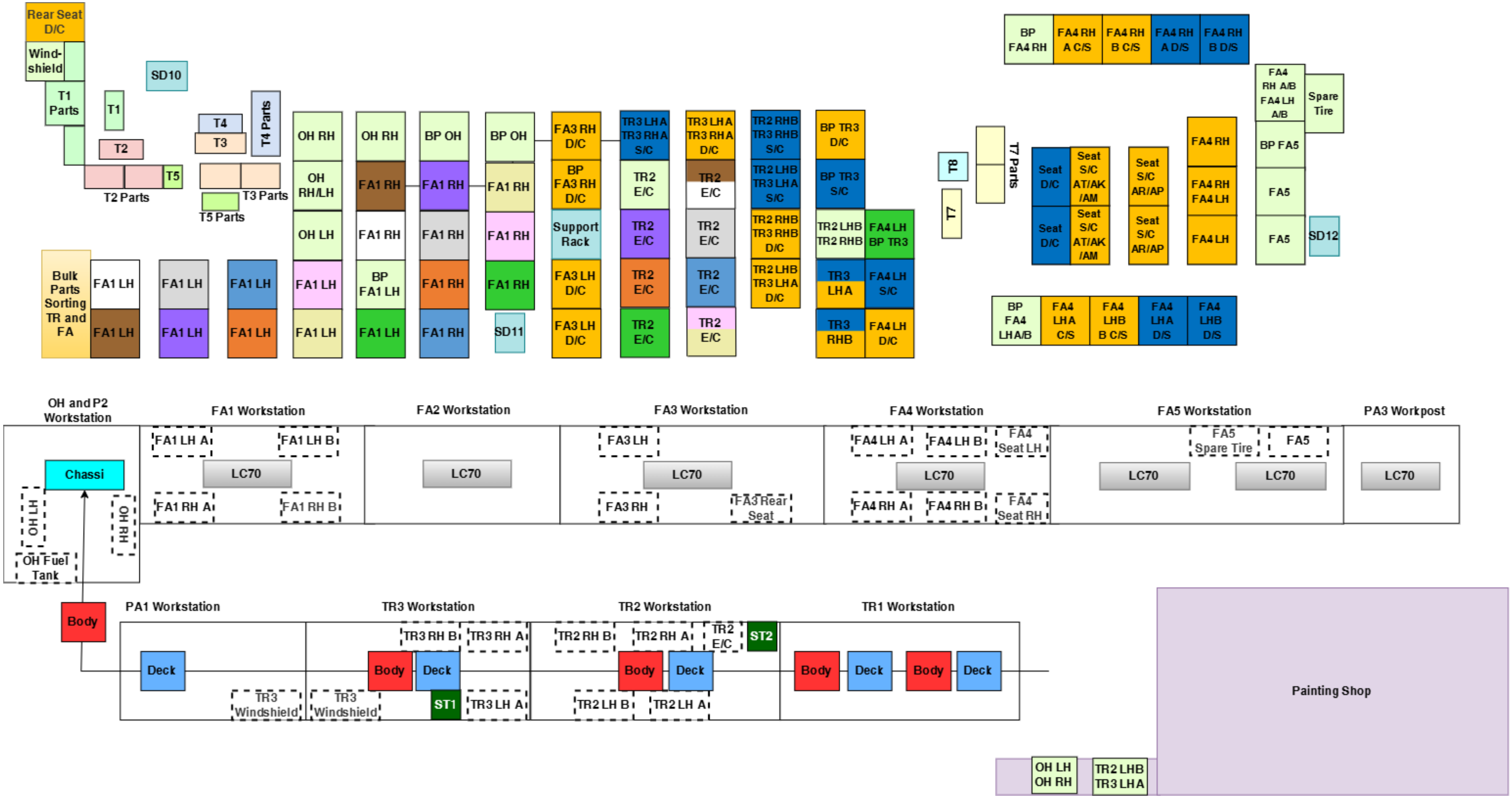


Figure B.2 - Chassi Assembly Layout and Supermarket



Appendix C - MIZUSUMASHI STOPS

Figure C.1 - Chassi Assembly Layout and Supermarket

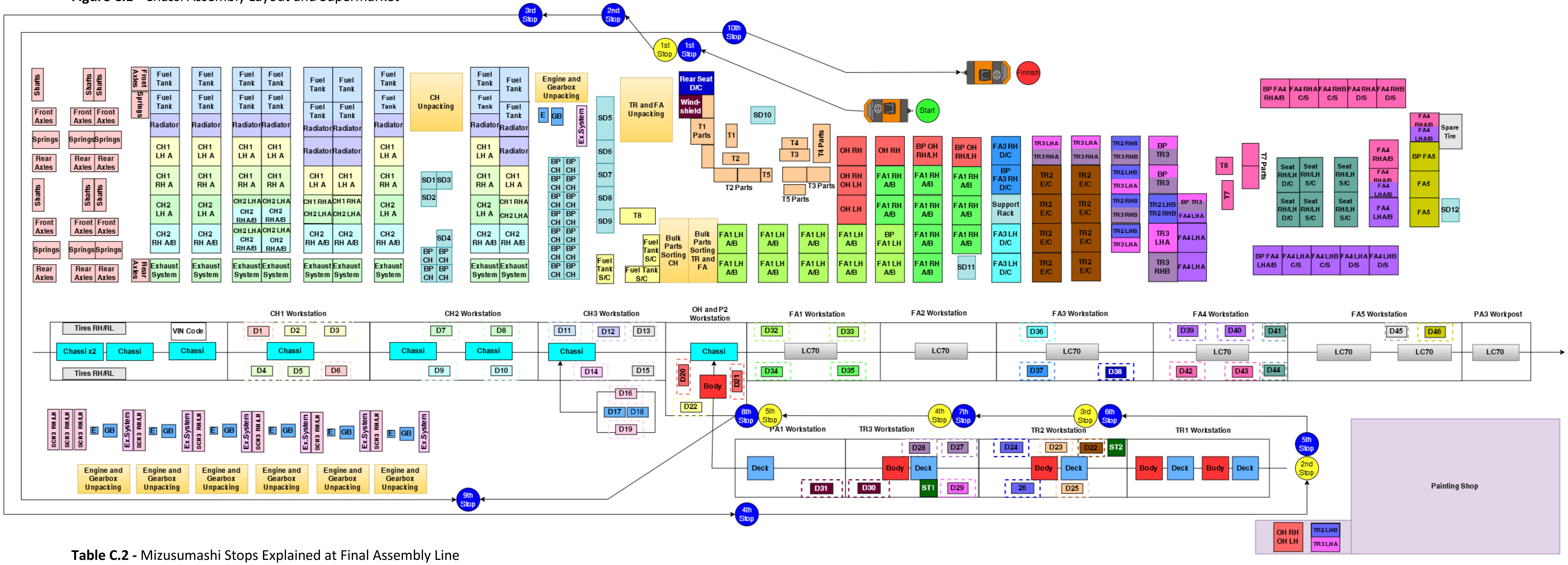


Table C.2 - Mizusumashi Stops Explained at Final Assembly Line

Route B (1st Trip)						Route A (2nd Trip)		
Stop	Action	Note	Stop	Action	Note	Stop	Action	Note
Start	Dock dollies OH LH, OH RH, FA1 RHB, FA4 RHB and FA4 Seat RH.		6th Stop	Swap dollies FA4 RHB and FA4 Seat RH.		Start	Dock dollies FA1 RHA, FA4 RHA and FA3 RH.	
1st Stop	Pick PA16 and PA18 and put them on the respectives dollies.		7th Stop	Swap dolly FA3 Rear Seat	Only on D/C cars	1st Stop	Pick PA11, PA17, PA21 and put them on the respectives dollies.	
2nd Stop	Pick dolly FA3 Rear Seat and dock it.	Only on D/C cars	8th Stop	Swap dollies FA1 RHB, OH RH and OH LH.		2nd Stop	Retrieve the grille support panele from the Paint Shop and place it on the dollie FA4 RHA.	
3rd Stop	Pick dolly OH Fuel Tank and dock it.	Only on S/C cars	9th Stop	Dock the empty OH Fuel Tank dollie.	Only on S/C cars	3rd Stop	Switch dolly FA4 RHA.	
4th Stop	Undock dolly OH Fuel Tank	Only on S/C cars	10th Stop	Undock FA3 Rear Seat.	Only on D/C cars	4th Stop	Switch dolly FA3 RH.	Only on D/C cars
5th Stop	Retrieve the RH and LH side step brackets and the lid for the door quarter hole from the Paint Shop. Place the step brackets on the OH RH and OH LH dollies, and the lid on the OH RH dolly.		Finish	Undock all the remaining empty dollies.		5th Stop	Switch dolly FA1 RHA.	
						Finish	Undock all the empty dollies.	

Figure C.3 - Chassi Assembly Layout and Supermarket

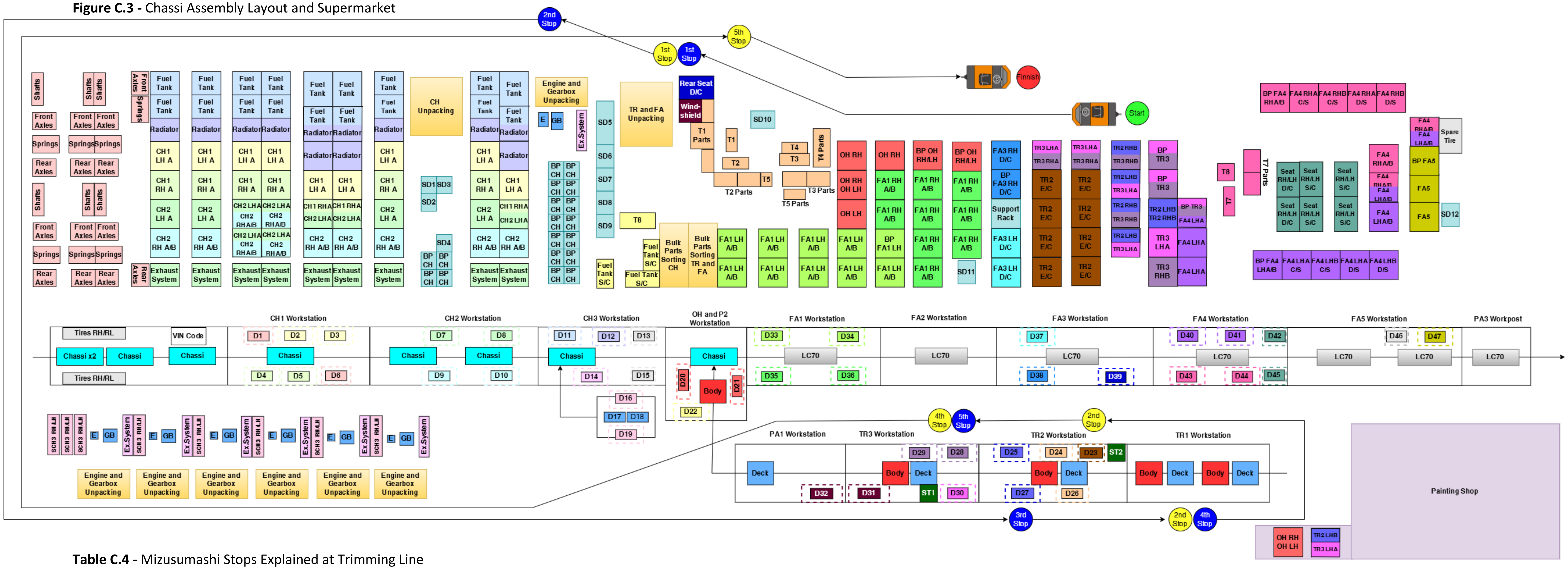


Table C.4 - Mizusumashi Stops Explained at Trimming Line

Route B (1st Trip)						Route A (2nd Trip)					
Stop	Action	Note	Stop	Action	Note	Stop	Action	Note	Stop	Action	Note
Start	Dock dollies TR3 RHB, TR2 RHB, TR2 LHB.		4th Stop	Check the renban on dollies TR2 LHB and TR3 RHB, and retrieve the cowl grille and the RH window seal channel from the Paint Shop. Place these parts on dollies TR2 LHB and TR3 RHB, respectively. Swap dolly TR2 LHB.		Start	Dock dollies TR3 RHA , TR2 RHA, TR2 E/C, TR2 LHA and TR3 LHA.		3rd Stop	Undock dolly TR2 E/C and swap dolly TR2 RHA. Put all wirings present on these dollies on ST2.	
1st Stop	Pick PA1, PA12, PA13 and PA14, PA23 and put them on the respectives dollies.					1st Stop	Pick PA2, PA3, PA4, PA5, PA6, PA7 PA8, PA9, PA10 and the key set and put them on the respectives dollies. The key set goes into dolly TR2 RHA.		4th Stop	Swap dolly TR3 RHA and dock empty dolly TR2 E/C.	
2nd Stop	Pick dolly TR3 Windshield and dock it.	Every 5 cars	5th Stop	Swap dollies TR2 RHB and TR3 RHB		2nd Stop	Retrieve the LH window seal channel from the Paint Shop and place it on dolly TR3 LHA. Swap dollies TR2 LHA and TR3 LHA.		5th Stop	Undock dolly TR3 Windshield.	Every 5 cars
3rd Stop	Undock dolly TR3 Windshield and put its weatherstrips on ST1.	Every 5 cars	Finnish	Undock empty dollies TR3 RHB, TR2 RHB, TR2 LHB.		2nd Stop	Dock dolly TR3 Windshield.	Every 5 cars	Finnish	Undock all the remaining empty dollies.	

Table C.5 – Dollies Identification

Code	Dolly	Code	Dolly	Code	Dolly
D1	CH1 Rear Axle	D17	SCH3 Engine	D33	FA1 LH A
D2	CH1 LH A Rear	D18	SCH3 Gear Box	D34	FA1 LH B
D3	CH1 LH A Front	D19	SCH3 LH	D35	FA1 RH A
D4	CH1 LH B Rear	D20	OH RH	D36	FA1 RH B
D5	CH1 LH B Front	D21	OH LH	D37	FA3 LH
D6	CH1 Front Axle	D22	OH Fuel Tank	D38	FA3 RH
D7	CH2 LH A	D23	TR2 E/C	D39	FA3 Rear Seat
D8	CH2 LH B	D24	TR2 RH A	D40	FA4 LH A
D9	CH2 RH A	D25	TR2 RH B	D41	FA4 LH B
D10	CH2 RH B	D26	TR2 LH A	D42	FA4 Seat LH
D11	CH3 Fuel Tank	D27	TR2 LH B	D43	FA4 RH A
D12	CH3 Radiator	D28	TR3 RH A	D44	FA4 RH B
D13	CH3 Tires LH	D29	TR3 RH B	D45	FA4 Seat RH
D14	CH3 RHA	D30	TR3 LH A	D46	FA5 Spare Tire
D15	CH3 Tires RH	D31	TR3 Windshield	D47	FA5
D16	SCH3 RH	D32	TR3 Windshield		