FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Operational Standardisation and Setup Optimisation in Beverage Bottling Lines

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Resumo

A presente dissertação foi desenvolvida no âmbito da especialização em Engenharia e Gestão da Produção do Mestrado em Engenharia Mecânica da Faculdade de Engenharia da Universidade do Porto (FEUP), em colaboração com o Super Bock Group (SBG). O estudo aborda os desafios associados às mudanças de formato em linhas de enchimento de bebidas de alta cadência produtiva, num contexto caracterizado por elevada diversidade de produtos e por frequentes reconfigurações dos equipamentos.

O estudo incidiu sobre as linhas de enchimento de garrafa da unidade industrial de Leça do Balio, onde as operações de mudança de formato constituem uma fonte significativa de paragens de produção, variabilidade operacional e dependência do conhecimento empírico dos operadores. Foi adotada uma metodologia qualitativa baseada num caso de estudo industrial, recorrendo à observação direta no terreno, à análise de dados operacionais históricos e à colaboração com as equipas de produção.

A investigação foi estruturada em três fases sequenciais. A primeira fase consistiu no diagnóstico do estado atual, identificando as principais ineficiências associadas à execução das mudanças de formato e à gestão dos componentes. A segunda fase envolveu o desenvolvimento de um sistema de identificação fundamentado nos princípios da metodologia 5S, com uma nova lógica de codificação, uma arquitetura de identificação normalizada e mecanismos de rastreabilidade dos componentes. A terceira fase consistiu na aplicação de princípios *Single Minute Exchange of Die (SMED)* por meio do desenvolvimento de um protótipo de uma ferramenta digital de apoio à execução das mudanças. Esta solução inclui funcionalidades de comparação automática de *Stock Keeping Units (SKUs)*, classificação de mudanças de formato, instruções guiadas, conteúdos visuais de apoio, consulta de dados históricos e ferramentas de auxílio à decisão.

As soluções propostas visam reduzir desperdícios associados à procura de componentes, minimizar a variabilidade das mudanças de formato, externalizar atividades e preservar o conhecimento organizacional. Embora não tenha sido possível realizar uma validação operacional de longo prazo durante o período do projeto, o sistema desenvolvido estabelece uma base estruturada para futuras reduções das perdas associadas às mudanças e contribui para a digitalização e normalização das mudanças de formato.

Uma avaliação do sistema de identificação e do protótipo da ferramenta digital, recorrendo a dados da janela de produção de 2026, revelou que, com um limite conservador de 50% de adoção por parte dos trabalhadores, o objetivo de recuperar 0,50% da capacidade global das linhas é atingido. Este resultado reduz o impacto total do tempo de mudanças de 4,55% para o teto estipulado de 4,05% e reduz os intervalos de arranque das linhas para um valor inferior ao definido de 30 minutos.

Palavras-chave: SMED • 5S • Otimização de Setups • Digitalização • Trabalho Normalizado

Abstract

This dissertation was developed within the Production Engineering and Management (EGP) specialisation of the Master's Degree in Mechanical Engineering at the Faculty of Engineering of the University of Porto (FEUP), in collaboration with Super Bock Group (SBG). The research addresses challenges related to format changeovers in high-speed beverage bottling lines operating in a high-mix production environment, characterised by a large number of Stock Keeping Units (SKUs) and frequent equipment reconfigurations.

The study examined the glass bottling lines at the *Leça do Balio* industrial unit, where setup activities were identified as significant contributors to machine downtime, operational variability, and reliance on operator expertise. A qualitative case-study methodology was employed, integrating direct shop-floor observation, analysis of historical operational data, and collaboration with production personnel.

The research was structured into three sequential phases. The first phase involved an AS-IS diagnosis to identify the main inefficiencies in setup execution and format-part management. The second phase entailed the development of a standardised identification system based on 5S principles, incorporating a new codification logic, a physical identification architecture, and traceability mechanisms for format components. The third phase implemented selected Single Minute Exchange of Die (SMED) principles by developing a digital framework prototype to support setup execution. This framework integrates SKU comparison logic, automatic changeover classification, guided instructions, visual aids, historical data consultation, and decision-support functionalities.

The proposed solutions were designed to reduce search waste, minimise setup variability, externalise setup activities, enhance knowledge retention, and support autonomous maintenance practices. Although long-term operational validation was not feasible within the project time frame, the developed system provides a structured foundation for future reductions in setup-related losses and advances the digitalisation and standardisation of changeover operations.

A comprehensive evaluation of the proposed physical standardisation system and the digital framework prototype, using Year-To-Date (YTD) data over the 2026 production window, revealed that, with a conservative 50% workforce adoption threshold, the primary strategic objective of recovering 0.50% of global line capacity is met. This outcome reduces the total changeover capacity overhead from 4.55% to the targeted 4.05% ceiling and brings post-changeover ramp-up intervals below the 30-minute objective.

Keywords: SMED • 5S • Setup Optimisation • Digitalisation • Standardised Work

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List of Acronyms

CIP Cleaning In Place
EBI Electronic Bottle Inspectors
EGP Production Engineering and Management
FEUP Faculty of Engineering of the University of Porto
JIT Just-in-Time
KPI Key Performance Indicator
MTBF Mean Time Between Failures
MTTR Mean Time To Repair
OEE Overall Equipment Effectiveness
PU Pasteurisation Units
SBG Super Bock Group
SDG Sustainable Development Goal
SMED Single Minute Exchange of Die
SKU Stock Keeping Unit
TAM Delayed Setup Time
TAR Ramp-up Time
TAV Equipment Breakdown Time
TMP Planned Changeover Time
TPM Total Productive Maintenance
TPS Toyota Production System
TQM Total Quality Management
VSM Value Stream Mapping
YTD Year-To-Date

Chapter 1

Introduction

This Master's dissertation in Mechanical Engineering was developed within the industrial and corporate context of the Super Bock Group (SBG). As the culminating project for the Master's Degree in Mechanical Engineering – Production Engineering and Management (EGP) at Faculty of Engineering of the University of Porto (FEUP), the research investigates the application of the 5S framework and the integration of Single Minute Exchange of Die (SMED) methodologies with digital standardisation tools. The objective is to optimise high-speed beer packaging lines, which are critical subsystems of the production chain. Conducted during the academic year 2025/2026, the study addresses the gap between traditional Lean Manufacturing and current digital requirements to reduce changeover and ramp-up times. This introductory chapter presents the industrial environment, defines the core problem, and specifies the technical objectives for improving the targeted metrics.

1.1 Context

Founded in 1927, SBG is the largest beverage producer in Portugal, with its primary manufacturing facility located in *Leça do Balio*, shown in Figure 1.1.



Figure 1.1: Super Bock Group, *Leça do Balio* [1]

The group manages an extensive portfolio, including beers, mineral waters, soft drinks, and ciders, and maintains a presence in over 50 international markets. The beverage industry is characterised by dynamic demand for product variety and diverse packaging options, which compels manufacturers to transition from traditional long-run production models. To maintain market relevance and competitive advantage, SBG must continually adapt its operations to accommodate an increasing number of Stock Keeping Units (SKUs) [1].

The increasing demand for alternative beverages, such as non-alcoholic beers and ciders, as well as specialised packaging, including various bottle sizes and formats, has significantly altered production planning. Rather than producing a limited number of SKUs, manufacturers now manage hundreds of configurations. This high-mix environment necessitates frequent production stops for machine reconfiguration.

1.2 Problem Statement

In high-speed packaging operations, each minute of downtime results in significant unproduced volume, making the efficiency of format changes a critical factor in sustaining high Overall Equipment Effectiveness (OEE). The primary motivation for this project arises from the substantial costs and capacity losses associated with downtime during changeover reconfigurations. At the *Leça do Balio* production facility, changeover operations account for approximately 6% of the annual production time. A portion of this loss is attributable to the ramp-up period, which involves fine-tuning equipment after the format change.

A measurable inter-shift variability of 0.1% has been identified, indicating that the quality and speed of setup are influenced by the expertise and subjective practices of the operating teams. Despite SBG's strong emphasis on operational quality and Lean Manufacturing, a technical ceiling has been reached with traditional, manual SMED methodologies. This lack of standardisation prevents the facility from achieving optimal process stability and the 'Right First Time' performance required by contemporary standards in Production Engineering and Management.

Given the high mechanical complexity and diversity of format-dependent equipment across the bottling lines, the scope of this dissertation is restricted to setup operations and handling components in the most critical machines affecting changeover performance. The study focuses mainly on the Filling and Crowner machine, the Labelling machine, and the handling systems in selected production lines, while also understanding the Pasteurizer setup requirements. These machines were selected based on their substantial contribution to total changeover time, the frequency of format changes, and the availability of reliable performance data. Focusing on these units ensures that the research addresses areas with the greatest operational impact, thereby maximising the potential for measurable improvement and generating insights that may be generalised to similar contexts within the facility.

1.3 Research Objectives

The primary objective of this research is to develop and implement a standardisation framework that integrates SMED principles. The main technical goal is to reduce global setup time from 6% to 5.5% of annual production time. To support this improvement, the study aims to stabilise ramp-up efficiency, ensuring that the time between physical changeover and achieving nominal production speed does not exceed 30 minutes.

Additionally, the research seeks to eliminate procedural variability across production shifts, with the objective of reducing it from 0.1% to 0%.

1.4 Dissertation Organisation

This dissertation is organised into eight consecutive chapters, each corresponding to a distinct and progressive phase of the industrial research, physical engineering, and digital development process.

Following this introductory chapter, Chapter 2 provides a comprehensive literature review and establishes the theoretical foundations for the dissertation. It synthesises established research on Lean Manufacturing, the classical mechanisms of the SMED methodology, 5S frameworks, and Standardised Work. Additionally, it examines the contemporary convergence of Industry 4.0 and digital standardisation tools, as well as an engineering analysis of high-speed beverage packaging dynamics and line-flow constraints.

Chapter 3 describes the research methodology and analytical engineering framework employed in the study. It outlines the case study design, beginning with baseline observation and progressing to workplace stabilisation and digital tool engineering. The chapter also details data acquisition methods, time measurement techniques, and quantitative performance metrics.

Chapter 4 presents the AS-IS diagnosis and describes the bottling environment at *Leça do Balio*. It maps the line flow-control configurations and evaluates the mechanical complexity of the core Filling and Labelling units. The chapter also identifies the root causes of changeover inefficiencies and areas for improvement.

Chapter 5 addresses the engineering and development of the physical standardisation model designed to stabilise shop-floor execution. This chapter focuses on the operational application of the 5S methodology, specifically detailing the creation of a new, zero-redundancy alphanumeric codification logic, the physical identification architecture, and the placement criteria for structural visual markers.

Chapter 6 presents the technical architecture and logic of the developed digital changeover framework prototype. It explains the rationale for the automated SKU comparison engine, machine-specific setup sequencing, phase-gated execution checklists, embedded visual instructions, and auxiliary decision-support tools.

Chapter 7 validates the overall efficacy of the combined physical and digital intervention. It provides a comparative quantitative analysis against the baseline performance metrics, evaluating

the reduction in changeover capacity overhead to the targeted thresholds, the decrease in shift-to-shift variability, and the stabilisation of the post-changeover speed ramp-up period.

Finally, Chapter 8 concludes the dissertation by summarising the main outcomes of the research, the study's limitations, identifying opportunities for future work related to the themes addressed, and relating the research to the United Nations Sustainable Development Goals (SDGs).

1.5 Synthesis of the Research Scope and Structure

This chapter established the industrial context, research problem, and macro-objectives, specifically targeting reductions in global changeover duration and inter-shift procedural variability. However, developing a sustainable optimisation model for a high-mix packaging environment requires grounding shop-floor observations in validated methodologies. To address these challenges, the following chapter presents a systematic review of Lean Manufacturing frameworks, the mechanisms of the SMED methodology, the digitalisation paradigms associated with Industry 4.0, and an analysis of beverage packaging dynamics and line-flow constraints.

Chapter 2

Literature Review

This chapter presents a comprehensive review of the theoretical principles and methodologies that support this research. It examines the evolution of Lean Manufacturing and the SMED methodology, and investigates how these traditional organisational tools are being transformed by Industry 4.0 and digital standardisation. Additionally, the review analyses the role of 5S and Standardised Work in reducing process variability, and discusses key concepts related to Packaging Line architecture.

2.1 Lean Manufacturing

Lean Manufacturing, also referred to as Lean Production or Lean Management, is a socio-technical production system with the primary objective of continuously and systematically eliminating waste from manufacturing processes. This comprehensive philosophy utilises human, physical, and temporal resources to maximise value for stakeholders. It operates as a unified system focused on creating customer value and embodies a long-term approach to value creation by eliminating waste, defined as any activity that consumes resources without adding value to the final product [2].

Originating from the Toyota Production System (TPS), Lean Manufacturing represents a shift from traditional mass production to a more flexible operational model. It prioritises value-added activities, guided by the principles of Just-in-Time (JIT) and Jidoka. The primary aim is to eliminate seven classic forms of waste: overproduction, waiting, transport, inappropriate processing, unnecessary inventory, motion, and defects. In the beverage industry, characterised by high production volumes and narrow profit margins, Lean principles are instrumental in enhancing efficiency and enabling rapid responses to changing consumer demand [3].

The implementation of Lean follows a five-stage process: exact product valuation from the final customer's perspective, identification of the value stream, creation of uninterrupted flow, implementation of pull systems, and pursuit of perfection. Value is defined as the capacity created for a customer at the appropriate time and price, typically expressed through features of quality, cost of ownership, and time [4].

Previous research has identified several key elements critical to implementing Lean manufacturing systems. Value Stream Mapping (VSM) serves as a primary diagnostic tool for distinguishing value-added from non-value-added activities by mapping the process and information flows necessary to transform raw materials into finished products. Process flows are further optimised by differentiating between pull systems, which are driven by customer demand, and push systems, which are based on predetermined schedules. To reduce processing, waiting, and transportation times, cellular manufacturing clusters facilitate efficient line flows, often supported by U-line and line-balancing strategies. Material control is maintained through Kanban systems, which ensure the delivery of the correct quantity of parts at the appropriate time during both production and withdrawal stages.

A key methodology for reducing operational downtime is the SMED. This approach systematically reduces changeover times by identifying internal activities conducted during machine stoppages and converting them into external activities that can be performed while equipment remains operational. Production levelling further supports this process by stabilising production volume and mix, thereby reducing waste, unevenness, and overburden.

Ultimately, the success of a Lean transition depends on improving employee perceptions, including commitment and communication, to foster the cultural change necessary for continuous improvement. While methodologies such as Total Productive Maintenance (TPM) and Total Quality Management (TQM) are recognised as supporting elements, they are often excluded from specialised review frameworks that aim to maintain focus on core Lean tools [5].

2.2 The SMED Methodology

The SMED is a quick-changeover methodology specifically designed to reduce operational setup times on machinery by analysing the assembly line's state during changeovers, and is one of the most effective Lean tools for reducing downtime associated with equipment reconfiguration.

Developed by Shigeo Shingo, the framework is based on the premise that all setup operations can be categorised into two distinct types: internal setup, which includes tasks that can only be performed when the machine is stopped, and external setup, which comprises tasks that can be executed while the machine is still in operation [6].

Implementation of SMED consists of four main stages. First, during the initial phase, internal and external setup activities are not differentiated, and exhaustive data is gathered. Subsequently, these tasks are sorted into those that must be performed during machine downtime and those that can be handled while equipment is running. The third stage is converting as many internal activities as possible into external ones, shifting tasks to periods when the machine is operational and thereby reducing total idle time. Finally, the remaining internal activities are streamlined to increase efficiency and meet the primary target of a setup time of under 10 minutes.

During the final streamlining phase, targeted engineering interventions are employed to simplify the remaining internal tasks. These include parallel operations, where tasks are distributed among multiple operators to eliminate idle time, and the use of functional clamps and adjustable

levers in place of traditional fasteners. Fine-tuning adjustments can be minimised through the use of measuring rulers, spacer plates, and the digitalisation of machine operating parameters. Despite these technical solutions, implementation faces significant socio-technical barriers, such as limited employee involvement, inadequate technical expertise, and organisational resistance to change.

A major challenge in SMED is the "Adjustment" phase. This part can account for a large share of changeover time, sometimes up to 50%, often due to missing clear mechanical settings. Streamlining these internal activities may require reorganising the production floor and relocating parts and materials to reduce wasted movement. When combined with workplace organisation frameworks such as 5S, these changes help improve OEE by reducing downtime caused by availability losses [7, 8].

The implementation of SMED is driven by the objective of mitigating high inventory costs and production losses. Excessive setup times often necessitate larger lot sizes and higher stock levels to compensate for downtime, so reducing changeover time is a primary tool for lowering production costs. To preserve operational rigour during these handovers, the methodology adopts safeguards, such as checklists, to ensure operators accurately distinguish between internal and external activities and understand their roles.

Within the Lean framework, changeovers are formally categorised as "necessary non-value adding" activities, as they are required for assortment changes, despite not contributing direct value to the product. To further refine the process, the literature suggests integrating SMED with Methods-Time Measurement to standardise optimal procedures through detailed motion studies. This technical approach is typically coupled with TPM and the 5S methodology to create an orderly work environment and high machine reliability, facilitating faster transitions.

Beyond the fundamental stages of implementation, the theoretical evolution of SMED encompasses advanced levels of optimisation, such as One-Touch Exchange of Die, which targets changeovers of less than one minute, and Non-Touch Exchange of Die, in which the changeover occurs instantaneously [9].

Although recent theoretical advancements in SMED optimisation exist, these methodologies are beyond the scope of this study. The research primarily aims to establish the essential physical and digital foundations necessary to stabilise traditional SMED. By prioritising workplace standardisation, process predictability, and stability, a reliable operational baseline is created, serving as a prerequisite for future integration of advanced quick-changeover frameworks.

2.3 The 5S Framework

The 5S framework, consisting of Sort (Seiri), Set in order (Seiton), Shine (Seiso), Standardise (Seiketsu), and Sustain (Shitsuke), serves as the physical foundation for standardised production processes. The overarching goal of 5S is to identify, minimise, and eliminate non-value-adding activities (waste) [10].

Within the scope of format changes, the "Set in order" (Seiton) phase is particularly important, as it involves the systematic labelling and identification of items. This phase directly targets

process efficiency by reducing the time required to access equipment and complete tasks. Proper physical identification acts as a visual Poka-Yoke, or mistake-proofing mechanism, ensuring that the correct components are retrieved and installed without delay or error.

To achieve this, the arrangement of tools and changeover parts must follow the "rational location rule", guided by the principle: "I see, I can take it and put it back, quickly and easily". This requires creating a specific, individually delimited place for every object, complete with clear visual indicators such as alphanumeric codes, standardised labels (indicating the item name, code, and quantity), and colour-coded markings. Furthermore, storage locations must be ergonomically optimised based on the rule of motion economy and the item's frequency of use. For optimal efficiency in a production environment, objects used daily should be locatable within 10 seconds, while items used weekly should take no more than 30 seconds to be found [11].

Ensuring that each mechanical part is uniquely identified and stored in a designated location eliminates variability associated with search waste. Research indicates that rigorous 5S implementation can reduce search time by 18.75% and decrease the total storage area required by more than 11%. To sustain these systems, recent literature highlights the importance of integrating 5S with user-centred approaches such as Design Thinking, thereby ensuring that physical organisation supports employees' daily workflows and minimises unnecessary movement [12].

2.4 Standardised Work and Operational Stability

Standardised Work is a fundamental principle of Production Engineering and a core component of the TPS, defining the most efficient, safe, and logical sequence of tasks for a given process, assuring consistency regardless of the personnel involved. Establishing this standard comprises creating a precise, documented method that outlines the exact steps, tools, materials, and timing required to complete an operation. To effectively standardise an operation, literature identifies three essential elements that must be integrated into the process: takt time, which dictates the pace of production needed to meet customer demand; the work sequence, defining the specific, logical order in which an operator must perform tasks within a determined cycle time; and standard in-process stock, representing the minimum quantity of work-in-progress inventory required to allow continuous process execution without machine interruptions [13, 14].

Standardised Work serves as the foundation for continuous improvement methodologies. In the absence of a documented and consistently followed standard, observed improvements are unreliable and unsustainable. Conversely, a fixed reference point enables immediate identification of operational deviations, bottlenecks, and inefficiencies.

In contemporary manufacturing, standardisation is the primary means of reducing human-induced variability. Detailed, standardised instructions are essential for breaking down complex tasks into manageable steps and are particularly important in high-volume operations, where minor variations can accumulate into significant inefficiencies and increased defect rates. Establishing clear, repeatable operational methods enables organisations to maintain a predictable production rhythm. This is especially important in mechanical environments lacking digital feedback, where

standard procedures serve as the main control mechanism for managing equipment adjustments and optimising the use of human and material resources to minimise waste [15, 16].

2.5 Industry 4.0 and the Digitalisation of Lean

Industry 4.0 marks the integration of Information Technology with operational processes, facilitating the transition of manufacturing towards interconnected, intelligent Cyber-Physical Systems. Rather than replacing traditional methodologies, recent literature identifies Lean Production as the foundational element of Industry 4.0, resulting in a synergistic framework known as "Lean 4.0". This integration bridges the gap between the human-centred structure of Lean and the technological capabilities of digitalisation, thereby significantly enhancing traditional shop-floor tools [17, 18].

A significant limitation of traditional Lean implementation in production lines is its dependence on static, manually collected, and potentially outdated data, which can render process models ineffective. The adoption of the Industrial Internet of Things addresses this challenge by enabling automated, real-time data acquisition. Within the framework of "Digital Lean", conventional tools such as Standardised Work and SMED are enhanced through digital interfaces and relational databases. Digitalisation facilitates centralised management of complex equipment parameters and SKU variables, establishing a single "source of truth" and reducing reliance on fragmented paper records and individual operator memory. The use of digital support tools allows organisations to implement a "Digital Poka-Yoke", guiding operators through standardised sequences and requiring digital verification of critical steps. This technology-driven approach ensures that the most efficient methods identified during process analysis are consistently applied across all production shifts [19, 20].

2.6 Technical Constraints of Packaging Line

Following the comprehensive review of industrial management methodologies, it is necessary to examine the specific technical themes that define the scope and operational context of this dissertation. Given that the empirical research is conducted within a beverage packaging facility, a detailed understanding of the technical constraints inherent to automated packaging lines is a fundamental prerequisite.

A modern packaging line functions as a complex, highly integrated network of independent machines connected through specialised conveying systems. Optimising line efficiency requires a delicate balance of engineering constraints, with the operational baseline and ultimate speed cap dictated by the line's slowest unit, typically the filling machine. To avoid machine disruptions, or "micro-stops", from causing a system breakdown, engineers must account for mechanical constraints such as accumulation zones, volumetric limitations, and asymmetric equipment over-speeds. Furthermore, in high-volume liquid processing environments, these lines are heavily constrained by strict sanitary guidelines, such as Cleaning In Place (CIP) standards, governing

sensor contact surfaces, as well as utility constraints related to steam pressure stability, stringent water conservation mandates, and limits on volatile organic compound air emissions [21, 22].

2.6.1 Brewing Preconditions and Product Complexity

While the primary focus of packaging engineering is the bottling line itself, upstream brewing operations establish critical preconditions that dictate packaging success. A fundamental upstream requirement is maintaining the integrity of the liquid supply before it reaches the filler. The beer supply system must deliver a sufficient quantity of liquid at the proper flow rate while preserving the product by retaining the correct temperature, typically around 3°C for modern fillers. Furthermore, an acceptable equilibrium pressure of carbon dioxide must be maintained to prevent product punishment and foaming, as pressure fluctuations can drastically affect the efficiency of the filling operation [21].

Modern breweries undergo operational complexity driven by varying consumer demands and marketing strategies. Changes in packaging, such as revised bottle styles, label shapes, and diverse secondary packaging formats, add substantial complexity to packaging lines. Facilities must accommodate a wide range of label and bottle geometries, resulting in frequent setup changes. This high SKU variety directly affects operational performance by increasing downtime and changeover frequencies. To establish a reliable baseline and justify line improvements, performance is typically tracked by applying metrics such as Machine Availability, which relies on Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). Additionally, a major source of inefficiency during production runs is the occurrence of "micro-stops", which are minor faults lasting less than 4 minutes, such as container misfeeds or flagging labels. These frequent minor incidents severely degrade overall line efficiency and impede reliable equipment operation [22].

2.6.2 Technical Restrictions and Line Flow Control

A packaging line is a highly integrated series of machines connected by a network of conveyors, in which the interaction among the machines, conveyors, and the packages they handle is defined as "line flow". While each piece of equipment functions best as a stand-alone unit, they are tied together through programmable logic controllers and machine control logic to form a coordinated, automated system. Each machine acts as a critical node, and a fault in one machine can easily cascade, shutting down the entire line if the integrated controls and physical layout do not properly manage container flow.

The underlying concept of line balancing centres around the filler, which acts as the critical focal point of the operation. To maximise the filler's efficiency, the line must be balanced by applying specific over-speed rules. Upstream equipment must be capable of running 10–15% faster than the filler to ensure a continuous supply of bottles, while downstream equipment must be capable of running 40–60% faster to achieve a "catch-up speed", as presented in Figure 2.1. This downstream over-speed reduces the effect of machine downtime on the filler by allowing the line to clear out accumulated bottles quickly.

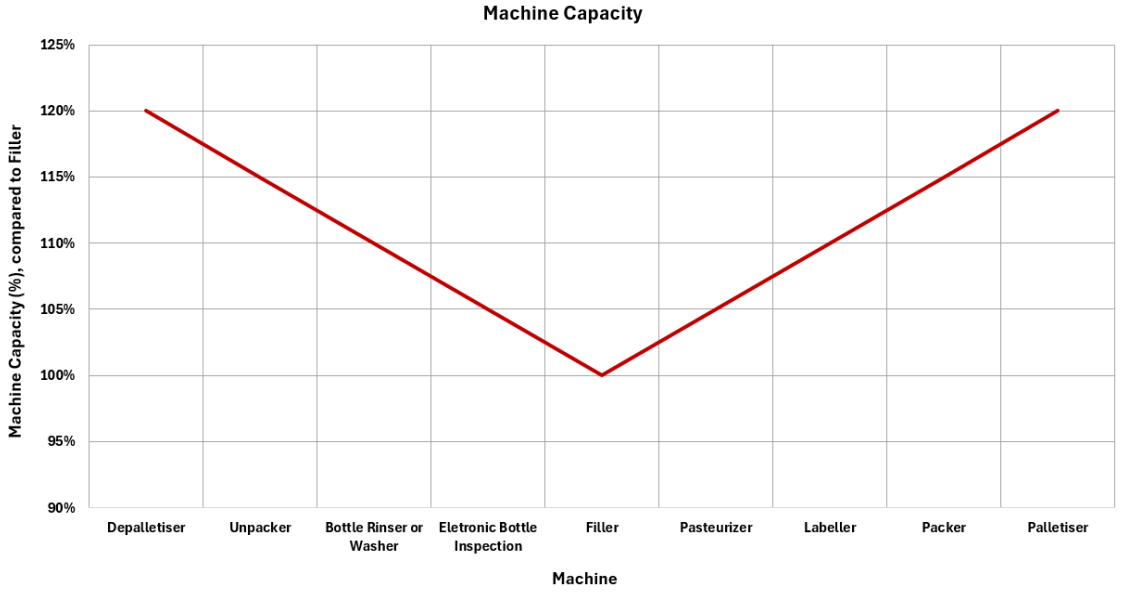


Figure 2.1: Line Balancing Speeds, Based on [22]

Buffers, referred to as accumulation tables, are essential for separating machine efficiencies and allowing the line to recover from "micro-stops" without immediately starving or blocking the filler. The primary design constraints for these buffers require that the upstream accumulation be kept 100% populated whenever possible to ensure maximum bottle availability. Conversely, the general rule of design is to keep all conveyors downstream of the filler 50% empty under normal conditions, creating a necessary gap that can temporarily store the filler's output if a downstream machine goes down [22].

2.6.3 Critical Equipment and Changeover Dynamics

The execution of an uninterrupted production run and an efficient changeover relies heavily on the mechanical intricacies of the critical equipment. The filler, as the heart of the line, must run continuously. The filling sequence involves introducing carbon dioxide under counter-pressure into the bottle, which provides sufficient pressure to preserve the product's carbonation and prevent foaming during liquid transfer. Immediately after the filler is placed, the crown is secured. Crowners utilise distribution discs and rectifier chutes to orient the crowns [21].

Sealed bottles are then routed to the pasteurizer, which is highly sensitive to interruptions in line flow. Stoppages from changeovers or downstream faults cause intermittent feeding into the pasteurizer, which can create temperature imbalances in the heating and holding zones, frequently leading to the quality defect of over-pasteurised product.

Following pasteurisation, labelling machines introduce the most significant mechanical complexity during changeovers. A typical high-speed rotary labeller operates through the precise synchronisation of multiple mechanical aggregates, including rubberised glue pallets, label magazines, and rotating gripper cylinders that physically transfer the label to the bottle. When changing

label or bottle sizes, operators face an intricate mechanical swap that requires adjusting or replacing the machine's core components.

The production line utilises primary quality gates such as Electronic Bottle Inspectors (EBI) and fill-height detectors, before and after the filler, respectively. These systems utilise state-of-the-art sensors to assess the physical integrity of the bottles, verify accurate fill volumes, and confirm proper closure application, automatically rejecting non-conforming units.

Finally, the bottles enter the secondary packaging phase, which relies heavily on case packers and palletisers, and requires meticulous reconfiguration of guide rails and grid modules to prevent case jams and subsequent upstream accumulation [22].

2.7 Synthesis of the Theoretical Framework

The literature demonstrates that integrating classical Lean production principles with advanced digital tools, known as the "Lean 4.0" paradigm, offers a strong theoretical framework for mitigating human-induced process variability. At the same time, recognising the mechanical, line-balancing, and thermodynamic constraints specific to high-speed packaging infrastructures establishes the technical boundaries of this research. Translating these theoretical frameworks into implementable industrial applications requires a structured, empirical operational strategy. Accordingly, the following chapter outlines the methodological roadmap, detailing the qualitative case-study architecture, data acquisition protocols, and the three-phase engineering sequence used to transform the changeover process.

Chapter 3

Methodology

This chapter presents the methodological framework designed to optimise changeover operations in beverage bottling lines. By integrating Lean principles with practical industrial applications, the methodology provides a systematic approach for diagnosing, stabilising, and accelerating format changeovers. The chapter describes the use of an empirical case study approach, followed by a three-phase operational framework: baseline diagnosis, implementation of physical 5S and format-part standardisation, and a SMED optimisation phase supported by a custom digital framework prototype. Data acquisition methods, performance indicators, and methodological limitations are also defined to ensure scientific rigour, validity, and reproducibility within mechanical and industrial engineering research.

3.1 Research Approach

In scientific and industrial engineering research, the selection of an appropriate methodological paradigm is crucial for ensuring the internal validity and reliability of the investigation. Establishing a methodological framework requires an evaluation of research approaches to identify the most suitable strategy for the research problem. Research designs are generally classified as either quantitative or qualitative.

Quantitative research tests objective theories by examining relationships among defined variables. These variables are measured using instruments, yielding numerical data that can be analysed through statistical methods. Grounded in a positivist philosophy, the quantitative approach relies on a deductive process to evaluate hypotheses, verify theories, and generate generalisable findings.

In contrast, qualitative research is designed to explore and understand the meanings that individuals or groups attribute to human, social, or organisational issues. Data are collected directly within participants' natural environments, and analysis typically follows an inductive process, progressing from specific observations to broader themes. By emphasising narratives, perceptions, and interpretations, qualitative inquiry effectively captures the complexity of situations in which variables are not easily isolated and contextual understanding is essential [23, 24].

Given the need to understand operational constraints, human factors, and process variability on the shop floor, this dissertation employs a qualitative research approach grounded in an industrial case study conducted in a real production environment. This methodology was selected for its suitability in analysing complex systems, such as high-speed bottling lines, in their operational settings. The research aims to diagnose inefficiencies and to develop and implement practical solutions with measurable outcomes.

3.2 Methodological Framework

The methodological approach is structured into three sequential phases, each reflecting a stage in the transformation of the setup process. The initial phase involves current-state analysis, the second phase addresses the physical standardisation of changeover component identification, and the third phase applies SMED principles using a digital support tool to optimise operations.

3.2.1 Phase 1: AS-IS Diagnosis and Baseline Establishment

The first phase consists of a detailed analysis of the existing setup process (AS-IS). This stage aims to characterise how changeovers are performed in practice on the shop floor, identifying the sequence of activities, the resources involved, and existing inefficiencies. The analysis is based on direct observation of setup operations, time measurements, and the decomposition of changeover activities into elementary tasks. This systematic observation permits the identification of critical stages, sources of variability, and non-value-adding activities. The results and findings of this preliminary phase provide the essential diagnosis and operational baseline, which are presented in detail in Chapter 4.

3.2.2 Phase 2: 5S and Format Parts Standardisation

To ensure sustainable improvements, a stabilisation-first strategy is implemented. Existing research indicates that Lean management is a holistic approach that combines a continuous improvement mindset with rigorously standardised procedures. In the absence of standardisation, operational improvements are unsustainable due to inherent variations in operator experience and fragmented shift practices. Therefore, the second phase builds upon the first by organising the physical work environment and developing a standardised component identification system to reduce variability. Utilising the 5S methodology, this phase specifically addresses the “Set in Order” (Seiton) stage, which involves systematic identification, labelling, and arrangement of format parts. A customised component identification and labelling system has been developed to enhance the organisation and accessibility of these parts, directly addressing inefficiencies in component searching, misidentification, and operator dependence. Ensuring that each mechanical part is uniquely identified and stored in a designated location eliminates variability associated with “search waste”. The implementation of these measures increases process stability and serves as a

prerequisite for advanced interventions. The development and application of this standardisation phase are detailed in Chapter 5.

3.2.3 Phase 3: SMED Optimisation and Digital Framework

The third phase draws on the previous standardisation efforts by optimising the setup process through the application of SMED principles, supported by a digital framework prototype. During this phase, setup activities are analysed and categorised as either internal or external operations, facilitating the identification of opportunities for task reorganisation and time reduction. Improvements include converting internal activities to external ones and introducing parallel operations.

To support and sustain these SMED improvements, a digital tool mock-up has been developed to guide operators during setup execution. Working as an interactive digital checklist, this tool ensures strict adherence to standard procedures and provides immediate access to relevant technical information. The implementation of this digital support tool guides operators through standardised sequences, ensuring consistent execution of the most efficient methods identified during the SMED analysis. This phase represents the transition from process stabilisation to performance optimisation and is described in detail in Chapter 6.

3.3 Data Acquisition Methods

Data collection was conducted within the industrial environment using a combination of observational and analytical methods. The primary approach involved direct observation of setup operations at the Gemba, which enabled the recording of task sequences, operator interactions, and physical process conditions. Time measurements were obtained through manual timing techniques and, when available, from historical data extracted from the production system. Additional qualitative data were gathered through informal discussions with operators and technical staff, providing insights into practical challenges, common deviations, and opportunities for improvement.

Several measures were implemented to ensure data validity and methodological rigour. Multiple direct observations were conducted at different times and shifts to capture representative practices and minimise observer bias. Informal discussions were triangulated among operators and technical staff to corroborate reported experiences and reduce subjectivity. Observational protocols and data-recording forms were standardised, and all recorded data were reviewed in collaboration with supervisory personnel to verify accuracy. These steps enhance the reliability and credibility of the qualitative findings presented in this research.

3.4 Data Analysis and Performance Indicators

The collected data on setup times were analysed by decomposing setup processes into individual tasks, enabling the clear identification of value-adding and non-value-adding activities. Setup time served as the primary performance indicator, supplemented by analysis of time variability across

different changeovers. Additionally, the impact of setup operations on OEE was evaluated, with particular attention to the setup metrics. This comprehensive analysis supports the identification of opportunities for improvement and provides a measurable basis for evaluating the effectiveness of the implemented physical and digital solutions.

3.5 Synthesis of the Methodological Design

It is important to acknowledge several methodological limitations of this research. The qualitative case-study approach focuses on a single industrial site, which may limit the generalisability of the findings to other contexts or industries. Reliance on direct observation and informal discussions introduces the potential for observer bias and subjective interpretations, despite measures implemented to enhance reliability. Furthermore, limited availability of historical production data constrained some long-term comparisons. While the results provide valuable insights for similar high-speed bottling environments, caution is warranted when generalising these findings to broader contexts.

Despite the limitations presented, the three-phase methodological framework formalised in this chapter provides a systematic and scientifically repeatable approach for analysing and improving changeover operations in high-speed bottling environments. By detailing the progression from workplace stabilisation to advanced digital integration, this design ensures that subsequent solutions are firmly rooted in industrial engineering principles. Before optimised solutions can be developed, however, it is essential to isolate the specific root causes of capacity losses and establish the empirical baseline. The research now transitions to the active manufacturing environment. The following chapter presents the AS-IS diagnosis, mapping technical restrictions, structural flaws, and critical equipment susceptibilities within the bottling lines.

Chapter 4

AS-IS Diagnosis: Production Context and Changeover Analysis

This chapter presents a comprehensive assessment of the current packaging operations at the *Leça do Balio* industrial unit. It details the technical constraints of the bottling lines, examines the impact of product complexity on operational efficiency, and identifies the primary inefficiencies that contribute to downtime during format changes. Establishing this operational baseline is essential for the subsequent implementation of physical standardisation measures (Chapter 5) and digital SMED methodologies (Chapter 6).

4.1 Industrial Context and Scope of Study

The operation at *Leça do Balio* is structured as a highly integrated system, where the synchronisation of raw material delivery and high-speed packaging is essential to maintain OEE. The bottling facility operates as a high-volume, automated production unit with 10 distinct filling lines, organised into three specialised blocks: Block 123 (Lines 1, 2, and 3 for bottles), Block 56L (Lines 5 and 6 for bottles, plus a dedicated can line), and a Barrel Block containing the remaining four lines. This study centres specifically on the glass bottle-filling lines in Blocks 123 and 56L.

A tracking initiative was implemented to establish a baseline of the operational environment by compiling and analysing all active SKUs across the target production blocks. Unlike the more standardised barrel or can lines, these bottle lines are characterised by a diverse rotation of 104 active SKUs, necessitating frequent mechanical reconfigurations and yielding unique operational complexities. Cataloguing this extensive SKU mix enabled the mapping of every permutation of bottle geometries, liquid profiles, closure types, and label variants, all of which directly influence retooling frequencies and mechanical setup variations on the shop floor. Part of this cataloguing initiative is presented in Appendix A.

4.2 Technical Restrictions and Line Flow Dynamics

The glass bottle lines employ an industry-standard sequential layout designed for continuous feed. The process initiates at the De-palletiser, where standard pallets are introduced, and concludes at the Palletiser, where finished packaged goods are systematically stacked into designated tier patterns for distribution. Between these points, the line functions as an integrated network of conveyors and control logic, with the interaction between machines and packages determining the overall line flow.

As described in Chapter 2, the operational rhythm of the entire line is determined by the Filler, which serves as the critical focal point and the slowest machine in the sequence. To optimise the filler's efficiency and shield it from minor stoppages, the line is balanced using over-speed principles and buffer zones. Figure 4.1 illustrates the over-speed principles implemented at the *Leça do Balio* plant, where, in contrast to the literature, the over-speed principles are not linear and do not have a mirror effect before and after the Filler. Machines marked with "*" are exclusive to returnable glass lines. Figure 4.2 provides an example of a buffer zone, which, as detailed, aims to protect the line from the impact of "micro-stoppages".

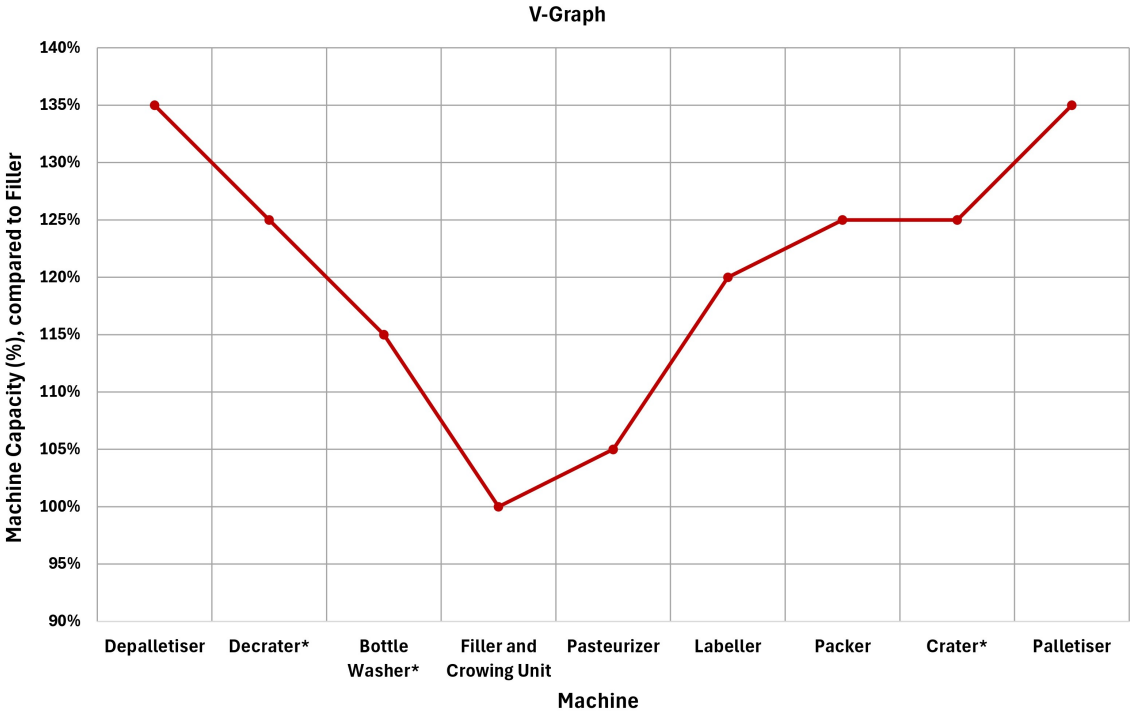


Figure 4.1: V-Graph, Illustrating the Over-Speed Principles Implemented at the *Leça do Balio* Plant



Figure 4.2: Buffer Zone, Protecting the Line From “Micro-Stoppages”

4.3 Critical Equipment and Changeover Complexity

Modern breweries face considerable operational complexity due to transforming consumer demands, necessitating versatile equipment capable of supporting diverse packaging configurations. Managing 104 active SKUs across Blocks 123 and 56L is challenging due to the numerous combinations of bottle formats, closures, labelling variations, and secondary packaging configurations. Weekly, this SKU diversity results in an average of almost 20 hours of downtime attributable solely to format changeovers. These downtime figures were compiled from analysis of digital production logs and direct observation of changeover events over multiple months of operation.

Although the bottling lines consist of multiple interconnected machines, not all equipment contributes equally to setup complexity and operational instability. Consequently, this study focuses exclusively on the most critical machines that influence changeover performance.

4.3.1 Filling and Crowning Unit

The Filler and Crowner assembly is the central component of the bottling line, serving as the master machine that drives the overall line rhythm. All upstream and downstream equipment blocks are structurally synchronised to match the output pace established by this assembly. As a result, any prolonged downtime or “micro-stops” at the filler directly undermines the process efficiency of the entire production line.

The setup sensitivity of the Filling block is strongly influenced by the specific bottle geometry and the volumetric capacity of the incoming SKU. Changeovers necessitate precise mechanical adjustments to fit varying container heights and diameters. This process involves replacing internal handling components, such as guide rails and star-wheels, as seen in Figure 4.3.

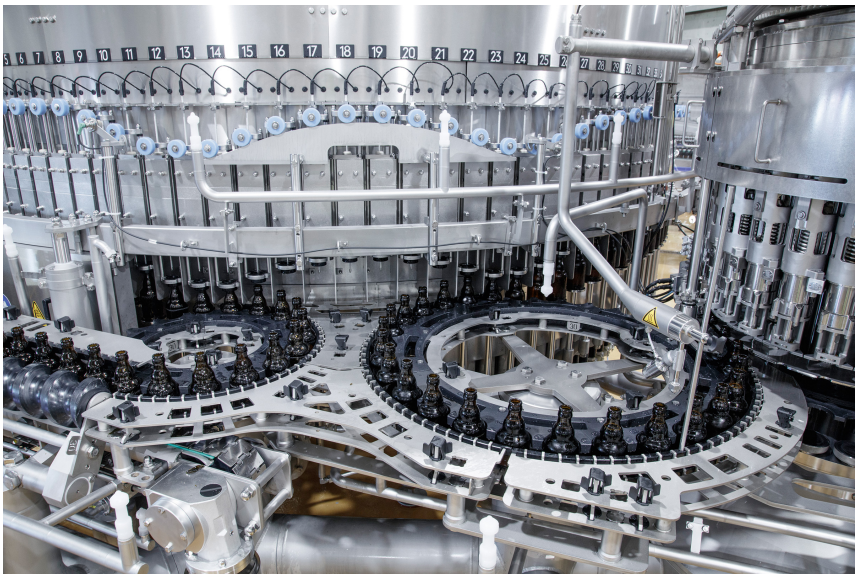


Figure 4.3: Filler Module and Guide-Rails [25]

The Crowning Module, depicted in Figure 4.4, imposes additional mechanical restrictions based on the closure profile, resulting in a precise geometric relationship between the bottle finish and the cap-feeding mechanisms. Since the Filler and Crowner unit govern production flow, the speed and consistency of adjustments directly influence the facility's post-changeover ramp-up performance.



(a) Crowning Module, Inside the Filler (b) Crowning Guide-Rails

Figure 4.4: Crowning Module

4.3.2 Pasteurisation Unit

The tunnel Pasteurizer, shown in Figure 4.5, operates differently from the Filler and Labeller blocks, as it does not contain mechanical handling parts that require physical replacement during format changeovers. Instead, transitioning this multi-stage heat exchanger to a new SKU profile is accomplished entirely through software by modifying the active thermal program.



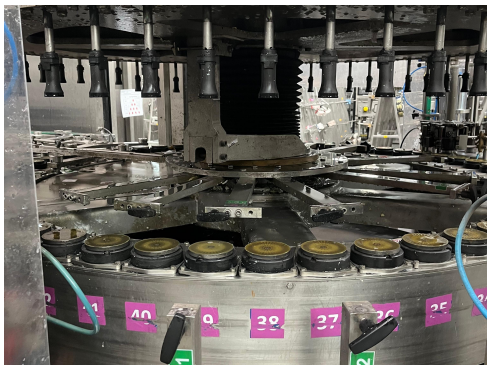
Figure 4.5: Pasteurisation Unit

Despite the absence of physical changeover components, the Pasteurizer represents a critical bottleneck due to its long thermal transition times and extreme sensitivity to line flow interruptions. When a format transition occurs between highly distinct liquid profiles, particularly between non-alcoholic beers and standard alcoholic beers or ciders, the time required to stabilise the internal water zones at the new target Pasteurisation Units (PU) can exceed 30 minutes. This delay is driven by the system's thermodynamic inertia, which must gradually heat or cool massive volumes of water to prevent the glass containers from breaking from thermal shock.

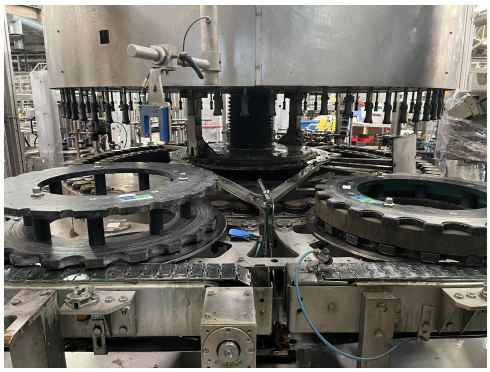
To minimise systemic delays, the timing of the Pasteurizer changeover is critical and must conform to SMED principles, which recommend performing as many changeover steps as possible while the line remains operational. Operators should not treat the Pasteurizer changeover as a strictly sequential task initiated only after a line stoppage. Instead, software modifications and zone temperature adjustments should be initiated as soon as the final bottle of the outgoing batch exits the pasteurizer tunnel's discharge conveyor, or, when feasible, during ongoing production. Adopting this technique reduces transition time and prevents artificial bottlenecks that could otherwise disrupt downstream labelling operations and unnecessarily extend the overall changeover duration.

4.3.3 Labelling Systems

Located downstream of the Pasteurizer, the rotary Labeller, shown in Figure 4.6, exhibits the greatest mechanical complexity and setup variability within the packaging infrastructure. While the Filler manages rigid fluid-handling geometries, the Labeller must accommodate flexible packaging and complex machine kinematics to obtain precise aesthetic placement.



(a) Labeller's Carousel

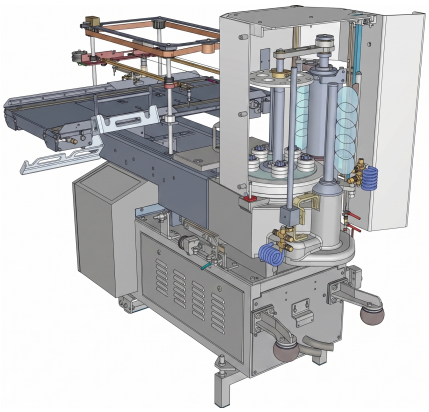


(b) Star-wheels and Guide rails

Figure 4.6: Labeller Macro-View

The significant setup variability of this machine results from its multi-aggregate architecture. Depending on the marketing requirements of the active SKU, a single bottle profile may require the simultaneous application of up to three independent labels: a front body label, a back label, and a wraparound neck label. Each label type is applied by a dedicated mechanical aggregate, as shown in Figure 4.7, mounted around the central rotary carousel.

The changeover process involves a complex, highly sensitive exchange of localised handling components. Operators must manually remove and install sets of guide rails and star-wheels as required, similar to the Filler, and frequently replace rubberised glue pallets, gripper cylinders, label baskets, wipe-down brushes, etc. The system exhibits pronounced alignment sensitivity, such that even minor deviations in the mechanical positioning or timing of these aggregates can result in significant operational defects, including skewed label alignment, bubbling, or tearing. Because these adjustments have traditionally depended on operators' tacit knowledge rather than standardised digital or mechanical benchmarks, the Labeller block remains one of the principal sources of shift-to-shift performance variability on the shop floor.



(a) Inside View [26]



(b) Outside View

Figure 4.7: Labeller's Aggregate

Empirical field investigations were performed to clarify the physical configuration of the wipe-down brush assemblies on Line 1. As these assemblies directly affect the structural finish and aesthetic positioning of the labels, a scrupulous manual positioning procedure was implemented for each brush component. Each unit was physically adjusted on inactive machinery to determine the position at which they fit. This field validation was fundamental for addressing the absence of physical reference markers and for formalising a geometric blueprint to guide subsequent standardised mounting workflows. While this data-gathering work was conducted within the variable AS-IS state to capture current shop-floor realities, the primary objective was to generate a reliable empirical dataset. This baseline positioning data was subsequently utilised to develop the standardised visual management model in Chapter 5, serving as the database for formalising the positioning criteria for the brush assemblies.

4.4 Current Inefficiencies and Baseline Performance

High SKU variety and complex retooling requirements directly and negatively impact operational performance by increasing equipment downtime. A significant inefficiency during production runs and changeovers is the occurrence of “micro-stops”. Due to their frequency, these incidents substantially reduce overall line efficiency and cause cascading starvation or accumulation blockages throughout the line.

4.4.1 Setup Sequences

The current setup and format change sequences across the bottling lines rely heavily on the tacit knowledge of individual operators and are further complicated by fragmented and outdated documentation. Operational procedures lack a defined, optimised structure to ensure standardised changeovers or promote stable equipment behaviour during subsequent production phases. This assessment is supported by a qualitative methodology based on direct operator interviews, structured on-floor observations, and a review of training records. Semi-structured interviews were conducted with both experienced and newly recruited operators across all shifts, focusing on their approach to changeover activities, perceived challenges, and knowledge transfer practices. On-floor observations were systematically carried out during multiple changeover events, with field notes used to capture common technical and procedural issues. Data from interviews and observations were analysed thematically to identify patterns of informal knowledge transfer and areas lacking formal documentation. These findings collectively indicate a reliance on informal knowledge transfer rather than standardised, documented procedures. As a result, operational “best practices” that support long-term line efficiency are communicated orally among shop-floor personnel rather than being formalised in industrial standards.

Reliance on uncodified experiential knowledge creates a significant cognitive barrier for newly recruited operators or personnel unfamiliar with specific machine configurations. In the absence of standardised visual aids or sequential work instructions, these workers must make mechanical

adjustments by trial and error, increasing human error rates and mental fatigue. This lack of institutionalised knowledge transfer not only extends training cycles but also exacerbates operational discrepancies when teams rotate across multiple shifts.

The absence of standardised sequences introduces considerable operational variability. Without organised guidelines, essential maintenance and setup tasks, such as lubricating critical mechanical components necessary for equipment longevity, are frequently omitted or performed inconsistently. The lack of a formalised, optimal sequence of operations hinders the stabilisation of the changeover process, directly affecting the post-changeover velocity ramp-up and increasing the line's susceptibility to early-stage "micro-stops".

4.4.2 Machine Components' Identification

The current identification system exhibits considerable limitations in both physical durability and design, consequently compromising the reliability and efficiency of setup operations. The absence of standardised physical organisation for the wide range of format components leads to considerable "search waste" (as defined in Lean manufacturing principles) and procedural variability during the changeover process.

Currently, for the labelling machines, a component identification system is in place in which adhesive labels are applied to individual components to map them to specific product groups (Super Bock, Somersby, Stout, etc.). This alphanumeric codification system integrates three variables: the liquid product, the tare, and the specific equipment sub-assembly or aggregate where the component is to be installed, e.g., *SB 33 KL2*, representing a component assigned to a Super Bock (SB), 0.33L bottle (33), allocated to the second aggregate of the Labeller (KL2). Also, up to 15 different colours were utilised across the various production lines and operational blocks, representing the liquid to be filled, often with inconsistent or contradictory meanings, as detailed in Appendix B. Figure 4.8 demonstrates the aforementioned: three different colours for a single format.

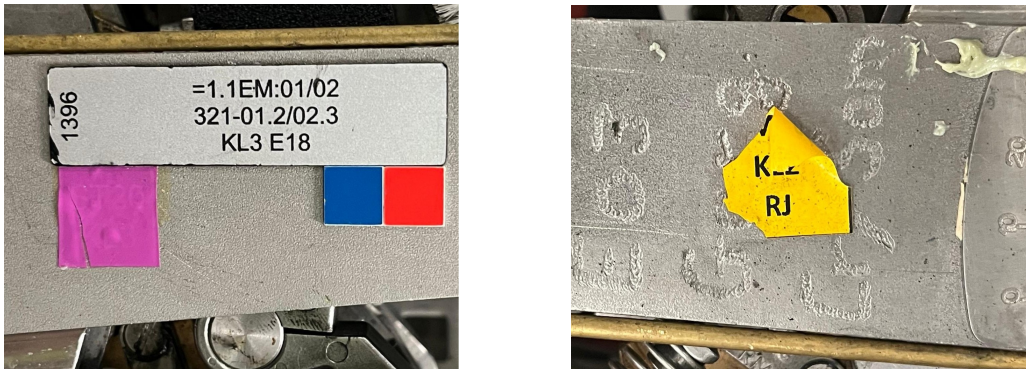


Figure 4.8: Multiple Stickers, for a Single Format, with Three Different Colours

This lack of standardisation violated fundamental principles and reduced the effectiveness of rapid component identification during setup operations.

With that taken into consideration, this identification system exhibits four critical failure modes that compromise its reliability:

- **Material Deterioration and Operational Response Times:** The identification labels consist of adhesive stickers applied directly to the mechanical components. When these components undergo mandatory industrial washing cycles, thermal and chemical exposure causes the adhesive to degrade rapidly within a few weeks. This results in illegible codes (Figure 4.9a) or complete or partial detachment of the labels (Figure 4.9b), rendering component identification impossible, as seen in Figure 4.9. Furthermore, the lead time required to replace missing labels is excessively long, and differences in the replacement process, for example, variations in the codification syntax or sticker colour schemes, generate confusion among operators.



(a) Illegible Code (b) Partial Detachment of Label

Figure 4.9: Material Deterioration in the Identification Labels of Format Parts

- **Codification Complexity and Redundancy:** Due to the inherent design of the current codification logic, components shared across multiple SKUs require multiple separate adhesive labels. This accumulation of stickers creates visual clutter, complicates data retrieval during setup, and increases the risk of human error from misleading or overlapping product designations on a single asset, as shown in Figure 4.10.



Figure 4.10: Sticker Accumulation on a Brush Assembly for the Labeller

- **Divergence Between Codification and Functional Reality:** The current alphanumeric nomenclature fails to accurately reflect the geometric interchangeability of parts on the shop floor, resulting in an excessive dependence on operator empiricism. For instance, for the Super Bock 0.25L SKU with a Pull-Off capsule, the machine's components required for the wraparound neck label differ from those used for the Super Bock 0.25L Crown capsule SKU, yet they are identical to those required for both the Crown and Pull-Off variants of the Super Bock 0.20L SKU. Figure 4.11 exhibits precisely that: in spite of these differences, the alphanumeric nomenclature does not display any differentiation, rendering both SKUs exactly the same, when they are not.



Figure 4.11: Lack of Detail in the Used Nomenclature

Because these non-linear associations are omitted from the physical tags and formal documentation, this critical operational mapping remains confined to the tacit knowledge of experienced personnel.

The dependence on operator subjectivity is compounded by the absence of technical data repositories or manufacturer-supplied specifications for localised calibration components. For example, during the study of the rotary labeller, no database or manufacturer reference data were available regarding the nominal heights of the active levelling shims. To address this information gap, a comprehensive metrological audit was conducted, involving manual measurement of the physical height of each aggregate levelling shim and gripper head levelling shim. These manual measurements were undertaken for technical reasons to establish the accurate geometric parameters required for Chapter 5, and the collected data is presented in Appendix C.

- **Absence of Line-Specific Traceability:** The current codification system lacks any reference designating the specific filling line to which a component belongs, leading to unauthorised cross-line part transfers. This omission induces a two-fold operational risk. Firstly, it produces considerable search waste, as even experienced operators expend time changing over to locate components that have been inadvertently or intentionally moved to adjacent

lines. Second, it poses an acute risk of mechanical failure and component breakage. While some machinery (such as the labellers) across parallel lines appears geometrically similar, minor tolerance differences exist, meaning a component optimised for one specific line can cause severe "micro-stops" or structural damage if forced onto another line. Figure 4.12 shows precisely that the labels for similar components are almost the same, despite the machines being different, making the parts incompatible if changed.



(a) Component for Line 1 (b) Component for Line 3

Figure 4.12: Similar Components for Different Machines

4.5 Synthesis of the AS-IS Diagnosis

The diagnostic assessment of the glass bottling lines in this chapter identifies systemic operational downtime resulting not only from setup activities but also from component misidentification, degraded visual indicators, and a critical reliance on operator empiricism. Consistent with the stabilisation-first strategy outlined in the research methodology, addressing these failure modes requires a structural transition from an uncodified operational state to a highly standardised workplace environment. Based on these findings, the following chapter addresses physical asset re-engineering, detailing the development of a zero-redundancy alphanumeric codification logic and a physical identification architecture based on the principles of 5S.

Chapter 5

Development of the Standardization Model: 5S and Format Parts Organization

This chapter outlines the development and implementation of a standardisation model to ensure process consistency on the bottling lines. Before applying advanced optimisation with SMED methodologies, it is essential to transition from a variable, tacit-knowledge-based state to a predictable, standardised environment.

The primary goal of this phase is to standardise the physical organisation related to the format components. By applying foundational principles, particularly the 5S methodology, the factory floor is prepared to minimise variability during changeovers.

5.1 Physical Standardisation and the "Set in Order" Phase

Effective production system steadiness depends on strict management of format change parts, as misidentification or misplacement directly affects machine availability and reliability. An analysis of historical production data showed that a significant portion of weekly downtime was attributed to the misuse or misplacement of these parts. Key issues include installing incorrect components, which can cause immediate mechanical failures and line blockages, or being unable to locate required parts, leading to improvisation and reduced line speeds.

Prior to defining the new codification architecture, a comprehensive inventory of the existing format-part portfolio was completed across the target bottling line (Line 1). This assessment identified several obsolete, duplicated, or operationally irrelevant components stored alongside active format parts. The presence of these components increased organisational complexity, consumed valuable storage capacity, and heightened the risk of operator confusion throughout changeover preparation. As a result, a rationalisation process was implemented to remove obsolete items from

operational storage and to align the physical inventory exclusively with the active SKU portfolio. This initial consolidation reduced visual clutter and established a controlled baseline for the development of subsequent standardisation measures.

The Labelling machine was chosen as the primary focus due to its significant mechanical variability. Unlike other equipment that may use a single component for multiple configurations, the rotary labeller requires a complex set of SKU-specific parts. This complexity, combined with inconsistent identification throughout production lines and blocks, greatly increased the risk of operator error during retooling.

To address these vulnerabilities, a new standardised codification model was developed with input from field team leaders. Based on the "rational location rule" of visual management, which ensures any operator can quickly identify, retrieve, and return items, the model emphasises structural durability and visual clarity. The system transitioned from an excessively complex liquid-based colour logic to a simplified format system.

5.2 Design Requirements

Implementing a standardised visual management system for format changeover parts requires an engineering framework that tackles the operational, physical, and cognitive constraints of the bottling lines. To minimise the problems detailed in Chapter 4, the identification system must meet five core design requirements: durability, readability, geometric compatibility, interoperability, and line traceability.

5.2.1 Durability Requirements

To ensure the system's longevity in a demanding industrial environment, materials and adhesives must be highly durable. Format parts on the bottling lines are frequently cleaned in industrial settings. Therefore, the design must meet two durability criteria: the marker material must resist mechanical vibrations, thermal stress, and industrial detergents without degrading, and the adhesive must maintain full integrity through repeated washing and operational use, preventing peeling or detachment throughout its lifecycle.

5.2.2 Readability

Consistent with the Seiton (Set in Order) phase of 5S and the rational location principle, maximising interface readability is essential to eliminate visual search waste during format transitions. Identification markers must present a clear, predictable vertical information hierarchy. The most relevant information should be visible from a distance and highlighted, while less critical details should be readable only up close.

5.2.3 Geometric Compatibility

Due to the varied mechanical configurations of handling components, especially in high-speed rotary Labellers, geometric compatibility must determine how identifiers physically interface with the equipment.

Identification parts should be universal across machines, parts, and lines while also adapting to the specific geometry of each part. For heavy-duty components, the system should employ robust identification methods to prevent the marker from separating from the part at high speeds. For parts with smooth or delicate profiles, identification methods must be compatible with their limitations while preserving performance.

5.2.4 Interoperability and Line Traceability

To decrease human error in codification across production blocks, the system must implement an interoperable visual standard throughout the facility. This involves shifting from a product or volume-specific logic to a line-based codification scheme that assigns a unique identifier to each production line. This coding acts as a "Visual Poka-Yoke", enabling operators to quickly verify component ownership during changeovers.

Line traceability must connect the physical organisation of the shop floor with continuous improvement tracking. Markers should provide clear, immediate access to the exact machine aggregate and format configuration. Standardising this data layout ensures that any operator can quickly verify a part's destination, decreasing operational variability caused by incorrect component selection.

5.3 Definition of the New Codification Logic

To implement the requirements described in the previous section, a structured alphanumeric codification system was created. This logic results from the need to replace unstable legacy naming systems that often confused temporary commercial product labels with fixed mechanical properties, with a clear, data-driven syntax. The primary goal is to establish an intuitive, zero-redundancy indexing method that maps each physical-format part to its exact operational destination.

5.3.1 First Iteration

As an initial development step, the first iteration adopted a codification logic closely aligned with the legacy system, in which format part identification was directly tied to the specific products that consumed those components. This intermediary version offered a distinct advancement over the AS-IS state. It introduced the same foundational physical principles intended for final deployment while preserving familiar coding logic to avoid an overwhelming, immediate paradigm shift for the workforce. Consequently, this iteration was projected to gain faster floor-wide acceptance among operators, as it eliminated the lack of process specification characteristic of the AS-IS phase without forcing an abrupt shift in their conceptual workflow. As seen in Figure 5.1, the

nomenclature is preserved: a component for a Super Bock (SB) 0.33 L bottle (33) in the second aggregate of the Labeller (KL2) for Line 1 (L1) still has the same overall design.

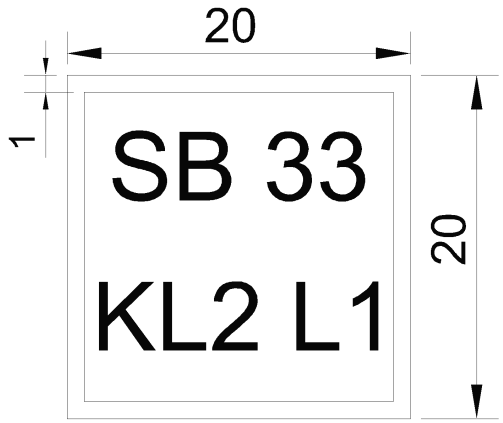


Figure 5.1: First Iteration Model

Despite initial acceptance, some resistance and scepticism within the workforce remained, and the system soon revealed scalability difficulties. The main problem with the product-centric logic was its high visual and cognitive strain, due to the large number of markers required for multi-product parts. For example, back-label format parts shared across many SKUs required more than eight markers. This created an operational bottleneck, failed to eliminate waste in search time, and increased the risk of personnel error during changeovers.

Ultimately, this iteration reduced some immediate user resistance by preserving familiar structures, although it lacked the simplicity, scalability, and direct correlation needed for mistake-proof operations. This transition phase supplied valuable feedback, demonstrating that operational excellence could not be achieved by incrementally adjusting the existing logic. With this in mind, a complete paradigm shift was necessary and is detailed in the following sections.

5.3.2 Codification Logic and Storage Reorganisation

To address the failures of the legacy product-centric system and meet the requirements in Section 5.2, a complete paradigm shift in codification logic was implemented. Instead of asking “Which SKUs does this part serve?” the new logic asks “Which specific parts does this SKU require?”

In this new system, format parts do not display a complex list of compatible products. Each component receives a single, permanent alphanumeric identifier, making it unique. The product now specifies the required part number, as shown in Figure 5.2.

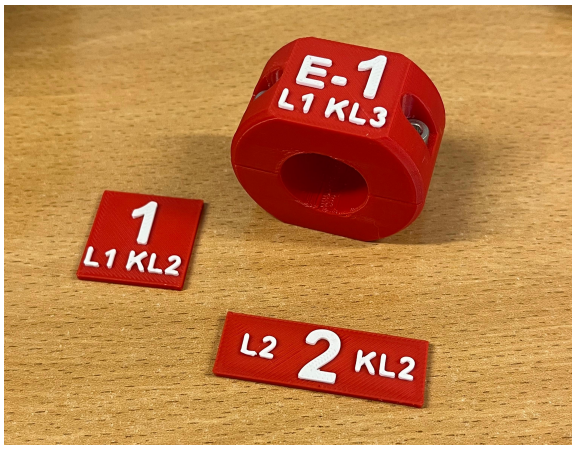
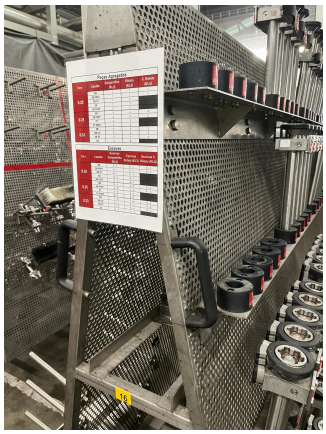


Figure 5.2: Examples of Identification Markers

To implement this logic on the shop floor, cross-reference matrix tables, as shown in Figure 5.3, are placed next to production machinery and fixed to storage carts.

Tare	Liquid	Neck Label (KL2)	Front Label (KL3)	Back Label (KL4)
0,20	SB	1	1	1
	SB POFF	1	1	1
	SB ST	1	2	-
	SO	2	3	-
	SO POFF	2	3	-
0,25	SB	3	4	2
	SB POFF	4	4	2
	CT	4	5	-
	CT POFF	4	5	-
0,33	SB	5	6	3
	SB 0.0	5	6	3
	SB ST	5	7	3
	SO	6	8	-

(a) Example of a Cross-Reference Table



(b) Table on a Storage Cart

Figure 5.3: Cross-Reference Matrix Tables

When retrieving parts, these tables are used to match the next product and container tare to an exact part number, following the presented workflow in Figure 5.4. Operators must select only the part number listed in the matrix, constructing a structured workflow that prevents incorrect component use. Any part that does not match the displayed code is immediately flagged as out of place, eliminating mistakes or errors during changeover. This error-proofing ensures only the correct parts, validated by both the matrix and the identifier, are selected and installed.

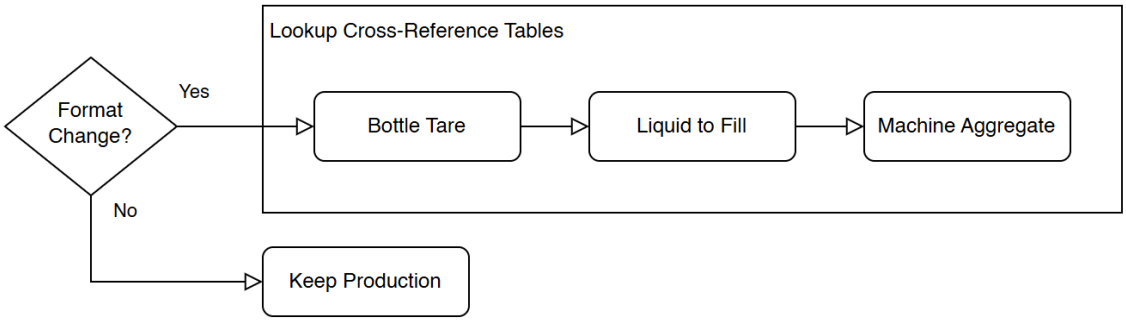


Figure 5.4: Flow for Deciding Format Number for an Aggregate

To strengthen this codification and optimise changeover workflow, a new storage layout for components on shelves and carts was proposed. Previously, parts were organised only by component type, regardless of operational zone or machine aggregate, as shown in Figure 5.5a, which caused uncertainty during sorting. The new proposed storage architecture is organised as follows:

- **The Filler and Crowner:** Components continue to be structured and grouped by container tare, as the physical dimensions of the container tare are the sole variables influencing format parts for these blocks.
- **The Labeller:** Components would be physically arranged strictly by machine aggregate (station), creating a direct spatial link between storage and machine architecture.

This reorganisation is meant to be integrated with the existing Pit-Stop Car project, shown in Figure 5.5b. Designed to address floor space constraints, this mobile changeover cart consolidates all format parts required for a complete Labeller changeover. It works as a visual staging tool, enabling operators to confirm that every required component is ready before changeover and eliminating unnecessary trips to central storage.



(a) Storage Carts



(b) Pit-Stop Car

Figure 5.5: Storage and Movement Solutions for Format Parts

Combining the unique alphanumeric codification, aggregate-based storage, and the Pit-Stop Car framework, the changeover workflow resembled a structured "grocery shopping" experience. Operators follow a clearly sectioned, sequential route, which reduces mental effort, eliminates wasted search time, and minimises opportunities for operator error during line changeovers. Although the proposed intervention received overall approval, high production demands and seasonal labour shortages ultimately prevented its timely execution.

5.3.3 Hierarchy and Information Layering

The architecture enforces a strict vertical hierarchy, as shown in Figure 5.6, prioritising mechanical compatibility over administrative tracking to accelerate line changeovers. The visual layers are structured as follows:

1. **Primary Geometric Layer (Top Half):** The Format Identifier (Field A) serves as the absolute focal point of the visual asset.
2. **Secondary Operational Layer (Bottom Half):** The structural boundaries of the lower zone are split horizontally into secondary and tertiary data fields. Human operators process this section from left to right, verifying the Filling Line (Field B) before confirming the matching Machine Aggregate (Field C).
3. **Tertiary Conditional Layer (Base Centre):** Reserved strictly for high complexity machinery blocks. Any deep-level variables (Field D) are layered directly beneath the line and aggregate data, guaranteeing that highly specific equipment selections do not clutter the primary macro-identifiers.

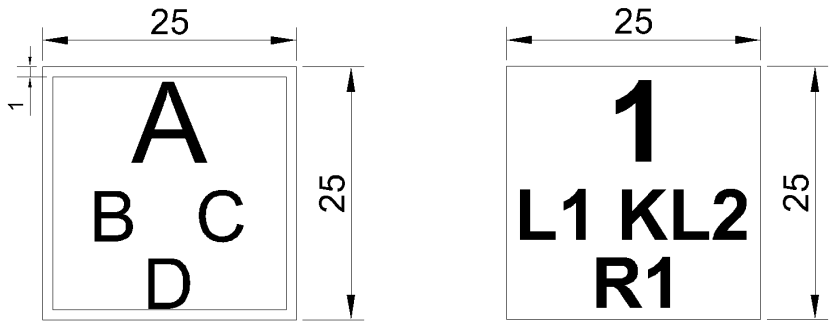


Figure 5.6: Extreme Case of Representation, Including All the Fields for a Standard Marker

5.3.4 Naming Conventions

To preserve consistency across all production blocks, standard string values were defined for each variable in the codification system.

Format identifiers use only nominal dimensions, ensuring label or recipe changes do not affect the marker. For brush assemblies, the conditional prefix "E" is mandatory, since the format

build-up is independent of the other parts, as a single brush can serve various formats. Aggregates for neck labels, labels, and back labels are designated as KL1/KA1, KL2/KA2, KL3/KA3, and KL4/KA4 and vary by machine and brand, mapping directly to the labelling structures of the machines' manufacturers, KHS and Krones. When treating complicated configurations in production Line 5, the aggregate string conditionally expands to include localised machine suffixes, specifically R1 and R2, mapping the dual rotary labeller architecture unique to that line.

5.3.5 Reduction of Redundancy

A key objective of this codification logic is to systematically eliminate information redundancy, which previously caused mental fatigue and increased the risk of selecting incorrect components. Legacy systems usually included multiple variables, such as brand names, volumes, and packaging styles, even when these variants used identical component geometry.

The updated logic uses the handling part's geometric profile as the sole reference. To implement this, all active product consumables, including labels, back labels, and neck labels, were reviewed and grouped by identical physical configurations, displayed in Appendix D.

This reduction in redundancy minimises the physical marker catalogue required, simplifies inventory management within the storage zones and effectively improves the changeover process by focusing the operator's attention exclusively on the mechanical variables that dictate line setup success.

5.4 Physical Identification Architecture

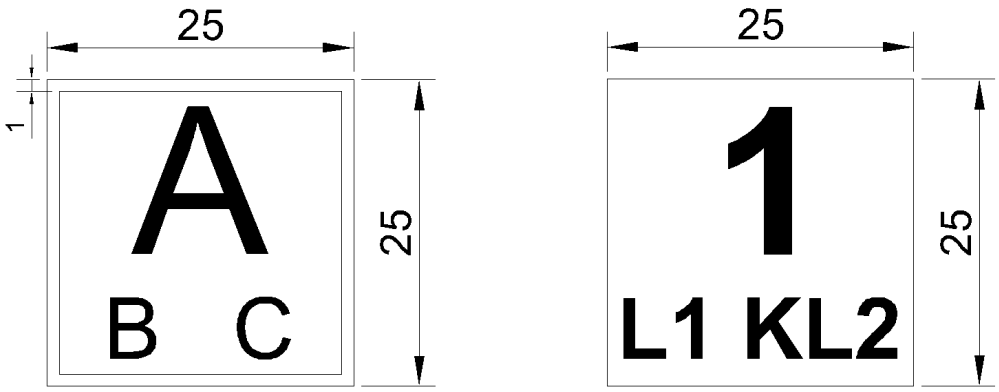
This section describes the physical deployment of the identification framework, which translates the aggregate-centric alphanumeric codification into intuitive shop-floor controls. The architecture is based on two pillars: standardised geometric arrangements that adapt to space and access constraints, and a high-contrast chromatic Poka-Yoke system for passive, error-proof validation of line routing. Together, these layers ensure mistake-proof execution on the shop floor.

5.4.1 Standardised Geometrical Arrangements

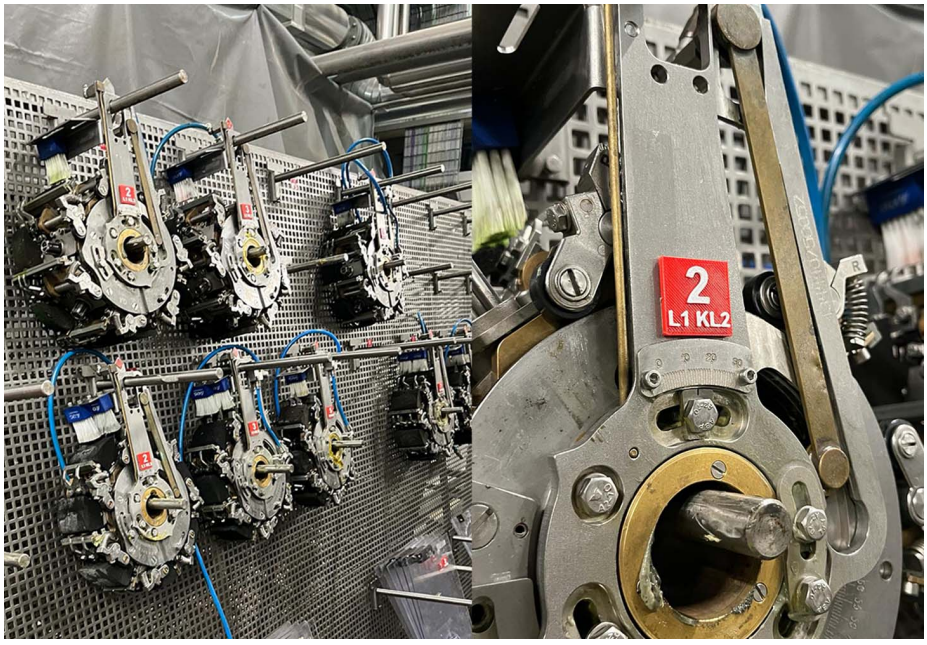
To apply the centralised codification logic to various handling components, the system uses six standardised spatial layouts. Each variant addresses specific spatial, component, or mechanical access constraints, ensuring the system adapts to local restrictions or unique shapes without sacrificing readability.

- **Standard Square Variant (Version I):** This serves as the baseline, standardised footprint utilised for the vast majority of format changeover components across the production blocks. As defined in the technical specifications, it features a flat, square profile with dimensions of 25 mm $\times$ 25 mm and a total thickness of 3 mm, as seen in Figure 5.7. This layout is optimised for rapid visual scanning on standard mounting surfaces, with the format field

(Field A) positioned superiorly and the filling line and machine part fields (Fields B and C) positioned inferiorly.



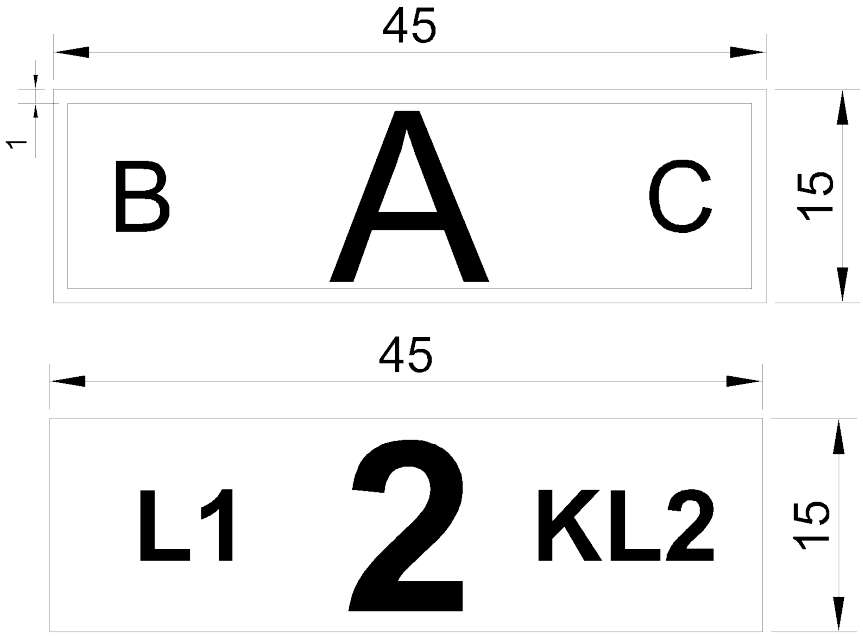
(a) Version I of Implementation: Geometric Template (left) and Manufacturing Example (right)



(b) Version I of Implementation: Storage Cart (left) and Format Part Identified (right)

Figure 5.7: Version I of Implementation

- **High-Constraint Rectangular Variant (Version II):** Engineered as a low-profile alternative, this elongated rectangular geometry is reserved for handling and format parts whose narrow or highly restricted physical dimensions prohibit the embedding of standard square markers. It measures 15 mm $\times$ 45 mm. This variant redistributes the information architecture horizontally (Field B, Field A, and Field C sequentially from left to right) to maintain strict scannability within cramped mechanical spaces, as seen in Figure 5.8.



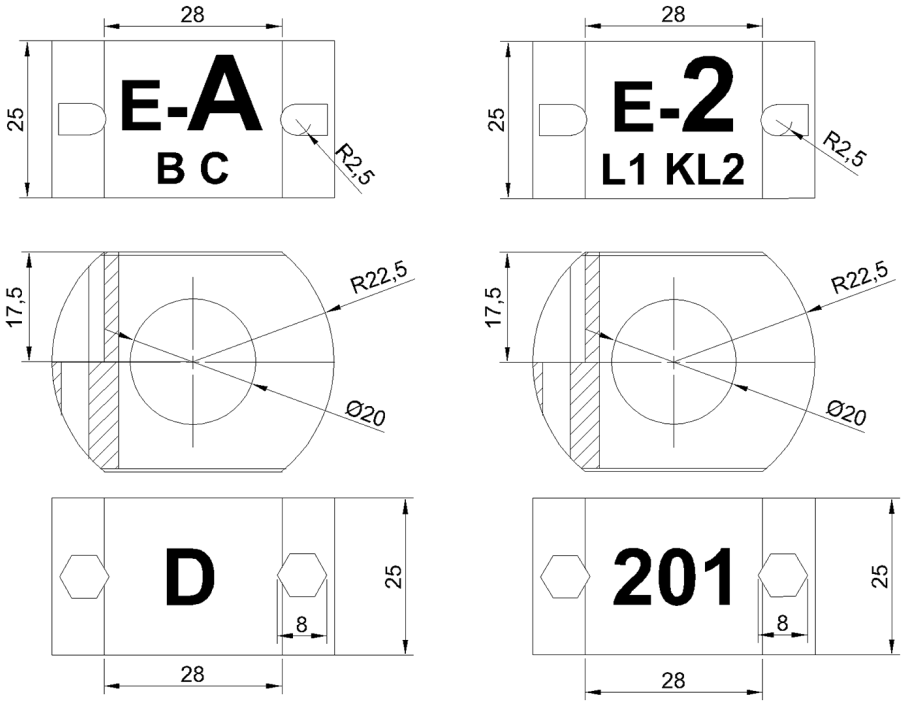
(a) Version II of Implementation: Geometric Template (top) and Manufacturing Example (bottom)



(b) Version II of Implementation: Format Part Identified

Figure 5.8: Version II of Implementation

- **Brush Assembly Variant (Version III):** Dedicated exclusively to brush assemblies, this configuration introduces a complex three-dimensional geometry. The component is manufactured as a face-cut half torus (doughnut profile) featuring an overall height of 25 mm, an internal diameter of 20 mm, and an external diameter of 45 mm. It incorporates specific mechanical provisions, including flat faces positioned 18.5 mm from the centre, twin M4 through-holes, and hexagonal cutouts for nut retention, ensuring seamless mechanical integration without interference, as shown in Figure 5.9.



(a) Version III of Implementation: Geometric Template (left) and Manufacturing Example (right)

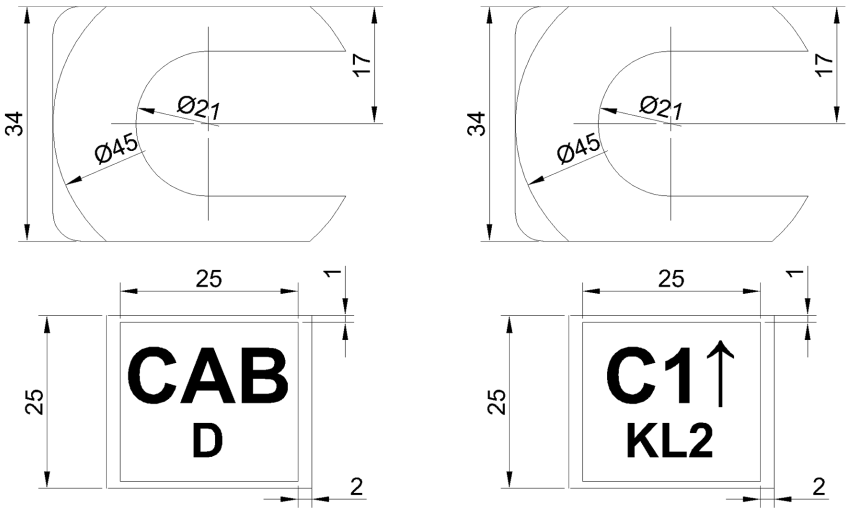


(b) Version III of Implementation: Storage Cart (left) and Format Part Identified (right)

Figure 5.9: Version III of Implementation

- **Levelling Shims Variant (Version IV):** This variant is dedicated specifically to the levelling and positioning shims of aggregates from KHS Labelling machines, and holds no application for Krones equipment. Rather than utilising external markers, these components are manufactured from the origin, with negative-etched codifications directly embedded at a minimum depth of 0.4 mm. The geometry comprises a circumscribed, cut-out rectangle with an internal diameter of 21 mm and an external diameter of 45 mm. A positional arrow

pointing up or down is mandatory to indicate relative alignment, as seen in Figure 5.10.



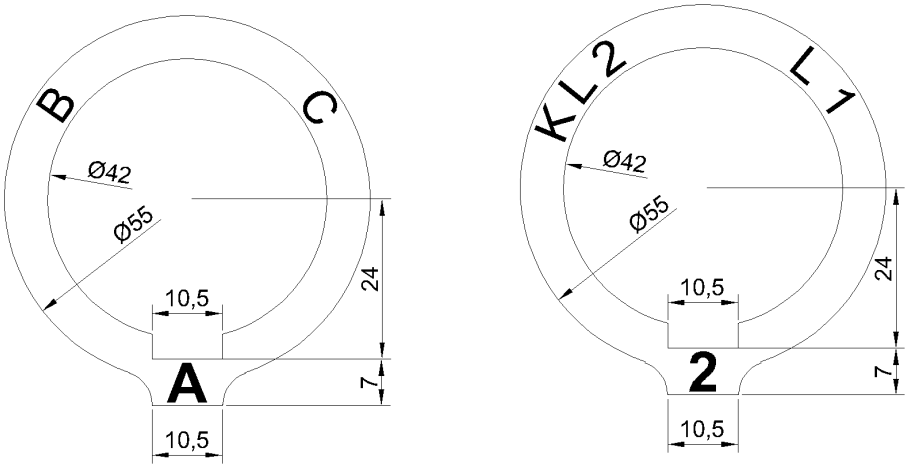
(a) Version IV of Implementation: Geometric Template (left) and Manufacturing Example (right)



(b) Version IV of Implementation: Printed Format Part in Use

Figure 5.10: Version IV of Implementation

- **Gripper Head Levelling Shims Variant (Version V):** Developed exclusively for the gripper head levelling shims within KHS rotary Labelling units, this configuration is likewise omitted for Krones machinery. It is produced with an integrated, direct negative engraving ($\geq$ 0.4 mm depth) on a ring structure characterised by an internal diameter of 42 mm and an external diameter of 55 mm. A keyway slot and a corresponding drive tab projection are integrated into the profile to facilitate precise key alignment on the shaft mechanism, as shown in Figure 5.11.



(a) Version V of Implementation: Geometric Template (left) and Manufacturing Example (right)



(b) Version V of Implementation: Printed Format Part

Figure 5.11: Version V of Implementation

- **Multi-Machine Variant (Version VI):** This configuration is dedicated exclusively to the complex operational environment of Production Line 5, which operates with duplicate, parallel Labeller machinery. While maintaining the standard external envelope, the information layout is expanded vertically to incorporate a fourth discrete field (Field D) at the bottom. This structural modification is designed specifically to append the local labeller identifier (R1 or R2), providing unambiguous routing indications for duplicate machinery lines, as seen in Figure 5.12.

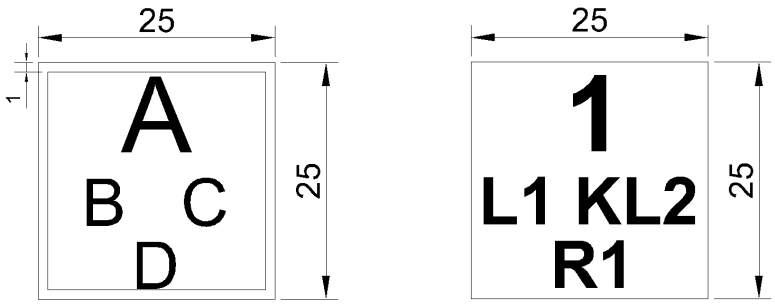


Figure 5.12: Version VI of Implementation: Geometric Template (left) and Manufacturing Example (right)

5.4.2 Chromatic Poka-Yoke System

To prevent cross-contamination, each marker background uses a high-contrast colour assigned solely to the production line routing, not to product or container variables.

To ensure compliance with corporate visual standards and maintain uniformity throughout replacements, all marker colours must conform to precise industrial colour space definitions. The chromatic allocation matrix for the bottling infrastructure is shown in Table 5.1.

Table 5.1: Correspondence Between Filling Line and Colour

Target Location	Visual Identifier
Production Line 1	Red
Production Line 2	Orange
Production Line 3	Blue
Production Line 5	Purple
Production Line 6	Black

Line-based colour assignment ensures that any misplaced component is immediately noticeable, passively preventing errors before mechanical setup.

5.5 Marker Fixation and Positioning Criteria

Effective implementation of the visual management standard calls for clear criteria for chemical integration. In addition to clear alphanumeric and colour structures, the system must maintain long-term adhesion and optimal visibility during normal operations. A detailed framework was established to guide fixation methods, environmental resistance, and marker placement across the bottling equipment.

5.5.1 Material Criteria

To guarantee compliance with the rigid safety standards for material selection in the food and beverage industry and to meet the specified functional design requirements, additive manufacturing using Polyethene Terephthalate Glycol was chosen to produce format parts markers. A comparative economic and operational analysis demonstrated that this method is more advantageous than traditional procurement approaches. Industrially fabricated alternatives currently in use incur acquisition costs exceeding 10 times the estimated unit cost of the 3D-printed markers. Additionally, this manufacturing approach substantially reduces supply chain lead times. The creation of a centralised digital repository for printable computer-aided design files ensures that the lead time for replacement parts depends only on the printing process, which is typically optimised to less than 1 hour per part. In contrast, conventional procurement from external suppliers imposes considerable constraints, including minimum order quantities and delivery lead times exceeding one week, consequently extending the period during which components stay unidentified.

5.5.2 Adhesion and Fixation Methods

Due to the varied mechanical profiles, surface finishes, and geometries of handling parts, the attachment strategy relies on a highly adaptable chemical bond. Mechanical fasteners are used solely when the parts do not allow for a simplified adhesive solution, as is the case for the brushes assembly.

To determine an optimal chemical solution to bond the identifiers to the machinery in a near-permanent manner, an empirical study was conducted in collaboration with 3M, a specialist in structural adhesives. Two distinct high-performance adhesives were selected and subjected to accelerated lifetime testing on physical component mock-ups, as seen in Figure 5.13.



Figure 5.13: Tested Mock-ups on an Unusable Part

To replicate real-world degradation, bonded assemblies underwent a rigorous test protocol consisting of repeated immersion in industrial washing with caustic agents. Each test cycle comprised 40 minutes of submersion, and a total of 14 cycles were conducted over a two-week period.

Based on the outcomes, the adhesive “3M VHB GPH060GF” was adopted as the facility standard for all polymer and metal substrates, providing a permanent chemical bond robust enough to withstand operational stresses.

5.5.3 Placement Logic and Installation Guidelines

To eliminate setup delays caused by search waste, each marker must be placed following a strict, predictable logic. Figure 5.14 shows precisely that, where the ideal placement is highlighted in yellow and the safe zone is highlighted in red. Identifiers must be permanently attached directly to active-handling parts, not to general storage racks or passive machine frames, to ensure line traceability throughout the changeover process.

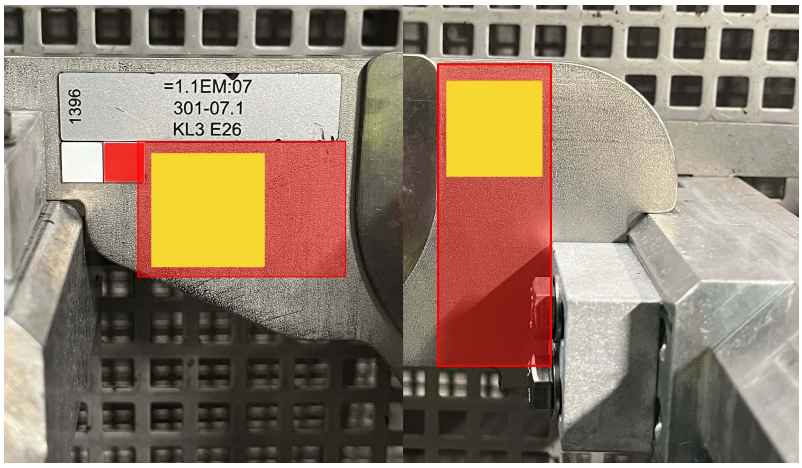


Figure 5.14: Example of a Dedicated Positioning

The structural positioning guidelines are governed by the following operational constraints:

- **Dedicated Part Positioning:** Markers must be placed within specific, designated structural zones on machine parts. These legal mounting zones are predefined to ensure the identifier does not interfere with the machine’s mechanical envelope. It must not impede the movement of mechanical assemblies, fluid channels, or product contact zones, thereby preventing operational friction or mechanical wear.
- **Line-of-Sight Optimisation:** Indicators must be positioned so that they are fully visible and unobstructed when the component is fully installed and operational within the machine aggregate. This requires the markers to face the operator’s natural line of sight, allowing instantaneous verification of component compatibility before the line is restarted.

To preserve consistency and prevent variability during maintenance and repairs, a standardised installation workflow was established. Before bonding, the component surface must be thoroughly degreased and cleaned to remove residues, oils, or caustic films that could affect adhesion.

The installation standard also sets rules for managing space on specialised machinery. For complex equipment like KHS and Krones gripper heads, where space is limited, the framework

may require relocating existing manufacturer data plates. This ensures standardised markers occupy the primary visual zone without exceeding tolerances.

5.6 Sustainability of the Standardised System

To ensure long-term viability and prevent a return to high variability, the physical implementation was formalised through a new technical Work Instruction. This document functions as the facility's single source of truth, governing implementation versions, geometric definitions, anchoring specifications, and alphanumeric mappings. The Work Instruction is regularly reviewed and updated, with biannual audits and additional revisions triggered by new SKUs, equipment changes, or process updates, to ensure the standard remains current and responsive to operational needs.

Beyond the standardisation of the physical assets themselves, the documentation was designed to support process continuity, knowledge retention, and personnel training. By formalising the codification logic and installation criteria in structured industrial documentation, the system decreases reliance on tacit operator knowledge and facilitates onboarding for newly recruited personnel.

Additionally, the standardised documentation aids future continuous improvement initiatives by creating a stable operational baseline from which component inconsistencies and organisational deviations could be systematically identified and corrected. The existence of a centralised reference framework also facilitates periodic auditing activities, enabling supervisors to assess compliance with the defined standards.

The complete documentation, detailing the implementation designs, the line-specific chromatic matrices, the centralised alphanumeric symbol registries, and the exact physical layouts across the machine aggregates, is presented in Appendices E, F and G to serve as the definitive guideline for future operational management and continuous improvement initiatives. The Appendices mentioned are written in Portuguese, since these Work Instructions are for in-house use.

5.7 Synthesis of the Standardisation Model

The physical standardisation model developed in this chapter establishes an organised, shift-invariant baseline across the shop floor. By replacing legacy product-centric labels with a unified alphanumeric syntax and a line-specific chromatic Poka-Yoke matrix, the engineered architecture reduces physical search waste, cross-line component contamination, and operational ambiguity. Although these passive visual management structures create more stable conditions for preventing immediate alignment errors, optimising the broader changeover process requires dynamic, real-time procedural gating. To rigorously quantify the operational advancements enabled by this model, its systemic efficacy is evaluated alongside the digital framework prototype in Chapter 7. Building on this physical foundation, the following chapter introduces the custom digital changeover framework prototype, detailing its architecture, data-matching logic, and interactive execution sequencing to support the practical application of SMED principles.

Chapter 6

SMED Optimisation and Digital Framework Prototype

While the standardised physical components developed in this research reduced initial setup variability, the execution of format changeovers continued to depend on operator judgment and tacit knowledge. Standardised handling components alone were insufficient to fully stabilise the setup process, particularly in high-mix production environments characterised by frequent SKU transitions and complex equipment interactions.

6.1 Introduction to the Digital Changeover Framework

The application of conventional Lean tools in industrial settings demonstrated that static documentation and paper-based standard operating procedures were inadequate for sustaining targeted efficiency gains. Operational variability persisted across shifts, primarily due to differences in individual operator skill levels. Minor deviations from prescribed setup steps frequently resulted in "micro-stoppages" and delayed speed recovery, leading to significant annual capacity losses.

Furthermore, the absence of a consolidated operational support system led to procedural irregularities among production teams, increased cognitive workload during setup execution, and constrained the systematic externalisation of preparation activities prior to line stoppage. These management challenges were intensified by inconsistent adherence to standardised procedures and resistance to new operational routines, both of which impeded process harmonisation. Consequently, production teams often relied on informal practices and individual adaptation, impeding the integration of universal best practices and the sustainability of continuous improvement. These limitations directly conflicted with the principles of SMED, which aim to reduce equipment downtime by separating, simplifying, and optimising setup operations.

Traditional standardisation models rely on experiential, tacit knowledge transferred between operators, which exposes production lines to process variation. To address this dependency and eliminate mental switching delays, a digital changeover framework prototype was conceptualised

and engineered by the author. This functional prototype was developed using the Python programming language within the Visual Studio Code integrated environment. This framework functions as a dynamic standardisation engine, translating complex changeover matrices into clear, real-time instructions to ensure reproducible setups across all teams. As illustrated in Figure 6.1, the user selects the Filling Line and the Team, enters the SKUs number, and selects the desired machine to start the guided setup.

The digital framework interface was deliberately engineered in Portuguese, as it represents the native operating language of the shop-floor personnel. Aligning the software vocabulary with the operators' daily linguistic reality minimises semantic ambiguity and eliminates potential language barriers.

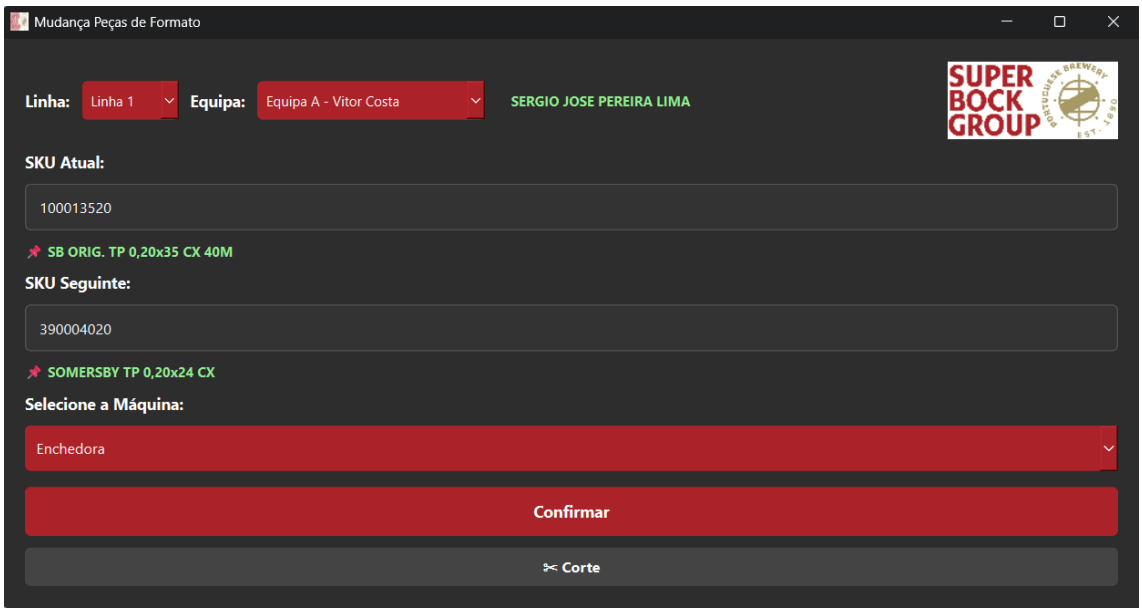


Figure 6.1: Main Window for Data Input

6.2 Principles Applied to the Changeover Process

The proposed framework integrates multiple optimisation mechanisms grounded in the principles of the SMED methodology. These mechanisms are incorporated into the application architecture to assist operators during the preparation, execution, and verification phases of format changeovers. The subsequent subsections outline the main functionalities implemented and their respective roles in minimising setup-related inefficiencies.

6.2.1 Separation of Internal and External Activities

One of the primary principles of the SMED methodology embraces the systematic separation of setup activities into internal and external operations. Converting internal tasks into external ones is one of the primary engineering mechanisms for lowering effective setup duration.

Historically, on the bottling lines studied, many preparatory tasks were started only after production stopped, even though they did not require machine downtime. These tasks included gathering format parts, retrieving consumables, confirming the availability of setup materials, and arranging assemblies. This behaviour unnecessarily extended downtime and increased operator movement during essential setup phases.

To mitigate these operational deficiencies, a comprehensive audit and compilation of all sequential steps required to replace the mechanical components across the machinery included in this study were conducted. The data collection process involved direct observation of numerous format changeovers, capturing variance across machine zones, component profiles, and changeover types. This methodology ensured that all operational scenarios were documented, effectively establishing worst-case boundaries that encompass the widest possible range of tasks.

Following the collection phase, the data analysis was structured according to the SMED methodology detailed in Chapter 3, focusing on the cataloguing of all macro and micro-steps required to modify the machine as a single entity, the strict separation between internal and external operations, and the systematic externalisation of eligible tasks. The macro-sequence of operations required to transform the analysed machinery is detailed in Appendices H and I, which is accompanied by a Gantt chart that illustrates the precise timing, parallel workloads, and sequencing dependencies throughout the changeover window.

With regard to the digital framework prototype, the setup process is systematically partitioned into three distinct operational phases: pre-changeover preparation, internal setup execution, and post-changeover stabilisation. This structural division provides absolute clarity on which tasks can be externalised and completed before equipment stoppage.

Consequently, this minimisation of internal setup duration maximises concurrent engineering workflows and guarantees that production assets are brought to a standstill exclusively for operations that strictly require a halted production line.

6.2.2 Reduction of Operational Movement and Search Waste

One major inefficiency identified was excessive operator movement among machines, component storage, and preparation zones. Without structured sequencing, operators often had to stop setups to search for specific format parts, confirm compatibility, or fetch missing tools.

The digital framework was designed to minimise unnecessary operator displacement through guided operational sequencing and centralised preparation logic. By enforcing a logical progression of tasks grounded in spatial proximity and mechanical dependencies, the system ensures that all components required for a specific machine section are handled in a single, uninterrupted sequence.

The integration of standardised visual instructions and stepwise task sequences reduces cognitive demand and switching waste during changeovers. For instance, when transitioning between two SKUs with different back-label configurations on the labeller, the framework automatically highlights the appropriate label station and displays the relevant image and adjustment settings. This eliminates the need for operators to reconcile product codes or calibrate machinery from

memory. By providing precise requirements in real-time, the application enables operators to focus on execution, thereby reducing setup time and enhancing line stability.

6.2.3 Standardisation of Setup Sequences

To mitigate the previously identified operational deficiencies detailed in Chapter 4, which primarily arose from individual shift teams developing localised, non-standardised mechanical adjustment approaches that led to erratic velocity ramp-ups and accelerated equipment wear, the digital framework systematically standardises setup sequences, thereby ensuring consistency in procedures and practices and eliminating reliance on tacit knowledge.

The baseline data utilised to construct these standardised pathways was acquired through an extensive empirical collection process, as established in the preceding sections. This involved multi-turn direct observations of changeover procedures and comprehensive technical consultations with shop-floor operators, team leaders, and engineers. The resulting dataset was rigorously cross-referenced and filtered to isolate the most efficient method of execution for each distinct procedural step. Consequently, this synthesis ensured that the developed standard operating sequences were fundamentally anchored to validated best practices.

Furthermore, by integrating the re-engineered component identification with the digital framework, a highly deterministic and linear operational sequence is achieved. This combined approach ensures that critical setup information is transmitted with absolute clarity and zero procedural ambiguity. To facilitate this visual management strategy, bespoke mechanical layout diagrams were developed for the specific machinery configurations of each production line within the designated equipment groups, and the assembling and disassembling order, as illustrated in Figure 6.2.

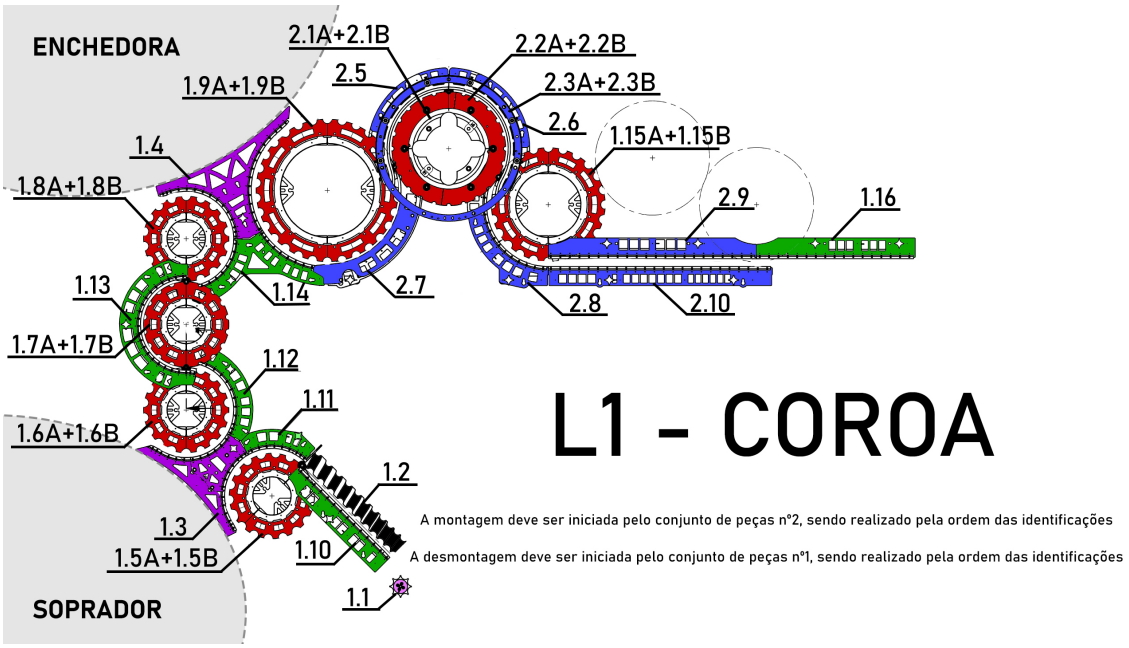


Figure 6.2: Machine Diagram of the Filler, for Line 1, Using Crown Capsule

By embedding these optimised setup trajectories directly into the tool's core computational logic, all operating teams are programmatically guided through a uniform operational sequence. The system serves as the single source of truth and the authoritative mechanism for bottling line configuration. By excluding human subjectivity and procedural ambiguity through a deterministic, digitally managed workflow, the framework forms the technical infrastructure required to minimise shift-to-shift operational variability.

6.3 Architecture of the Digital Framework

To implement these architectural requirements on the shop floor, the model is divided into four primary software sub-modules responsible for core database queries, equipment dependencies, time-estimation equations, and preventative care tracking. The following subsections describe the specific logic and functional constraints designed for each of these structural dimensions.

6.3.1 SKU Comparison Logic

The application's core function is an automated product comparison engine. By analysing the codes of the current and next product, the system automatically identifies which operational variables need adjustment for the setup.

The comparison logic assesses multiple product attributes stored within an embedded relational database, including bottle geometry, liquid type, cap specification, label configuration, neck label presence, back label configuration, and secondary packaging format, as shown in Figure 6.3. As the operator enters SKU codes, the system executes real-time database queries to return the exact product nomenclature, eliminating data-entry errors.

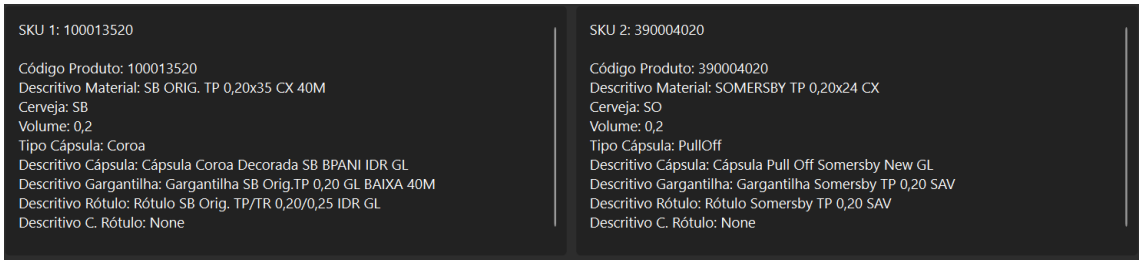


Figure 6.3: SKU Comparison Between On-Course Production and Next Product

Through automated analysis, the framework identifies only the variables that differ between product references, excluding unnecessary setup actions and streamlining decision-making. This automation eliminates the need for manual interpretation of product sheets and reduces the risk of setup errors caused by overlooked differences, providing a more consistent basis for operational decisions.

However, it should be acknowledged that automation relies on the accuracy and completeness of the underlying product database, so any lapses in data updates or unanticipated product variations could limit the system's effectiveness and lead to overlooked setup requirements. To

mitigate these data reliability limitations, a regular schedule for database maintenance and review has been instituted, ensuring the prompt incorporation of new SKUs and updates to existing product attributes. Feedback regarding missing, outdated, or incorrect data is systematically collected from frontline operators and supervisors. Upon receiving a submission, the shift supervisor first reviews the feedback to verify its validity and relevance. Verified entries are then forwarded to the designated process engineer responsible for this data management, who investigates the report and implements necessary database corrections or attribute updates. Periodic audits and cross-functional reviews are conducted to ensure the robustness of this process and maintain data integrity over time. Nevertheless, the framework's automation underpins automatic sequence generation, changeover classification, and time estimation, thereby streamlining and standardising the changeover process.

6.3.2 Machine and Line Specific Changeover Logic

The bottling infrastructure at *Leça do Balio* consists of specialised, diverse machines, each having unique setup requirements and adjustments. The digital framework contains dedicated logic for the machines encompassed in this project: Filler and Crowner, and Labeller. The Pasteurizer is not included because there are no changes to the machine other than software.

For the bottle Filler, the logic centres on hygiene, vial height adjustments based on bottle size, and liquid compatibility. The Labeller module uses highly detailed, component-specific logic. Since the Labeller has multiple stations, the application aggregates the required changes for body, neck, and back labels. If only the back label changes, the system isolates that station and leaves others unchanged.

Furthermore, the specific architecture of each production line must be integrated, as heterogeneous manufacturing assets introduce distinct operational variables throughout the bottling hall. Distinct lines feature equipment sourced from different manufacturers. Moreover, even when assets share a common manufacturer, significant physical and functional variations exist between installations. For illustrative purposes, the Fillers on Line 3 and Line 5 lack a secondary capping module, whereas the others do not. Consequently, the digital framework must dynamically adapt its sequential logic and technical instructions to accommodate these line-specific hardware constraints.

6.3.3 Automatic Changeover Classification and Time Estimation

Once the system processes product differences using machine logic, it assigns each changeover a specific letter code indicating the scope of the required intervention, as shown in Figure 6.4. Simultaneously, it runs a deterministic time estimate based on changed components rather than historical data.

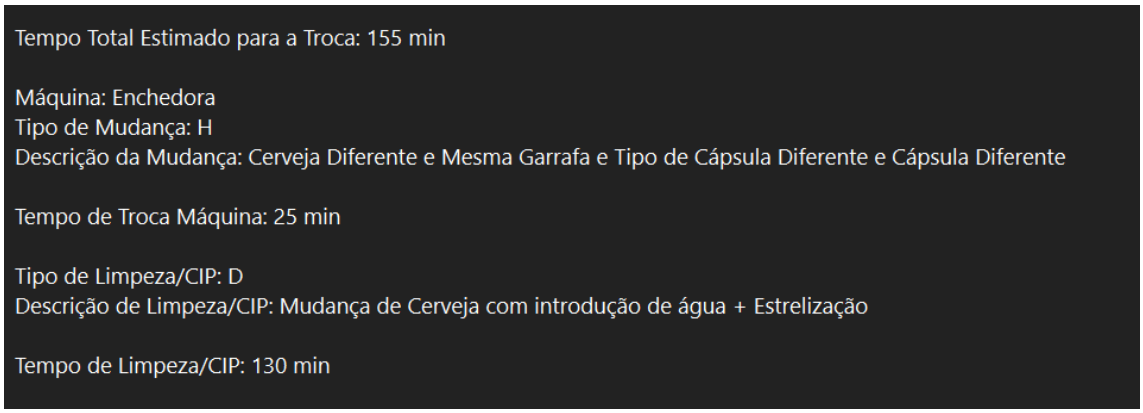


Figure 6.4: Changeover Classification For a Setup of the Filler

For example, on the labelling machine, the total estimated time is calculated as the sum of the standard times assigned to each label aggregate's changeover. This total is presented to the operator, broken down into mechanical changeover time, cleaning or CIP time, and overall target time.

6.3.4 Support for Autonomous Maintenance Activities

During the mapping and standardisation of setup activities, several recurring maintenance tasks were identified as critical to equipment reliability and post-changeover stability. These activities include lubrication points, inspection routines, cleaning procedures, and verification of mechanical conditions.

To ensure consistent execution, the digital framework embraces maintenance-related instructions directly within the operational workflow, presenting these activities at the appropriate stage of the changeover process. By integrating basic maintenance tasks into standardised work procedures, the system encourages the embracement of autonomous maintenance practices and contributes to improved equipment condition, reduced "micro-stoppages", and enhanced operational stability.

6.4 Guided Changeover Execution System

The implementation of the standardised changeover trajectory depends on a dynamic human-machine interface that guides operators throughout the re-engineering process. Instead of providing a static list of instructions, the system operates as a phase-gated wizard that responds to real-time shop-floor activities and technical dependencies, converting the underlying data-matching logic into sequential work steps. The subsequent subsections outline the interactive tracking mechanisms and embedded visual aids that constitute this system.

6.4.1 SMED-Based Phase Structure

To operationalise the SMED philosophy within the bottling environment, the setup workflow implemented in the application was structured into three sequential execution phases, as shown in Figure 6.5.

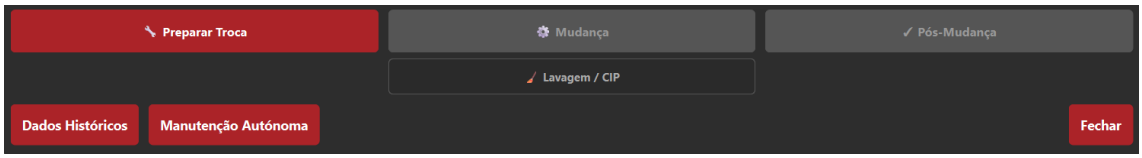


Figure 6.5: Setup Workflow

The first phase, designated as *Preparar Troca*, contains external setup activities that can be completed while the production line remains operational. These tasks primarily involve preparing format components, verifying setup materials, and staging consumables required for the subsequent SKU.

The second phase, designated as *Mudança*, corresponds to the internal setup operations performed during equipment stoppage. This phase includes the physical replacement of format parts, machine adjustments, and aggregate-specific configuration procedures.

Finally, the third phase, *Pós-Mudança*, includes stabilisation and verification activities performed after line restart. These tasks include quality verification, operational confirmation, storage of components, and final adjustments intended to stabilise production conditions and minimise post-changeover "micro-stops".

Furthermore, the architectural design of the digital framework entails a strict procedural gatekeeping mechanism, whereby the internal execution phase remains locked until all pre-changeover preparation tasks have been fully validated. This sequential constraint structurally enforces the completion of external operations before line stoppage, thereby preventing premature downtime and ensuring strict adherence to the prescribed methodology, guaranteeing parallel work is fully optimised.

6.4.2 Interactive Task Sequencing and Progress Evaluation

Within each operational phase, tasks are organised into specialised step groups presented via an interactive checklist interface, as seen in Figure 6.6.

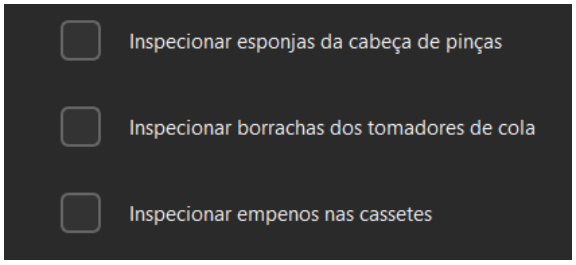


Figure 6.6: Interactive Checklist Interface

To optimise user navigation, a numbered navigation strip is anchored at the top of the interface, as seen in Figure 6.7, allowing operators to visualise the entire progression and jump directly to specific task clusters. An integrated progress bar dynamically calculates the percentage of completion for the active phase based on the number of completed sub-steps.

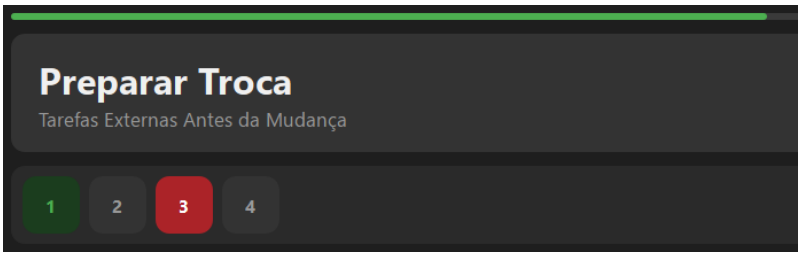


Figure 6.7: Navigation Strip

Each sub-step is associated with a digital checkbox, so when all sub-steps within a group are validated, the application marks the group as complete and advances the view to the next group. To reduce visual and cognitive fatigue, the interface employs collapsible accordion logic. Step groups identified as less important to the setup by the comparison engine, based on the current SKU delta, are automatically collapsed and display only a notification badge indicating the sub-step count. This approach ensures that operators receive only functional, context-specific information and prevents experienced workers from being overwhelmed by unnecessary detail.

6.4.3 Visual Work Instructions and Embedded Media

One of the most potent features of the framework is the complete elimination of text-heavy instruction manuals through embedded visual media. Some step groups in the guided wizard are mapped to specific visual assets stored in the application directory, as shown in Figure 6.8.



Figure 6.8: Embedded Visual Media

When an operator selects a task, the interface dynamically populates images illustrating the exact mechanical component, the correct tool orientation, or the specific scale setting required for the target SKU.

For complex manual procedures, the framework provides short, auto-playing video loops. This immediate visual feedback eliminates ambiguity, functions as a continuous on-the-job training tool, and standardises execution across operators with varying experience levels.

6.5 Auxiliary Decision-Support Tools

To reduce non-productive downtime and raw material losses commonly associated with product handovers, the application incorporates specialised utilities within its interface. These modules enhance the framework by automating engineering calculations that previously depended on estimations. By standardising sanitation procedures and determining precise inventory depletion targets, these decision tools support process stability and minimise resource waste.

6.5.1 CIP Decision Logic

Sanitation procedures in a brewery environment are critical, yet manual interpretation of cleaning requirements commonly leads to excessive downtime or quality risks. The digital framework handles this by embedding an automated CIP decision matrix within the filling machine operational module.

When a changeover involves a shift in fluid type, the logic analyses the chemical compatibility and flavour profiles of the outgoing and incoming liquids. It automatically queries an internal lookup table to determine the exact cleaning procedure required, such as a hot-water flush, a caustic wash, or a full sanitisation cycle.

The digital framework presents the required procedure in clear language and automatically accounts for the standard CIP duration when estimating overall changeover time. This automation removes human interpretation from the quality-assurance loop, assuring safety compliance whilst preventing unnecessary over-cleaning.

6.5.2 Consumable Cut Calculator

To optimise production costs and minimise material waste, the framework includes a specialised utility, the Consumable Cut Calculator, displayed in Figure 6.9. During a format changeover, significant material waste can occur if raw consumables, such as bottles, caps, labels, or product within the pipelines, are not stopped before the production batch is exhausted.

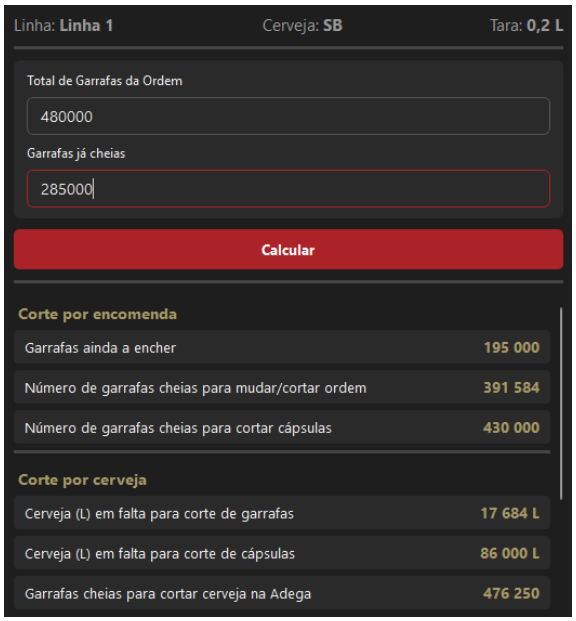


Figure 6.9: Consumable Cut Calculator Output

The operator enters the total target volume for the active production order and the number of units already filled. The calculator automatically processes this data against the specific volumetric consumption rates, physical line speeds, and capacity of the active filling line.

The system then outputs critical performance parameters, including the remaining target units, the exact bottle supply cut point for the de-palletiser operator, the capsule supply cut point for the capping mechanism, the number of labels needed to be prepared in advance and the beer supply cut point. This latter parameter calculates the exact volume remaining in the overhead filling bowl and supply line to prevent discarding excess product.

6.6 Traceability and Administrative Features

Although the primary objective of the framework is to provide operational guidance, it also functions as a data-logging hub for supervisory oversight, as shown in Figure 6.10. This data layer enables full traceability, allowing precise identification of performance trends by linking setup durations to specific filling lines, team compositions, machines, SKUs, and setup types. Comprehensive traceability supports targeted process improvements, facilitates root-cause analysis of deviations, and enhances accountability, thereby contributing to more effective continuous improvement initiatives.



Figure 6.10: Historical Data Window

To safeguard the operational database from unauthorised modifications, an administrative gateway is integrated via a secure password prompt triggered by interacting with the corporate branding elements. Once authenticated, engineering and administrative personnel gain access to a dedicated backstage interface. This view exposes the raw database records for all SKUs, displays low-level machine-comparison diagnostics, and provides utilities to append or modify SKU attributes, as seen in Figure 6.11, as new products are introduced to the company's portfolio, guaranteeing long-term scalability of the digital tool.

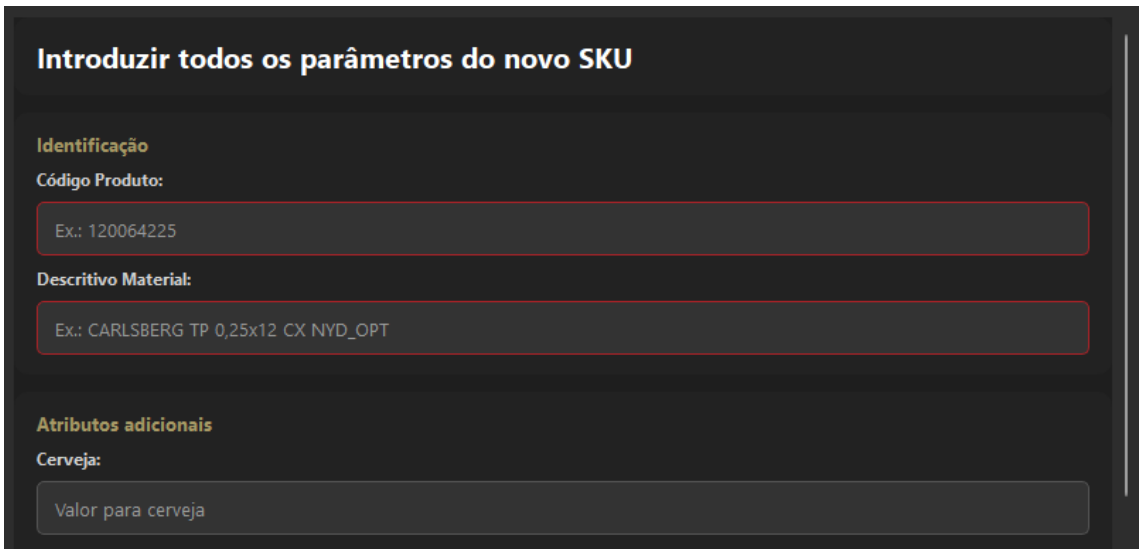


Figure 6.11: SKU Adding Feature

6.7 Synthesis of the SMED Optimisation and Proposed Digital Framework

The digital changeover framework engineered in this chapter completes the operational component of the "Lean 4.0" intervention by transforming static standard operating procedures into a dynamic, algorithmic single source of truth. By combining automated SKU comparison logic,

machine-specific step-gating, visual work instructions, and auxiliary decision-support tools, the software interface systematically mitigates switching delays and enforces adherence to standardised procedures. A full industrial rollout on the shop floor was not possible within the project time frame, primarily because the system requires deployment on industrial tablets to be readily accessible to operators at the filling lines. However, while this digital architecture establishes the computational infrastructure for consistent changeover execution, its capacity to recover annual production volume must be validated. With the design and development phases concluded, the following chapter utilises the active 2026 Year-To-Date (YTD) historical dataset to perform a rigorous performance evaluation, quantifying the resultant reductions in technical delays, shift variability, and velocity ramp-up curves.

Chapter 7

Results and Discussion

This chapter presents a comprehensive evaluation of the integrated physical standardisation system and the digital framework prototype developed in this research. To assess the technical efficacy of these interventions within the high-speed glass bottling hall at the *Leça do Balio* production unit, a quantitative mathematical simulation using historical operational data is performed. As the digital architecture is currently at a functional prototype stage, a sensitivity analysis is conducted to establish robust, shift-invariant performance boundaries and to project capacity-recovery thresholds in alignment with the dissertation objectives.

7.1 Projected Impact on Performance

To provide a data-driven justification for the engineered models prior to long-term plant implementation, historical data compiled in Power BI was filtered to focus on OEE losses and their decompositions.

7.1.1 Methodological Prioritisation of Setup Indicators

Achieving a sustainable reduction in global setup overheads requires a clear operational distinction between Planned Changeover Time (TMP) and Delayed Setup Time (TAM). Although the primary objective of a SMED intervention is to compress the standardised target baseline (TMP), traditional Lean implementations frequently fail when applied directly to unstable processes.

The sum of TMP and TAM constitutes the total actual setup time on the shop floor. Methodologically, optimising the theoretical standard while the process exhibits high operational volatility (TAM) introduces significant analytical noise. Therefore, this study adopts a sequential optimisation strategy: immediate delays (TAM) are systematically eliminated to stabilise the process and establish a reproducible operational baseline. Once stability is achieved, a predictable foundation enables future subsequent iterative cycles focused on compressing the standardised changeover tasks (TMP).

To fully minimise packaging downtime, it is important to also look beyond just finishing the mechanical changeover. Instead, it is also necessary to focus on how quickly the production line returns to full speed, measured by the Ramp-up Time (TAR).

7.1.2 Data Alignment and Baseline Reconciliation

To ensure alignment with current operational conditions and enhance the robustness of the engineering conclusions, the simulation framework utilises updated YTD data from the active 2026 production cycle. The selection of 2026 YTD data over the 2025 aggregate is justified by its direct representation of present operational practices, equipment configurations, and personnel dynamics, which may have changed since the previous year. Leveraging the most recent and contextually relevant dataset allows the model to account for process improvements, technology upgrades, or changes in production scheduling that are not reflected in historical aggregates. Employing these precise metrics ensures that projected capacity recovery models are grounded in current operational constraints, thereby strengthening the validity of the post-implementation conclusions.

The initial industrial proposal for this dissertation established a changeover downtime baseline of approximately 6.00% of annual production capacity across the glass bottling lines. However, for the year 2026, the changeover downtime was extracted from Power BI as 4.55%, calculated as the sum of the TMP and TAM.

Despite the increased difficulty of optimisation due to the shift to a lower baseline index, the strategic objective of recovering 0.50% of annual line capacity remains unchanged. Operating within a compressed baseline of 4.55% and a target ceiling of 4.05%, rather than the previously considered 6.00% to 5.50% spread, forces the developed framework to operate under tighter operational tolerances. This conservative approach ensures that the resulting capacity gains represent a genuine stabilisation of line floor dynamics rather than a statistical artefact of outdated 2025 data sets.

7.1.3 Characterisation of Historical Data

Operational delays and ramp-up periods vary depending on the type of setup. These factors depend on the specific nature of the SKU transition. For example, minor changes such as updating a product's back label can be made dynamically almost without stopping the line, allowing these running changeovers to avoid typical post-setup acceleration phases. It is important to distinguish between major structural setups that require mechanical re-tooling of key equipment and minor adjustments that have minimal impact on line availability and ramp-up efficiency.

The empirical baseline utilised for the simulation comprises a facility-wide dataset spanning a 172-day production window. This dataset tracks all Key Performance Indicators (KPIs) under analysis, along with their percentage and time equivalents. These metrics were gathered from Power BI and are detailed in Table 7.1. The productive time exceeds the number of hours in 172 days because it is calculated as the sum of all glass lines' productive time, being the same as applied to the indicators.

Table 7.1: Analysis of Production and Lost Times, by Typology

Typology	**Entries**	**%**	**Time (Hours)**	**Time (Min)**	**Time/Occ. (Min)**
TMP	488	3.29%	422.2	25,333	51.91
TAM	379	1.26%	161.7	9,702	25.6
TAR	115	0.46%	59.0	3,541	30.79
Productive Time	—	100.00%	12,833	770,000	—

7.1.4 Identification of Addressable Causes

A programmatic root cause analysis was conducted on the recorded delay entries to isolate the specific operational variables that this thesis addresses.

The granular decomposition of the cumulative delayed setup duration from the dataset is detailed in Table 7.2.

Table 7.2: Decomposition of Historical TAM Dataset

Programmatic Root Cause Category	**Count**	**Duration (min)**	**Weight (%)**	**Addressable Status**
1. Primary Retooling & Component Exchange	213	3,506.74	36.14%	Yes (Packaging)
2. Generic Reference/Product Switching	24	2,048.71	21.12%	Yes (Packaging)
3. Mechanical Calibrations & Tuning	98	1,907.43	19.66%	Yes (Packaging)
4. CIP & Fluid Line Sanitation Cycles	21	1,279.41	13.19%	No (Production)
5. Ancillary Material Logistics	16	362.54	3.74%	No (Logistics)
6. Upstream Supply & Process Waiting	3	224.77	2.31%	No (Production)
7. Secondary Packaging & Robotics	2	180.76	1.86%	No (Downstream)
8. Workforce Competency & Handover	1	101.75	1.05%	Yes (Packaging)
9. Tool Availability & Staging	1	89.89	0.93%	Yes (Packaging)
Global Recorded TAM Profile	**379**	**9,702**	**100.00%**	

The sum of the durations for Categories 1, 2, 3, 8, and 9 defines the total control boundary for this research, yielding a $TAM_{addressable}$ of 78.9% (7,654.52 minutes). In contrast, Categories 4, 5, 6, and 7 are excluded from the addressable scope because their root causes lie outside the Packaging Department's direct operational control. These categories represent delays due to upstream production processes, external cleaning and sanitation managed by other departments, plant-wide logistics constraints, and downstream automation factors. As these variables are managed by separate functional teams or depend on systemic infrastructure beyond the scope of this study's interventions, their inclusion would compromise methodological rigour and the validity of the results. Accordingly, these excluded categories constitute a $TAM_{unaddressable}$ value of 21.1% (2,047.48 minutes), establishing a clear and transparent boundary for the impact analysis.

A root cause analysis was also conducted on the 115 recorded TAR entries to isolate the specific operational variables that this thesis addresses. Following the same filtration rules used for the setup analysis, downstream secondary packaging adjustments (e.g., cardboard wrap units and box packers) and upstream quality audits/sterilisations governed by the laboratory are classified as external constraints.

The decomposition of the cumulative delayed ramp-up duration from the active dataset is detailed in Table 7.3.

Table 7.3: Decomposition of Historical TAR Dataset

Programmatic Root Cause Category	**Count**	**Duration (min)**	**Weight (%)**	**Addressable Status**
1. Post-Setup Mechanical Fine-Tuning & Calibrations	77	1,950.05	55.07%	Yes (Packaging)
2. Upstream Quality Controls & Line Sanitation	13	875.21	24.72%	No (Production)
3. Extended Retooling & Consumable Inefficiencies	6	375.10	10.59%	Yes (Packaging)
4. Secondary Packaging & Downstream Adjustments	18	307.03	8.67%	No (Downstream)
5. Workforce, Clean-up & General Startup Constraints	1	33.62	0.95%	Yes (Packaging)
Global Recorded TAR Profile	**115**	**3,541**	**100.00%**	

Summing the durations of Categories 1, 3, and 5 yields the total control boundary for the ramp-up phase, resulting in a $TAR_{addressable}$ of 66.61% (2,358.76 minutes). Conversely, Categories 2 and 4 depend on external departments or secondary downstream assets, forming a $TAR_{unaddressable}$ of 33.39% (1,182.24 minutes) that remains an irreducible baseline constant.

7.1.5 Scenario-Based Impact Assessment

The sensitivity analysis evaluates the global reduction of delayed setup thresholds and delayed ramp-up times by applying two discrete compliance limits exclusively to the $TAM_{addressable}$ and the $TAR_{addressable}$.

7.1.5.1 Conservative Scenario

This boundary assumes a partial floor adoption rate of 50% of the proposed improvements across the operating teams, due to cultural inertia or inconsistent adherence to digital work instructions. The remaining addressable overhead is formulated as:

$$\text{TAM}_{\text{addressable remaining}} = \text{TAM}_{\text{addressable}} \times (1 - 0.50) = 39.45\% \tag{7.1}$$

Adding the fixed $\text{TAM}_{\text{unaddressable}}$ yields the projected operational delay coefficient, relative to baseline delays:

$$\text{TAM}_{\text{conservative}} = \text{TAM}_{\text{addressable remaining}} + \text{TAM}_{\text{unaddressable}} = 60.55\% \tag{7.2}$$

$$\text{TAR}_{\text{addressable remaining}} = \text{TAR}_{\text{addressable}} \times (1 - 0.50) = 33.305\% \tag{7.3}$$

Adding the fixed $\text{TAR}_{\text{unaddressable}}$ yields the projected ramp-up delay coefficient, relative to baseline delays:

$$\text{TAR}_{\text{conservative}} = \text{TAR}_{\text{addressable remaining}} + \text{TAR}_{\text{unaddressable}} = 66.695\% \tag{7.4}$$

This compression reduces the historical TAM from 1.26% down to 0.76% and the TAR from 0.46% to 0.31%, relative to the nominal production window.

7.1.5.2 Ideal Scenario

This boundary assumes a 100% compliance rate across all packaging shifts, in which step-gated digital checklists and localised tool staging eliminate all addressable packaging-delay modes. In practice, completely eliminating these inefficiencies is unrealistic due to resistance to change, imperfections in the proposed improvements, external failure points, and other factors. However, simulating this ideal scenario serves as a useful benchmark for quantifying the maximum potential for improvement, regarding the baseline delays:

$$\text{TAM}_{\text{addressable remaining}} = \text{TAM}_{\text{addressable}} \times (1 - 1.00) = 0.00\% \tag{7.5}$$

$$\text{TAM}_{\text{ideal}} = \text{TAM}_{\text{addressable remaining}} + \text{TAM}_{\text{unaddressable}} = 21.1\% \tag{7.6}$$

$$\text{TAR}_{\text{addressable remaining}} = \text{TAR}_{\text{addressable}} \times (1 - 1.00) = 0.00\% \tag{7.7}$$

$$\text{TAR}_{\text{ideal}} = \text{TAR}_{\text{addressable remaining}} + \text{TAR}_{\text{unaddressable}} = 33.39\% \tag{7.8}$$

This compression minimises the operational delay profile to its technical limit, reducing the TAM from 1.26% down to 0.26% and the TAR from 0.46% to 0.16% relative to the nominal production window.

7.1.5.3 Adoption Threshold Analysis

To establish the precise operational boundary at which the combined physical standardisation model and digital changeover framework fulfil the project's success criteria, a continuous parametric simulation was performed. Instead of assessing discrete compliance limits, this analysis considers the workforce adoption rate (α, where $0\% \leq \alpha \leq 100\%$) as a continuous independent variable. By modelling the mathematical variations in TAM and TAR derived from the equations presented earlier, the minimum procedural compliance threshold required to meet the capacity targets can be identified.

Continuous evaluation of the operational tracking curves yields significant insights into the structural dynamics of the proposed solutions. As shown in Figure 7.1, which depicts the continuous decay of addressable waste, the linear optimisation slope for TAM shows a greater response magnitude than that for TAR. This outcome results from the mathematical structure of the baseline datasets. Since the unaddressable constant for setup delays is much smaller than the corresponding threshold for velocity recovery, a larger proportion of the TAM is susceptible to packaging standardisations. Therefore, any increase in workforce compliance yields a more substantial systemic reduction in TAM profiles than in TAR profiles.

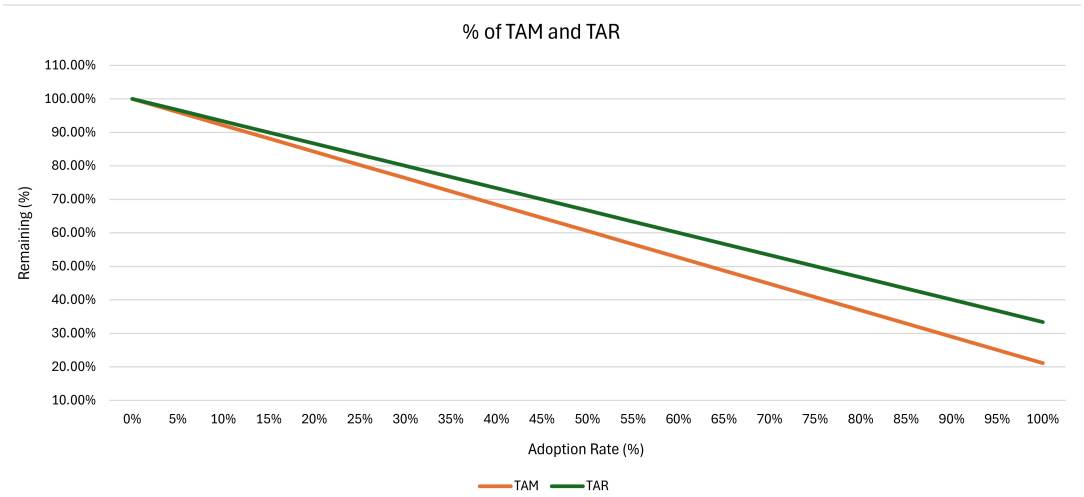


Figure 7.1: Remaining Percentage of TAM and TAR by Adoption Rate (%)

Translating these localised savings into global efficiency metrics, relative to absolute annual productive time, highlights the framework's significant impact. As indicated in Figure 7.2, the primary strategic objective of recovering 0.50% of global line capacity, requiring a reduction in total setup capacity overhead from 4.55% to a target ceiling of 4.05%, is achieved at a workforce adoption rate of $\alpha = 50\%$. This finding demonstrates that the main capacity-recovery target can be attained even if cultural inertia or shift-rotation patterns restrict framework deployment to half of the Ideal Scenario, leading to achievable outcomes under the Conservative Scenario.

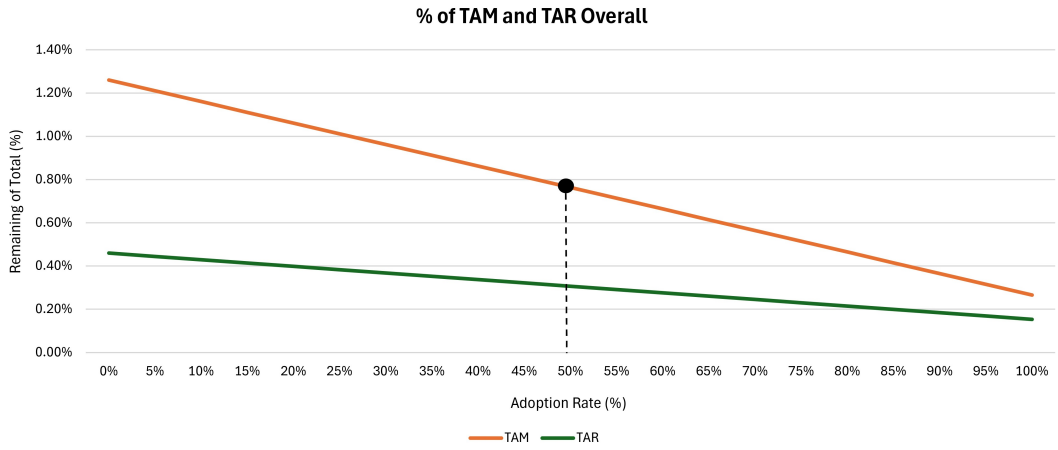


Figure 7.2: Remaining Percentage of TAM and TAR Overall by Adoption Rate (%)

In contrast, evaluating performance metrics on a per-occurrence basis, to directly represent the ramp-up time, reveals a significantly lower optimisation threshold for the speed-acceleration phase. As illustrated in Figure 7.3, which presents absolute durations per changeover event, the TAR curve reflects the continuous trajectory of average post-changeover ramp-up time. Given that the historical baseline is 30.79 minutes, the required reduction to meet the dissertation's velocity threshold is only 0.79 minutes. The analysis shows that an adoption rate of approximately 3.8% is sufficient to reduce the ramp-up curve below the 30-minute success criterion. This notably low threshold demonstrates that constraints managed by external functional teams do not impede the packaging department from rapidly achieving its speed stabilisation objective.

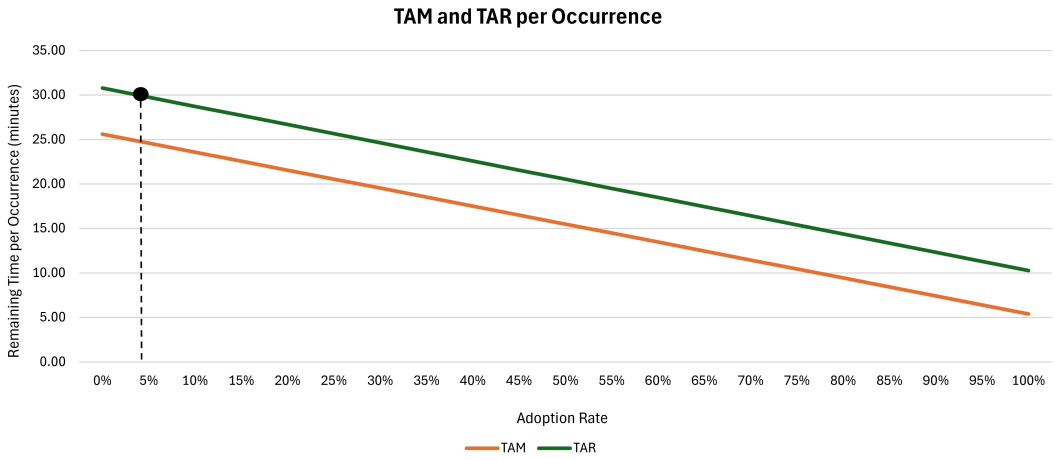


Figure 7.3: Remaining Time per Occurrence (minutes) of TAM and TAR by Adoption Rate (%)

7.1.6 Expected Reduction of Setup Delays

To verify compliance with the dissertation requirements established in Chapter 1, the proportional scenario gains are compiled against the baseline packaging indicators in Table 7.4.

Table 7.4: Global Performance Projection Matrix

Operational Indicator	YTD Baseline	Conservative	Ideal	Target
Addressable Packaging Reduction	0.00%	50.00%	100.00%	N/A
TAM Overhead	1.26%	0.76%	0.26%	N/A
TAR Overhead	0.46%	0.31%	0.16%	N/A
Global Setup Capacity Overhead	4.55%	4.05%	3.55%	**4.05%**
Ramp-up Overhead	30.78 min	20.74 min	10.71 min	**30 min**
Inter-Shift Procedural Variability	0.10%	0.05%	0.00%	**0.00%**

The mathematical modelling validates the following performance vectors:

- **Setup Capacity Overhead:** By compressing the TAM profile, the global setup time, which initially consumed 4.55% of annual production time, is reduced to 4.05% under the Conservative Scenario. Under the Ideal Scenario, the global setup overhead drops to 3.55%.
- **Post-Changeover Ramp-Up Curve:** The actions outlined in this dissertation provide the necessary guidance and standardisation to reduce the ramp-up time to 20.74 minutes under the Conservative Scenario. Under the Ideal Scenario, the ramp-up times are reduced to 10.71 minutes.
- **Eradication of Shift Variability:** Because the digital framework acts as a deterministic gatekeeper enforcing a linear task progression, manual trial-and-error variations are reduced to 0.00% under full adoption, standardising the operational cadence across all shift teams.

7.2 Qualitative and Organisational Benefits

Although the quantitative models in Section 7.1 demonstrate substantial capacity-recovery potential, the overall systemic value of the physical standardisation model and the digital framework prototype also includes significant qualitative and organisational transformations. These structural improvements directly address underlying sociotechnical barriers on the shop floor that have historically impeded operational stability.

7.2.1 Reduced Dependency on Tacit Knowledge

Before the proposed intervention, the operational quality and execution speed of setup changeovers depended heavily on the individual expertise and subjective practices of operating personnel. Implementing a standardised codification syntax and embedding setup steps within a centralised digital repository transfers this critical operational mapping from individual memory to the institutional domain. As a result, reliance on informal knowledge is eliminated, ensuring that format transitions are executed with consistent precision regardless of the team or operator assigned.

7.2.2 Acceleration and Optimisation of Personnel Training

The traditional uncodified training paradigm, which relied on oral transmission and trial-and-error adjustments during live operations, imposed significant cognitive barriers for newly recruited and temporary operators. The implementation of the guided changeover execution system serves as an on-the-job training mechanism. Less experienced operators receive context-specific visual feedback that details the precise tool orientation and mechanical scale coordinates required for the target SKU, thereby significantly reducing training time and mitigating cognitive fatigue.

7.2.3 Institutionalisation of Setup Standardisation

By integrating physical layout reorganisation, such as aggregate-centric *Pit-Stop Car* staging carts, with a rule-based digital gatekeeper, setup standardisation is actively enforced rather than passively recommended. Operators are required to complete all mandatory preparation steps in the prescribed sequence. This enforced operational pathway ensures that the most efficient, validated execution methods are systematically replicated across all lines, establishing a highly predictable production rhythm throughout the packaging hall.

7.2.4 Support for Autonomous Maintenance Practices

The mapping and optimisation processes conducted during this research enabled the integration of basic maintenance operations directly into the changeover workflow. Incorporating explicit checklists for localised lubrication points, component wear inspections, and mechanical condition verifications into the digital framework shifts basic maintenance into an autonomous, front-line routine. This cross-functional integration enhances machine care ownership, supports equipment longevity, and prevents micro-stoppages after restart.

7.2.5 Indirect Mitigation of Equipment Breakdown Time (TAV)

Beyond containing setup-specific indices, the stabilisation of retooling procedures indirectly mitigates the plant's overall breakdown log, categorised as TAV. In high-speed packaging infrastructures, a considerable proportion of mechanical failures and subsequent unplanned stoppages are caused by poor component fitment, incorrect component selection, or minor misalignments during changeovers. By replacing subjective operational habits with line-specific visual Poka-Yokes, the components' lifetime is increased. Consequently, the standardisation framework serves as a proactive asset-protection barrier, systematically reducing stress-induced component wear, minimising mechanical blockages post-restart, and indirectly reducing the cumulative annual duration of unplanned technical breakdowns (TAV).

7.2.6 Preservation of Organisational Knowledge

In high-mix manufacturing environments, commercial variations often necessitate rapid modifications to product consumables and SKU portfolios. The secure administrative gateway within the framework prototype offers a systematic approach for appending, modifying, and archiving machine parameters as new references are introduced. This capability transforms the changeover framework into a scalable, long-term organisational knowledge repository, preserving the facility's operational memory against personnel turnover or structural plant changes.

7.3 Synthesis of Results in the Context of the Research Objectives

The quantitative sensitivity simulations and scenario-oriented assessments in this chapter validate the technical efficacy of both the integrated physical standardisation model and the digital framework prototype. The analysis shows that even with a conservative 50% workforce adoption threshold, the primary strategic objective of recovering 0.50% of global line capacity is achieved. This outcome compresses the total changeover capacity overhead from 4.55% to the targeted 4.05% ceiling and reduces post-changeover ramp-up intervals to well below the 30-minute success criterion. After verifying these performance metrics and examining broader qualitative benefits, namely improved training effectiveness and knowledge preservation, the research now requires a final structural synthesis. Accordingly, the dissertation transitions to its closing phase. The following chapter will formalise the principal conclusions, discuss empirical limitations, establish a strategic trajectory for future industrial development and define the contribution of this work regarding the United Nations SDGs.

Chapter 8

Conclusions and Future Work

8.1 Conclusions

This dissertation developed and evaluated an integrated physical and digital standardisation framework to optimise format changeover operations within the SBG glass-bottling infrastructure. By applying Lean Manufacturing principles, specifically the 5S framework and the SMED methodology, with Industry 4.0 capabilities, the research addressed the limitations intrinsic in traditional setup practices.

Field diagnosis across Blocks 123 and 56L at the *Leça do Balio* plant revealed operational volatility due to reliance on operators' empirical knowledge. The absence of a proper component identification system and centralised data repositories led to frequent production drawbacks. This documentation and control gap was evident on Production Line 1, where the lack of manufacturer data required a comprehensive audit to manually measure the height of each levelling shim and a detailed physical experiment to map the mechanical position of each brush assembly.

To systematically eliminate these baseline inefficiencies, a zero-redundancy physical standardisation model was engineered. This model introduced a universal alphanumeric codification syntax and a line-specific chromatic Poka-Yoke matrix applied across six different geometric marker profiles. Supported by additive manufacturing using Polyethene Terephthalate Glycol and advanced industrial adhesives, and verified through caustic immersion testing, this system reduced cross-line component contamination and search waste on the shop floor.

Building on this physical stability, a digital changeover framework prototype was developed to function as a dynamic, standard operating procedure. The automated SKU comparison engine isolates product differences to programmatically generate step-gated task sequences and determine precise CIP sanitation and volumetric consumable cut-off targets. This digital tool replaces subjective operator interpretation with deterministic visual instructions, establishing the infrastructure required to ensure uniform operational tasks.

Although excessive procurement lead-times and commercial requirements for continuous plant output prevented long-term empirical measurement of a complete, floor-wide rollout, quantitative modelling was conducted using the active 2026 YTD operational dataset.

Sensitivity analysis confirmed that a conservative workforce adoption rate of 50% of the proposed framework achieves the primary strategic objective of recovering 0.50% of annual line capacity, reducing the global changeover capacity overhead from 4.55% to the target ceiling of 4.05%. Additionally, the model projected accelerated post-changeover speed recovery, surpassing the target threshold of a maximum 30-minute ramp-up window. The framework also established qualitative advantages, including faster personnel training cycles, institutionalisation of autonomous maintenance routines, indirect mitigation of equipment breakdown time, and preservation of organisational knowledge.

This rigorous evaluation allows a definitive conclusion regarding the dissertation's core premise: the research objectives established in Section 1.3 were successfully achieved. The analytical findings conclusively confirm that the proposed physical standardisation and digital frameworks effectively address the identified operational inefficiencies.

This conclusion is strongly reinforced by the operational workforce, who provided universally favourable feedback regarding the full integration of both the physical standardisation tools and the digital framework prototype.

8.2 Limitations of the Study

To maintain academic integrity and recognise the real-world constraints of this industrial case study, some technical and methodological limitations are delineated to establish a transparent trajectory for future research and full-scale factory deployment.

8.2.1 Functional Prototype Status

A primary limitation of this research is that the developed digital changeover framework functions solely as a stand-alone prototype interface. Despite overall approval and enthusiasm among the operators, a shop-floor rollout was not possible within the project's time frame, as deploying this system directly to the operating teams requires it to be permanently hosted on industrial tablets at the filling lines. Consequently, it operates as an offline decision-support and data-repository tool, rather than as an integrated node within the plant's core automation network. As a result, data entry and parameter tracking depend on manual operator confirmation via checkboxes, introducing a reliance on human input accuracy that could be improved through automated data collection. In the long term, to mitigate the risk of manual-entry errors, data-accuracy measures were considered, including targeted operator training on correct data-entry procedures, periodic double-checks of critical parameter entries by shift supervisors, and routine cross-verification of digital records against physical logbooks. These measures help maintain dataset integrity and ensure robust outcomes.

8.2.2 Procurement Lead-Times and Late-Stage Deployment

A notable structural constraint encountered during the empirical validation phase was extended procurement lead times from external technology suppliers. Despite executing all part specifications, design modelling, and material requisitions well ahead of scheduled implementation dates, the external delivery timelines for critical deployment materials, specifically the customised 3D printing equipment, filaments, and industrial adhesives and primers, substantially exceeded corporate forecasts. This delay deferred the physical application of the line-specific alphanumeric indicators to a late stage of the industrial residency, resulting in their incorporation only on Line 1. Consequently, collecting empirical post-implementation field data that could be systematically cross-compared with the long-term historical baseline was unfeasible, as comparing a full year of baseline industrial data against a condensed post-implementation observation window would compromise statistical validity. To preserve analytical rigour, the study transitioned to the scenario-based sensitivity analysis framework detailed in Chapter 7.

8.3 Future Work

To build upon the physical and digital pillars established in this dissertation, future deployment efforts should focus on the following topics:

- **Horizontal Physical Replication:** Scale the deployment of the physical standardisation model across all remaining glass bottling lines. Since the core conceptualisation, geometric profiles, and codification syntax have already been established, future rollouts require only the fabrication of line-specific physical assets and the direct integration of defined work instructions, enabling rapid replication across the site.
- **Longitudinal Field Validation:** Conduct a structured, multi-month study on a selected glass bottling line to collect empirical data across all four active packaging shifts, enabling statistical validation of the projected results presented in Chapter 7.
- **Industrial Interoperability:** Enable a digital "handshake" in which a machine cannot physically restart until sensors verify that the installed physical component matches the specific code requested by the digital SKU comparison engine, thereby enforcing an absolute digital Poka-Yoke.
- **Integrated Line-Flow Cut Optimisation:** Link the Consumable Cut Calculator directly to the Line's logic controllers to enable the tool to automatically update cut-off points based on real-time rejection rates from fill-height and EBI quality gates. This continuous calculation loop would protect against production overshoots or raw material gaps during batch transitions.

- **Dynamic Database Synchronisation:** Link the prototype's relational database directly with the plant's global Enterprise Resource Planning and Manufacturing Execution Systems to automate the tracking of production orders, consumable availability counts, and continuous OEE metrics.

8.4 The United Nations Sustainable Goals

The United Nations SDGs provide a global framework for achieving a better and more sustainable future for all. They include 17 goals to address the world's most pressing challenges: poverty, inequality, climate change, environmental degradation, peace, and justice.

This work was developed in accordance with the United Nations SDGs, specifically SDG 8, SDG 9 and SDG 12, which aim to promote sustained, inclusive, and sustainable economic growth, build resilient infrastructure and foster innovation, and ensure responsible consumption and production patterns. Based on these goals, the proposed changeover standardisation model and digital framework were engineered to optimise setup procedures, stabilise machinery performance, and eliminate localised waste of product and packaging materials during batch transitions in the bottling lines.

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

SDG 9 Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.

SDG 12 Ensure sustainable consumption and production patterns.

SDG	Target	Indicator	Contribution of this work
8	8.2	8.2.1	Contributes to industrial productivity by utilising technological innovation, specifically the development of a guided digital changeover framework, to optimise packaging line capacity, targeting a reduction in global changeover by 0.5%
9	9.4	9.4.1	Contributes to infrastructure retrofitting by modernising existing packaging machinery without requiring capital-intensive replacements. The implementation of custom 3D-printed identifiers improves the efficiency of localised resource use.
12	12.5	12.5.1	Contributes directly to preventing and reducing industrial waste generation at the source by engineering a Consumable Cut Calculator embedded within the digital framework, preventing the scraping and discarding of liquid remaining in supply lines and filling bowls at the end of a production order.

Declaration of Generative AI and AI-assisted Technologies in the Dissertation Preparation Process

During the preparation of this work, Gemini, ChatGPT, and Grammarly were used in order to improve the overall quality of the writing, ensure text cohesion and coherence, and enhance grammatical accuracy. These tools were additionally utilised to support the development and refinement of the prototype software code. After using these tools and services, the author reviewed, changed as needed, and validated all suggested material, thereby taking full responsibility for the content of this dissertation.

References

[1] Super Bock Group. *Quem Somos*. 2026. URL: https://superbockgroup.com/grupo/quem-somos/ (visited on 03/21/2026).

[2] Lean Production. *What is Lean Manufacturing?* 2026. URL: https://www.leanproduction.com/ (visited on 04/12/2026).

[3] R. Mendoza-Sotomayor, J. Sabogal-Arias, and J. C. Quiroz-Flores. "Optimizing Beverage Manufacturing: Integrating Lean Manufacturing and Machine Learning to Enhance Efficiency and Reduce Waste". *International Journal of Engineering Trends and Technology* 72 (Nov. 2024), pp. 155–174. DOI: 10.14445/22315381/IJETT-V72I11P118.

[4] A. Ramezani. "Lean and its Basic Components". *Academic Journal of Research in Business & Accounting* 2 (May 2014), pp. 36–45.

[5] R. Sundar, A.N. Balaji, and R.M. Satheesh Kumar. "A Review on Lean Manufacturing Implementation Techniques". *Procedia Engineering* 97 (2014). "12th Global Congress on Manufacturing and Management" GCMM - 2014, pp. 1875–1885. ISSN: 1877-7058. DOI: 10.1016/j.proeng.2014.12.341.

[6] S. Shingō and A. P. Dillon. *A revolution in manufacturing: The SMED System*. Productivity Press, Jan. 1985.

[7] M. K. Karasu, M. Cakmakci, M. B. Cakiroglu, E. Ayva, and N. Demirel-Ortabas. "Improvement of changeover times via Taguchi empowered SMED/case study on injection molding production". *Measurement* 47 (2014), pp. 741–748. ISSN: 0263-2241. DOI: 10.1016/j.measurement.2013.09.035.

[8] P. Guzmán Ferradás and K. Salonitis. "Improving Changeover Time: A Tailored SMED Approach for Welding Cells". *Procedia CIRP* 7 (2013). Forty Sixth CIRP Conference on Manufacturing Systems 2013, pp. 598–603. ISSN: 2212-8271. DOI: 10.1016/j.procir.2013.06.039.

[9] W. Ocieczek, D. Kraśniewski, and J. Furman. "Implementation of the SMED method on a production line to improve work efficiency". *Production Engineering Archives* 31 (2025), pp. 346–355. DOI: 10.30657/pea.2025.31.32.

[10] R. Ranjith Kumar, L. S. Ganesh, and C. Rajendran. "An entropy based approach to 5S maturity". *Materials Today: Proceedings* 46 (2021). 3rd International Conference on Materials, Manufacturing and Modelling, pp. 8103–8110. ISSN: 2214-7853. DOI: 10.1016/j.matpr.2021.03.048.

[11] N. Moro. "Set in Order – Fundamental Stage for 5S Methodology". *International conference KNOWLEDGE-BASED ORGANIZATION* 26 (June 2020), pp. 238–244. DOI: 10.2478/kbo-2020-0038.

[12] S. Muotka, A. Togiani, and J. Varis. "A Design Thinking Approach: Applying 5S Methodology Effectively in an Industrial Work Environment". *Procedia CIRP* 119 (2023). The 33rd CIRP Design Conference, pp. 363–370. ISSN: 2212-8271. DOI: 10.1016/j.procir.2023.03.103.

[13] S. Spear and H. K. Bowen. "Decoding the DNA of the Toyota Production System". *Harvard Business Review* 77 (Sept. 1999), pp. 96–106.

[14] J. Liker and J. Franz. "THE TOYOTA WAY: Helping Others Help Themselves". *Manufacturing Engineering* 149 (Nov. 2012), pp. 87–95.

[15] Orca Lean. *Standardized work: A path to efficiency and continuous improvement*. Oct. 2024. URL: https://www.orcalean.com/article/standardized-work:-a-path-to-efficiency-and-continuous-improvement (visited on 04/19/2026).

[16] J. Fin, G. Vidor, I. Cecconello, and V. de Campos Machado. "Improvement based on standardized work: an implementation case study". *Brazilian Journal of Operations & Production Management* 14 (Sept. 2017), pp. 388–395. DOI: 10.14488/BJOPM.2017.v14.n3.a12.

[17] S. Schumacher, A. Bildstein, and T. Bauernhansl. "The Impact of the Digital Transformation on Lean Production Systems". *Procedia CIRP* 93 (2020). 53rd CIRP Conference on Manufacturing Systems 2020, pp. 783–788. ISSN: 2212-8271. DOI: 10.1016/j.procir.2020.03.066.

[18] S. V. Iyer, K. S. Sangwan, and Dhiraj. "Digitalization: a tool for the successful long-term adoption of lean manufacturing". *Procedia CIRP* 116 (2023). 30th CIRP Life Cycle Engineering Conference, pp. 245–250. ISSN: 2212-8271. DOI: 10.1016/j.procir.2023.02.042.

[19] A. Tashkinov. "The implementation of lean and digital management techniques using artificial intelligence in industrial settings". *Discover Artificial Intelligence* 4 (Nov. 2024). DOI: 10.1007/s44163-024-00186-5.

[20] D. Powell, E. Alfnes, J. O. Strandhagen, and H. Dreyer. "Lean manufacturing and Industry 4.0—a review and integration framework". *International Journal of Production Research* 54.20 (2016), pp. 6155–6171. DOI: 10.1080/00207543.2016.1145737.

[21] S. Blüml and S. Fischer. *Manual of filling technology: The theory and practice of filling liquid products*. Behr's Verlag, 2004. ISBN: 9783899471977.

[22] R. Klimovitz and K. Ockert. *Beer packaging*. 2nd. Master Brewers Association of the Americas, 2014. ISBN: 9780978772673.

[23] W. Creswell and D. Creswell. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publications, 2017. ISBN: 9781506386690.

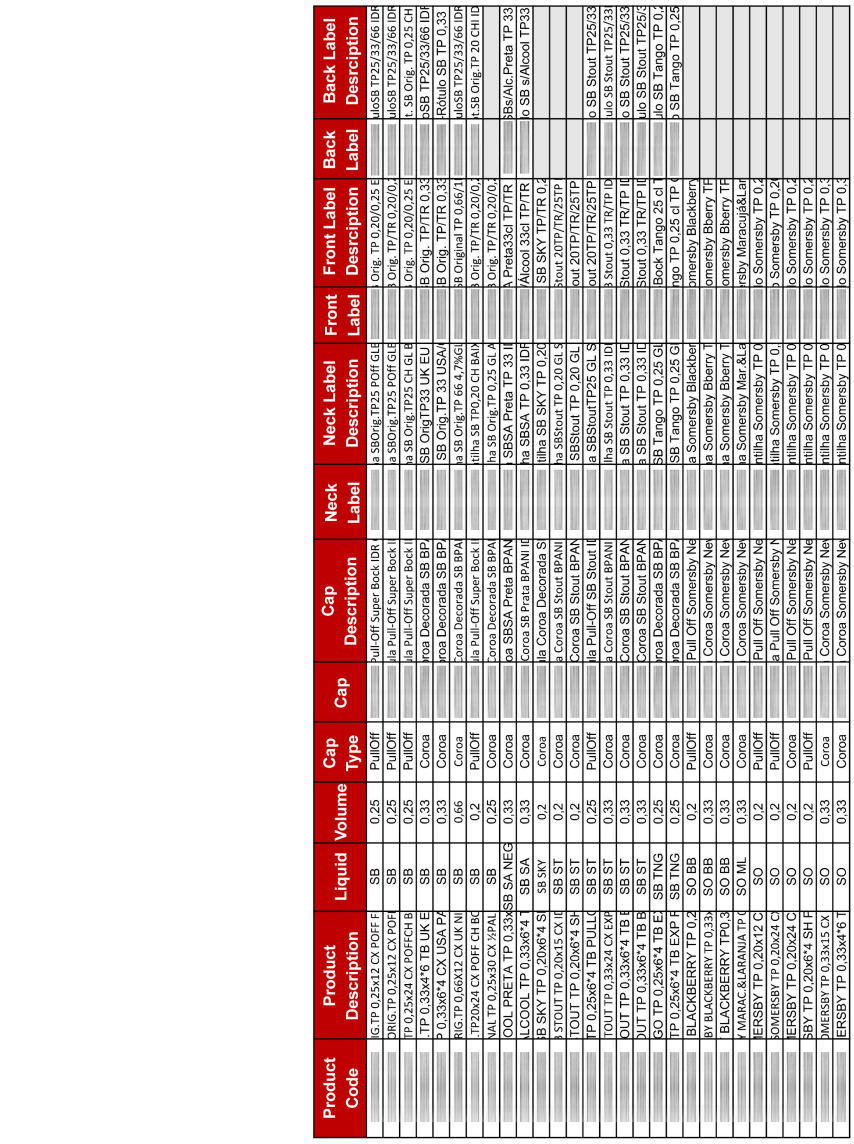
[24] M. Saunders, P. Lewis, and A. Thornhill. *Research Methods for Business Students*. 2023. ISBN: 9781292402727.

[25] KHS. *New generation of fillers sets standards in consumption values and product quality*. Jan. 2021. URL: https://www.khs.com/en/company/news/press-releases/detail/new-generation-of-fillers-sets-standards-in-consumption-values-and-product-quality (visited on 04/06/2026).

[26] KHS. *User Manual - Innoket SE 2090*. 1st. KHS GmbH. Juchostr. 20 D-44143 Dortmund, Feb. 2018.

Appendix A

Active SKUs Catalogue



Product Code	Product Description	Liquid	Volume	Cap Type	Cap	Cap Description	Neck Label	Neck Label Description	Front Label	Front Label Description	Back Label	Back Label Description
[redacted]	IG.TP 0,25x12 CX POFF F	SB	0,25	PullOff	[redacted]	Pull-Off Super Bock IDR	[redacted]	a SBOrig.TP25 POff GLE	[redacted]	l Orig. TP 0,20/0,25 E	[redacted]	ulloSB TP25/33/66 IDR
[redacted]	DRIG.TP 0,25x12 CX POF	SB	0,25	PullOff	[redacted]	lla Pull-Off Super Bock I	[redacted]	a SBOrig.TP25 POff GLE	[redacted]	g Orig. TP/TR 0,20/0,2	[redacted]	ulloSB TP25/33/66 IDR
[redacted]	TP 0,25x24 CX POFFCH B	SB	0,25	PullOff	[redacted]	lla Pull-Off Super Bock I	[redacted]	a SB Orig.TP25 CH GL A	[redacted]	l Orig. TP 0,20/0,25 E	[redacted]	t. SB Orig. TP 0,25 CH
[redacted]	.TP 0,33x4*6 TB UK E	SB	0,33	Coroa	[redacted]	yroa Decorada SB BP/	[redacted]	SB Orig.TP33 UK EU	[redacted]	B Orig. TP/TR 0,33	[redacted]	pSB TP25/33/66 IDF
[redacted]	P 0,33x6*4 CX USA PA	SB	0,33	Coroa	[redacted]	yroa Decorada SB BP/	[redacted]	SB Orig.TP 33 USA/	[redacted]	B Orig. TP/TR 0,33	[redacted]	RÓtulo SB TP 0,33
[redacted]	RIG.TP 0,66X12 CX UK NI	SB	0,66	Coroa	[redacted]	Coroa Decorada SB BPA	[redacted]	a SB Orig.TP 66 4,7%GI	[redacted]	SB Original TP 0,66/1	[redacted]	ulloSB TP25/33/66 IDR
[redacted]	TP20x24 CX POFF CH BC	SB	0,2	PullOff	[redacted]	lla Pull-Off Super Bock I	[redacted]	rtilha SB TP0,20 CH BAI	[redacted]	g Orig. TP/TR 0,20/0,2	[redacted]	t.SB Orig.TP 20 CH ID
[redacted]	NAL TP 0,25x30 CX XPAL	SB	0,25	Coroa	[redacted]	Coroa Decorada SB BPA	[redacted]	lha SB Orig.TP 0,25 GL A	[redacted]	g Orig. TP/TR 0,20/0,2	[redacted]	[redacted]
[redacted]	OOL PRETA TP 0,33x	SB SA NEG	0,33	Coroa	[redacted]	oa SBSA Preta BPAN	[redacted]	SBSA Preta TP 33 II	[redacted]	A Preta33cl TP/TR	[redacted]	SBs/Alc.Preta TP 33
[redacted]	LCOOL TP 0,33x6*4 T	SB SA	0,33	Coroa	[redacted]	Coroa SB Prata BPANI II	[redacted]	lha SBSA TP 0,33 IDF	[redacted]	Alcool 33cl TP/TR	[redacted]	o SB s/Alcool TP33
[redacted]	B SKY TP 0,20x6*4 St	SB SKY	0,2	Coroa	[redacted]	lla Coroa Decorada S	[redacted]	tilha SB SKY TP 0,20	[redacted]	SB SKY TP/TR 0,2	[redacted]	[redacted]
[redacted]	STOUT TP 0,20x15 CX IE	SB ST	0,2	Coroa	[redacted]	a Coroa SB Stout BPANI	[redacted]	na SBStout TP 0,20 GL S	[redacted]	Stout 20TP/TR/25TP	[redacted]	[redacted]
[redacted]	TOUT TP 0,20x6*4 SH	SB ST	0,2	Coroa	[redacted]	Coroa SB Stout BPAN	[redacted]	SBStout TP 0,20 GL	[redacted]	out 20TP/TR/25TP	[redacted]	[redacted]
[redacted]	TP 0,25x6*4 TB PULL(	SB ST	0,25	PullOff	[redacted]	lla Pull-Off SB Stout II(	[redacted]	a SBStoutTP25 GL S	[redacted]	out 20TP/TR/25TP	[redacted]	o SB Stout TP25/33
[redacted]	TOUT TP 0,33x24 CX EXF	SB ST	0,33	Coroa	[redacted]	a Coroa SB Stout BPANI	[redacted]	lha SB Stout TP 0,33 IDI	[redacted]	B Stout 0,33 TR/TP ID	[redacted]	ulo SB Stout TP25/33
[redacted]	OUT TP 0,33x6*4 TB E	SB ST	0,33	Coroa	[redacted]	Coroa SB Stout BPAN	[redacted]	a SB Stout TP 0,33 IE	[redacted]	Stout 0,33 TR/TP IE	[redacted]	o SB Stout TP25/33
[redacted]	OUT TP 0,33x6*4 TB B	SB ST	0,33	Coroa	[redacted]	Coroa SB Stout BPAN	[redacted]	a SB Stout TP 0,33 IE	[redacted]	Stout 0,33 TR/TP IE	[redacted]	ulo SB Stout TP25/3
[redacted]	GO TP 0,25x6*4 TB EX	SB TNG	0,25	Coroa	[redacted]	yroa Decorada SB BP/	[redacted]	SB Tango TP 0,25 GI	[redacted]	Bock Tango 25 cl T	[redacted]	ulo SB Tango TP 0,2
[redacted]	TP 0,25x6*4 TB EXP F	SB TNG	0,25	Coroa	[redacted]	yroa Decorada SB BP/	[redacted]	SB Tango TP 0,25 G	[redacted]	ngo TP 0,25 cl TP 6	[redacted]	o SB Tango TP 0,25
[redacted]	BLACKBERRY TP 0,2	SO BB	0,2	PullOff	[redacted]	Pull Off Somersby Ne	[redacted]	a Somersby Blackber	[redacted]	omersby Blackberry	[redacted]	[redacted]
[redacted]	BY BLACKBERRY TP 0,33	SO BB	0,33	Coroa	[redacted]	Coroa Somersby Ne	[redacted]	a Somersby Bberry T	[redacted]	omersby Bberry TF	[redacted]	[redacted]
[redacted]	BLACKBERRY TP0,3	SO BB	0,33	Coroa	[redacted]	Coroa Somersby Ne	[redacted]	a Somersby Bberry T	[redacted]	omersby Bberry TF	[redacted]	[redacted]
[redacted]	Y MARAC.&LARANJA TP(	SO ML	0,33	Coroa	[redacted]	Coroa Somersby Ne	[redacted]	a Somersby Mar.&La	[redacted]	rsby Maracujá&Lar	[redacted]	[redacted]
[redacted]	ERSBY TP 0,20x12 C	SO	0,2	PullOff	[redacted]	Pull Off Somersby Ne	[redacted]	ntilha Somersby TP 0	[redacted]	o Somersby TP 0,2	[redacted]	[redacted]
[redacted]	OMERSBY TP 0,20x24 C	SO	0,2	PullOff	[redacted]	a Pull Off Somersby N	[redacted]	ntilha Somersby TP 0,	[redacted]	o Somersby TP 0,2	[redacted]	[redacted]
[redacted]	ERSBY TP 0,20x24 C	SO	0,2	Coroa	[redacted]	Pull Off Somersby Ne	[redacted]	ntilha Somersby TP 0	[redacted]	o Somersby TP 0,2	[redacted]	[redacted]
[redacted]	SBY TP 0,20x6*4 SH F	SO	0,2	PullOff	[redacted]	Pull Off Somersby Ne	[redacted]	ntilha Somersby TP 0	[redacted]	o Somersby TP 0,2	[redacted]	[redacted]
[redacted]	OMERSBY TP 0,33x15 CX	SO	0,33	Coroa	[redacted]	Coroa Somersby Ne	[redacted]	ntilha Somersby TP 0	[redacted]	o Somersby TP 0,3	[redacted]	[redacted]
[redacted]	ERSBY TP 0,33x4*6 T	SO	0,33	Coroa	[redacted]	Coroa Somersby Ne	[redacted]	ntilha Somersby TP 0	[redacted]	o Somersby TP 0,3	[redacted]	[redacted]

Figure A.1: Active SKUs Catalogue of a Fraction of Products

Appendix B

Format Parts Identification (AS IS)

Format Parts					
	TP	SB	0,2	Red	
			0,2	Orange	
			0,25	Blue	
			0,25	Red	
			0,33	Orange	
			0,33	Dark Blue	
		ST	0,2	Purple	
			0,25	Gold	
			0,33	Purple	
			0,33	Purple	
		CT	0,2	Grey	
			0,25	Green	
			0,25	White	
			0,33	Green	
		SM	0,2	Yellow	
			0,25	Yellow	
			0,33	Yellow	
		EU	0,25	Dark Blue	
			0,25	Black	
		AB	0,33	Purple	
		GRN	0,33	Brown	
	TR	SB	0,2	Purple	
			0,33	Purple	
		ST	0,2	Purple	
			0,33	Purple	
		CT	0,2	Purple	
			0,33	Purple	
		CB	0,25	Purple	

Figure B.1: Format Parts Identification (AS IS)

Appendix C

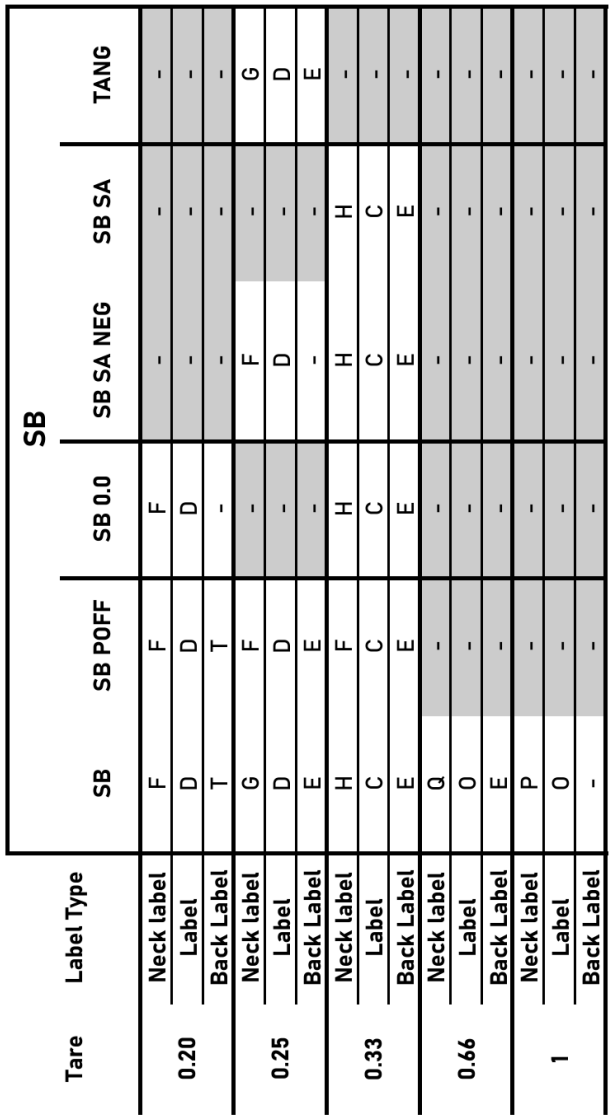
Shims Height Database

Tare	Liquid	Shim KL2 Top	Shim KL2 Bottom	Shim Gripper Head KL2	Shim KL3 Top	Shim KL3 Bottom	Shim Gripper Head KL3	Shim KL3 Top	Shim KL3 Bottom	Shim Gripper Head KL3
0,20	SB	106	113	152.8	100	15	14	89	17.5	59
	SB POFF	106	113	152.8	100	15	14	89	17.5	59
	SB ST	106	113	152.8	88.5	15	14			
	SO	110	106	150	118	16	14			
	SO POFF	110	106	150	118	16	14			
0,25	SB	109	126	163	100	23	23	92	11	24
	SB POFF	106	127.5	171	100	23	23	92	11	24
	CT	106	127.5	171	108	23	21.5			
	CT POFF	106	127.5	171	108	23	21.5			
0,33	SB	107	157	194	100	31.5	41.8	92.5	21	32.5
	SB 0.0	107	157	194	100	31.5	41.8	92.5	21	32.5
	SB ST	107	157	194	106	36	41.8	92.5	21	32.5
	SO	135	158	192.8	125	17.5	36			

Figure C.1: Shims Height Database For Line 1

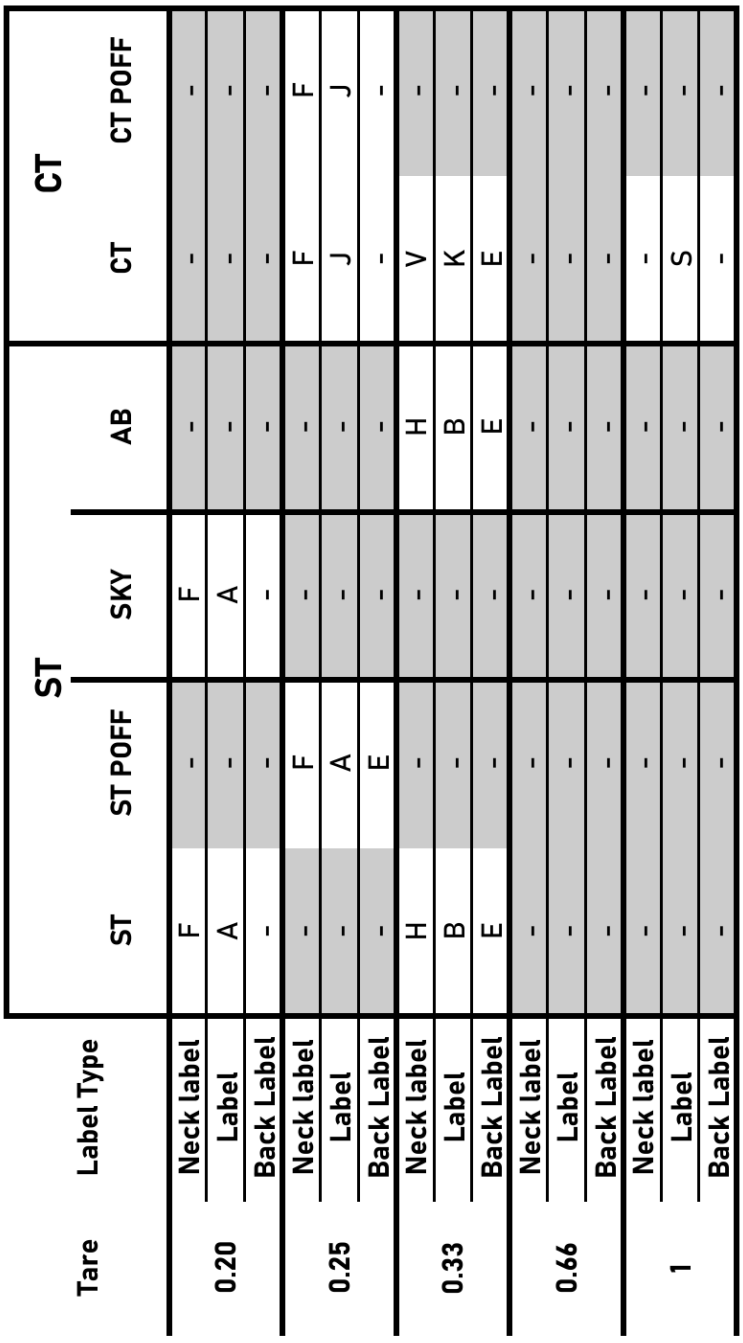
Appendix D

Product Clusters



Tare	Label Type	SB	SB POFF	SB 0.0	SB SA NEG	SB SA	TANG
0.20	Neck label	F	F	F	-	-	-
	Label	D	D	D	-	-	-
	Back Label	T	T	-	-	-	-
0.25	Neck label	G	F	-	F	-	G
	Label	D	D	-	D	-	D
	Back Label	E	E	-	-	-	E
0.33	Neck label	H	F	H	H	H	-
	Label	C	C	C	C	C	-
	Back Label	E	E	E	E	E	-
0.66	Neck label	Q	-	-	-	-	-
	Label	O	-	-	-	-	-
	Back Label	E	-	-	-	-	-
1	Neck label	P	-	-	-	-	-
	Label	O	-	-	-	-	-
	Back Label	-	-	-	-	-	-

Figure D.1: Super Bock Product Clusters



Tare	Label Type	ST				CT	
		ST	ST POFF	SKY	AB	CT	CT POFF
0.20	Neck label	F	-	F	-	-	-
	Label	A	-	A	-	-	-
	Back Label	-	-	-	-	-	-
0.25	Neck label	-	F	-	-	F	F
	Label	-	A	-	-	J	J
	Back Label	-	E	-	-	-	-
0.33	Neck label	H	-	-	H	V	-
	Label	B	-	-	B	K	-
	Back Label	E	-	-	E	E	-
0.66	Neck label	-	-	-	-	-	-
	Label	-	-	-	-	-	-
	Back Label	-	-	-	-	-	-
1	Neck label	-	-	-	-	-	-
	Label	-	-	-	-	S	-
	Back Label	-	-	-	-	-	-

Figure D.2: Stout and Cristal Product Clusters

Tare	Label Type	CH	CH NEG	SO	SO POFF	GR	CB	CRJ
0.20	Neck label	-	-	M	M	-	-	-
	Label	-	-	L	L	-	-	-
	Back Label	-	-	-	-	-	-	-
0.25	Neck label	-	-	-	-	-	-	-
	Label	-	-	-	-	-	U	-
	Back Label	-	-	-	-	-	R	-
0.33	Neck label	V	V	V	-	F	-	-
	Label	C	C	I	-	C	-	N
	Back Label	-	-	-	-	E	-	-
0.66	Neck label	-	-	-	-	-	-	-
	Label	-	-	-	-	-	-	-
	Back Label	-	-	-	-	-	-	-
1	Neck label	-	-	-	-	-	-	-
	Label	-	-	-	-	-	-	-
	Back Label	-	-	-	-	-	-	-

Figure D.3: Cheers, Somersby and Other Products Clusters

Letter	Type of Label	Product served	Dimensions
A	Label	ST	50.5 x 57
B	Label	ST	64.2 x 75.4
C	Label	SB 0.33	71.5 x 71.5
D	Label	SB 0.20/0.25	59.4 x 59.4
E	Back Label	0.20/0.25/0.33/0.66	45 x 64
F	Neck label	Crown 0.2 Pull-Off 0.20/0.25	106.5 x 22.65
G	Neck label	Crown 0.25	106.5 x 27.30
H	Neck label	IDENTITY/SB/SA/ST 0.33	108.9 x 33.9
I	Label	Somersby 0.33	74 x 80.6
J	Label	Cristal 0.25	59 x 80
K	Label	Cristal 0.33	75 x 91.1
L	Label	SO 0.20	62 x 55
M	Neck label	SO 0.20	111.5 x 28
N	Label	Coruja 0.33	130 x 80
O	Label	SB 0.66/1L	95.2 x 95.2
P	Neck label	SB 1L	126 x 52.37
Q	Neck label	SB 0.66	127.03 x 48.53
R	Back Label	CB 0.25	62.17 x 54.25
S	Label	CT 1L	90 x 110
T	Back Label	Small	45 x 45
U	Label	CB 0.25	62.3 x 79
V	Neck label	SO, CT, CH 33	110.9 x 35

Figure D.4: Correspondence of Labels for Product Clusters

Appendix E

Work Instruction - Alphanumeric Codification

SUPER BOCK GROUP

1. Codificação alfanumérica

Definição e descrição das correspondências de produto à identificação das Peças de Formato

Todas as peças de identificação carecem de três tipos de identificação alfanumérica obrigatória: o Formato, a Linha e a Posição na Máquina. Opcionalmente, é possível identificar outras duas componentes: Número da Máquina e/ou Tipologia da Peça
A correspondência entre os diversos SKUs e a simbologia usada é descrita nos seguintes sub-capítulos.

1.1 Correspondência de Formato

Todas as Peças de Formato das máquinas apresentadas no Capítulo 3 carecem de Identificação das Peças de Formato. As correspondências de formato dão-se por Linha, de acordo com a respetiva folha associada à Linha.

1.2 Correspondência de Produto

As correspondências de produto dão-se do seguinte modo, de acordo com a Tabela 1.1:

Tabela 1.1 - Correspondência de Produto com nomenclatura alfanumérica

Produto	Nomenculatura
Carlsberg	CB
Cheers	CH
Cheers Preta	CH NEG
Cristal	CT
Super Bock Coruja	SB CRJ
Super Bock Green	SB GRN
Super Bock Original	SB
Super Bock 0.0%	SB 0.0
Super Bock Sem Álcool	SB SA
Super Bock Negra Sem Álcool	SB SA NEG
Super Bock Tango	SB TNG
Super Bock Stout	SB ST
Super Bock Sky	SB SKY
Super Bock Abadia	SB ABA
Somersby	SO
Somersby Blackberry	SO BB
Somersby Maracujá Laranja	SO ML
Somersby Pear 0.0%	SO PR
Somersby Morango	SO MG

Figure E.1: Work Instruction - Alphanumeric Codification - Page 1

1.3 Correspondência de Tara

As correspondências de Tara dão se do seguinte modo, de acordo com a Tabela 1.2:

Tabela 1.2 - Correspondência de Tara com nomenclatura alfanumérica

Tara	Simbologia
0,20 L	0,20
0,25 L	0,25
0,33 L	0,33
0,66 L	0,66
1 L	1 L
Alumínio	ALUM

1.4 Tipo de Peça

Dependendo do Tipo de Peça, é requerida uma Letra antes do número de Formato. As peças que necessitam desta identificação são as mencionadas na Tabela 1.3.

Tabela 1.3 - Correspondência de Tipo de Peça com Letra requerida

Peça	Letra
Escovas	E
Calços da Mesa	C

1.5 Outras correspondências

Neste sub-capítulo são apresentadas outras correspondências, aplicadas de acordo com o conjunto Linhas de Produção, Máquina e Tipo de Cápsula.

1.5.1 Parte da Máquina

As correspondências do Agregado dão se do seguinte modo, de acordo com a Tabela 1.4:

Tabela 1.4 - Correspondência da Máquina, por Linha de Enchimento, com nomenclatura alfanumérica

Máquina	Linha de Produção	Descrição	Simbologia
Rotuladoras KHS	L1	Agregado referente à Gargantilha	KL2
		Agregado referente ao Rótulo	KL3
		Agregado referente ao Contra-Rótulo	KL4
	L2	Agregado referente à Gargantilha	KL2
		Agregado referente ao Rótulo	KL3
		Agregado referente ao Contra-Rótulo	KL4
	L3	Agregado referente ao Rótulo	KL1
		Agregado referente à Gargantilha	KL2
		Agregado referente ao Contra-Rótulo	KL3
Rotuladoras Krones	L5	Agregado referente à Gargantilha	KA1
		Agregado referente ao Rótulo	KA2
		Agregado referente ao Contra-Rótulo	KA3
	L6	Agregado referente à Gargantilha	KA1
		Agregado referente ao Rótulo	KA2
		Agregado referente ao Contra-Rótulo	KA3

Figure E.2: Work Instruction - Alphanumeric Codification - Page 2

1.5.2 Linha de Enchimento

As correspondências da Linha de Enchimento dão se do seguinte modo, de acordo com a Tabela 1.5:

Tabela 1.5 - Correspondência da Linha com nomenclatura alfanumérica

Linha de Produção	Simbologia
Linha de Enchimento nº 1	L1
Linha de Enchimento nº 2	L2
Linha de Enchimento nº 3	L3
Linha de Enchimento nº 5	L5
Linha de Enchimento nº 6	L6

1.5.3 Tipo de Cápsula

As correspondências do Tipo de Cápsula dão se do seguinte modo, de acordo com a Tabela 1.6:

Tabela 1.6 - Correspondência do Tipo de Cápsula com nomenclatura alfanumérica

Cápsula	Simbologia
Coroa	COROA
Pull-Off	POFF

1.5.4 Número da Máquina

Este sub-sub-capítulo dedica-se exclusivamente à Linha de Enchimento nº 5, com duas máquinas. Surge a necessidade de identificar o número da Máquina, tal como descrito na Tabela 1.7.

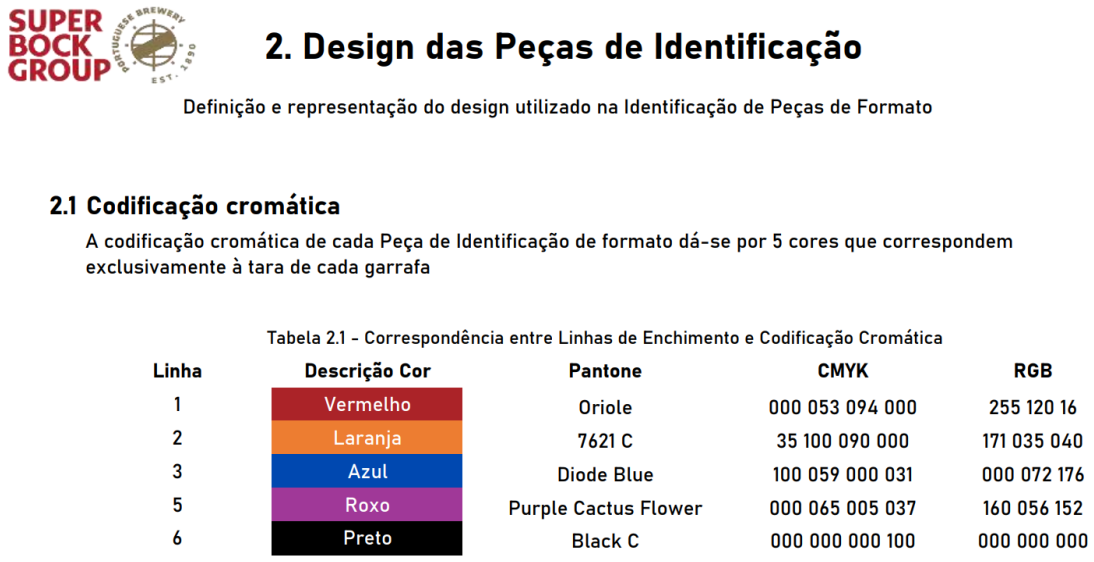
Tabela 1.7 - Correspondência da Rotuladora com nomenclatura alfanumérica

Máquina	Simbologia
Rotuladora nº1	R1
Rotuladora nº2	R2

Figure E.3: Work Instruction - Alphanumeric Codification - Page 3

Appendix F

Work Instruction - Physical Identification Architecture



SUPER BOCK GROUP

2. Design das Peças de Identificação

Definição e representação do design utilizado na Identificação de Peças de Formato

2.1 Codificação cromática

A codificação cromática de cada Peça de Identificação de formato dá-se por 5 cores que correspondem exclusivamente à tara de cada garrafa

Tabela 2.1 - Correspondência entre Linhas de Enchimento e Codificação Cromática

Linha	Descrição Cor	Pantone	CMYK	RGB
1	Vermelho	Oriole	000 053 094 000	255 120 16
2	Laranja	7621 C	35 100 090 000	171 035 040
3	Azul	Diode Blue	100 059 000 031	000 072 176
5	Roxo	Purple Cactus Flower	000 065 005 037	160 056 152
6	Preto	Black C	000 000 000 100	000 000 000

Figure F.1: Work Instruction - Physical Identification Architecture - Page 1

2.2 Versões de Implementação

2.2.1 Versão I (V1)

A Versão I (V1) de Implementação dedica-se a todas as Peças de Formato, salvo exceções mencionadas adiante. Funciona como a dimensão standard de aplicação.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser quadrangular de dimensões 25mm x 25mm
A peça deve ter uma espessura total de 3mm
As codificações devem ter uma espessura de 1mm
O tamanho da letra da codificação principal não pode exceder os 12 mm e a secundária 8 mm
A fonte da codificação deve ser Arial (Bold)
A codificação superior não pode exceder 15mm, para o centro, da parte superior da peça
A codificação inferior não pode exceder 10mm, para o centro, da parte inferior da peça
As codificações devem estar centradas vertical e horizontalmente segundo as secções correspondentes
Devem ser preservadas margens correspondentes a 1 mm em todas as arestas da peça

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.2.

Tabela 2.2 - Correspondência entre Posicionamento e Codificações (V1)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Linha de Enchimento	Sub-sub-Capítulo 1.2
C	Parte da Máquina	Sub-sub-Capítulo 1.3.1

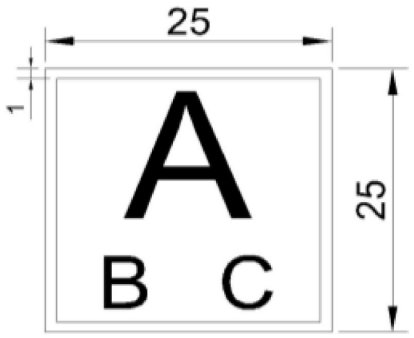


Figura 2.1 - Desenho de Implementação V1

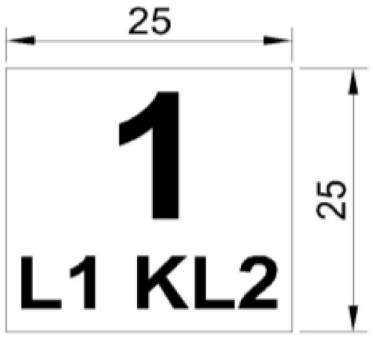


Figura 2.2 - Exemplo de Implementação V1

Figure F.2: Work Instruction - Physical Identification Architecture - Page 2

2.2.2 Versão II (V2)

A Versão II (V2) de Implementação dedica-se à aplicação em Peças de Formato que não permitam, dimensionalmente, a fixação das peças mencionadas anteriormente.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser retangular de dimensões 15mm x 45mm
A peça deve ter uma espessura de mm
As codificações devem ter uma espessura de 1mm
O tamanho da letra da codificação principal não pode exceder os 12 mm e a secundária 5 mm
A fonte da codificação deve ser Arial (Bold)
A codificação central não pode exceder mais de 10mm, para cada lado da peça
As codificações laterais não podem exceder 10mm, para o centro da peça
As codificações devem estar centradas verticalmente segundo a secção vertical correspondente
As codificações devem estar centradas horizontalmente segundo a secção horizontal correspondente
Devem ser preservadas margens correspondentes a 1 mm em todas as arestas da peça

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.3.

Tabela 2.3 - Correspondência entre Posicionamento e Codificações (V2)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Linha de Enchimento	Sub-sub-Capítulo 1.2
C	Parte da Máquina	Sub-sub-Capítulo 1.3.1

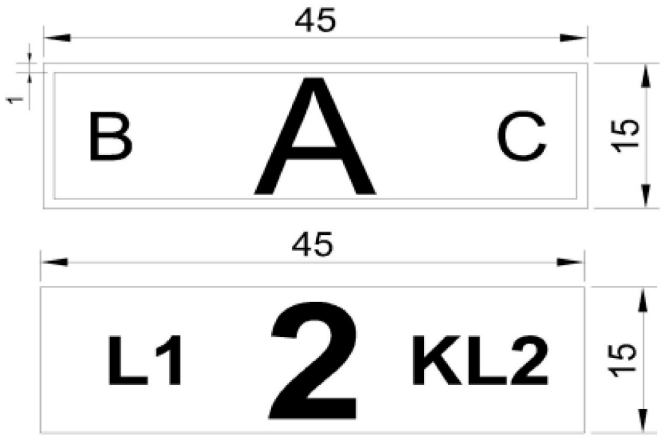


Figura 2.3 - Desenho de Implementação V2 e Exemplo de Implementação V2

Figure F.3: Work Instruction - Physical Identification Architecture - Page 3

2.2.3 Versão III (V3)

A Versão III (V3) de Implementação dedica-se a todas os Conjuntos de Escovas.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser um *Torus* (donut), de altura 25mm, diâmetro interior 20mm, diâmetro exterior 45mm, facejado em ambos os lados. Estas faces devem estar a 18.5mm do centro da peça.

A peça deve ter 2 furos passantes M4, em horizontalidade com o centro, a 16.5mm, para cada lado.

Devem existir recortes para as porcas, que correspondem a hexágono de diâmetro entre vértices 8mm

As arestas vivas do topo e da base devem estar chanfradas com um valor de 1.5mm

As codificações devem ter uma espessura de 1mm

A letra da codificação principal não pode exceder os 12 mm, a secundária 5 mm e a de posição 9mm.

A fonte da codificação deve ser Arial (Bold)

A codificação superior não pode exceder 15mm, para o centro, da parte superior da peça

A codificação inferior não pode exceder 10mm, para o centro, da parte inferior da peça

As codificações devem estar centradas vertical e horizontalmente segundo as secções correspondentes

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.4.

Tabela 2.4 - Correspondência entre Posicionamento e Codificações (V3)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Linha de Enchimento	Sub-Capítulo 1.2
C	Parte da Máquina	Sub-sub-Capítulo 1.3.1
D	Posição na Máquina	Anexo A
E	Indicativo de Escovas	Sub-Capítulo 1.4

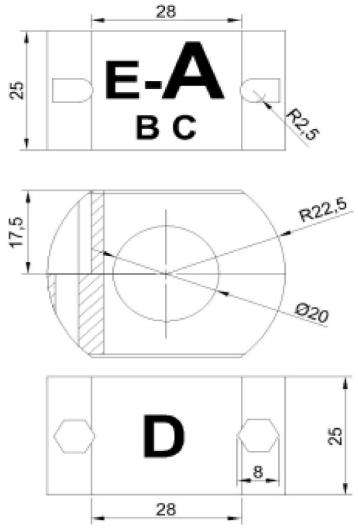


Figura 2.4 - Desenho de Implementação V3

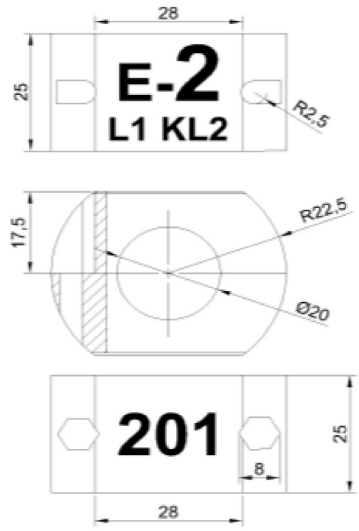


Figura 2.5 - Exemplo de Implementação V3

Figure F.4: Work Instruction - Physical Identification Architecture - Page 4

2.2.4 Versão IV (V4)

A Versão IV (V4) de Implementação dedica-se meramente aos calços niveladores/posicionadores dos agregados das Rotuladoras KHS. Não tem aplicação nas rotuladoras KRONES.

Ao invés de identificar os calços, estes são feitos de origem, com a identificação embutida.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser um um retângulo circunscrito, recortado, tal como se representa na Figura 2.6, onde o Diâmetro interior é 21mm e o exterior 45mm. As faces devem estar a 17mm do centro da peça

As codificações devem ser gravadas negativamente com uma profundidade de, pelo menos, 0.4mm

O tamanho da letra da codificação principal não pode exceder os 8 mm e a secundária 5 mm

A fonte da codificação deve ser Arial (Bold)

As codificações devem estar centradas vertical e horizontalmente segundo as secções correspondentes

Para os calços da mesa, é necessária a adição de uma seta, a apontar para cima ou baixo, correspondente à posição relativa dos mesmos.

Para peças com altura superior a 30mm, os fillets representados devem ser de 8mm

Para peças com altura inferior a 30mm, os fillets representados devem ser de 4mm

Nas peças onde a altura assim não o permite, a identificação faz-se por texto corrido, em linha

Devem ser preservadas margens correspondentes a 1 mm nas arestas de tioi e 2mm nas arestas laterais

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.5.

Tabela 2.5 - Correspondência entre Posicionamento e Codificações (V4)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Seta de Posição	-
C	Indicativo de Calço	Sub-Capítulo 1.4
C	Parte da Máquina	Sub-sub-Capítulo 1.3.1

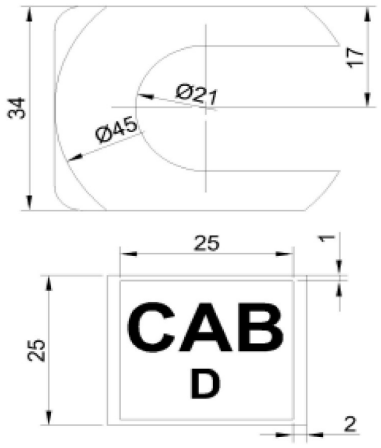


Figura 2.6 - Desenho de Implementação V4

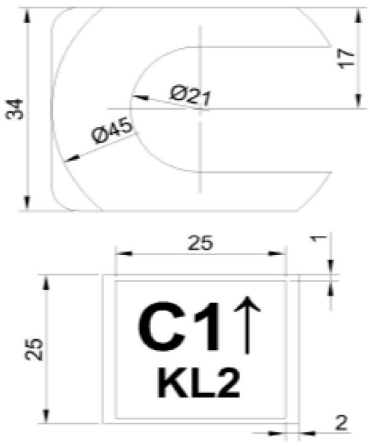


Figura 2.7 - Exemplo de Implementação V4

Figure F.5: Work Instruction - Physical Identification Architecture - Page 5

2.2.5 Versão V (V5)

A Versão V (V5) de Implementação dedica-se aos calços niveladores da Cabeça de Pinças das Rotuladoras KHS. Não tem aplicação nas rotuladoras KRONES.

Ao invés de identificar os calços, estes são feitos de origem, com a identificação embutida.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser um *Torus* (donut), de diâmetro interior 42mm, diâmetro exterior 55mm. Deve ser feita uma ranhura para a chaveta do veio e a respetiva saliência

As codificações devem ser gravadas negativamente com uma profundidade de, pelo menos, 0.4mm

O tamanho da letra da codificação não pode exceder os 5mm

As codificações devem estar, em relação a um eixo vertical (de topo) a 45° para cada lado.

A fonte da codificação deve ser Arial (Bold)

Os fillets exteriores devem ter um raio de 6mm

Devem ser preservadas margens de 1 mm entre as marcações e o exterior da peça

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.6

Tabela 2.6 - Correspondência entre Posicionamento e Codificações (V5)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Parte da Máquina	Sub-sub-Capítulo 1.3.1
C	Linha de Enchimento	Sub-Capítulo 1.2

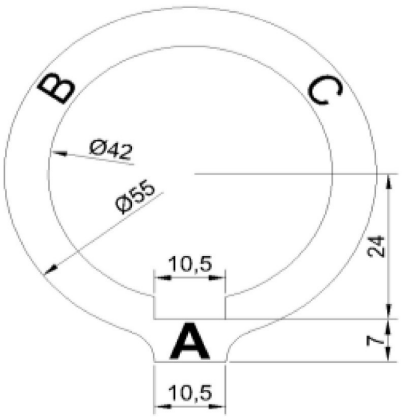


Figura 2.8 - Desenho de Implementação V5

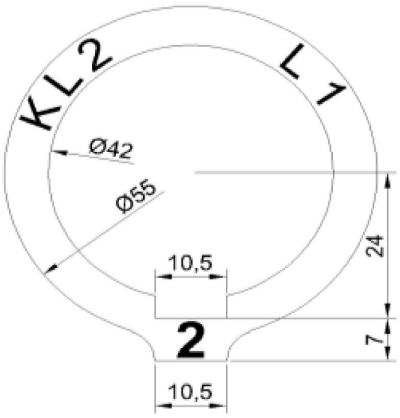


Figura 2.9 - Exemplo de Implementação V5

Figure F.6: Work Instruction - Physical Identification Architecture - Page 6

2.2.6 Versão VI (V6)

A Versão VI (V6) de Implementação dedica-se a todas as Peças de Formato da Linha 5, devido à presença de 2 rotuladoras. A arte final desta versão não tem de seguir este exemplo, visto que, para as escovas, o formato é diferente. Apenas se pertende localizar a adição da identificação da Rotuladora.

O conteúdo deve obedecer às seguintes regras:

A peça deve ser quadrangular de dimensões 25mm x 25mm
A peça deve ter uma espessura de 2mm
As codificações devem ter uma espessura de 1mm
O tamanho da letra da codificação principal não pode exceder os 12 mm e a secundária 5 mm
A fonte da codificação deve ser Arial (Bold)
A codificação superior não pode exceder 12mm, para o centro, da parte superior da peça
A codificação central não pode exceder 3mm, na vertical, para cada lado, do centro da peça
A codificação inferior não pode exceder 6mm, para o centro, da parte inferior da peça
As codificações devem estar centradas verticalmente segundo a secção vertical correspondente
As codificações devem estar centradas horizontalmente segundo a secção horizontal correspondente
Devem ser preservadas margens correspondentes a 1 mm em todas as arestas da peça

A correspondência entre posicionamento e codificações encontra-se descrita na Tabela 2.7

Tabela 2.7 - Correspondência entre Posicionamento e Codificações (V6)

Campos	Correspondências	Sub-Capítulo a Consultar
A	Formato	Sub-Capítulo 1.1
B	Linha de Enchimento	Sub-Capítulo 1.2
C	Parte da Máquina	Sub-sub-Capítulo 1.3.1
D	Outros	Sub-sub-Capítulo 1.3.3 e 1.3.4

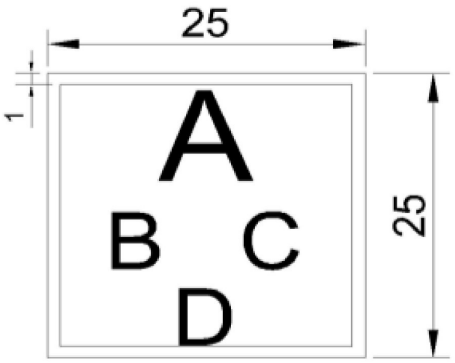


Figura 2.10 - Desenho de Implementação V6

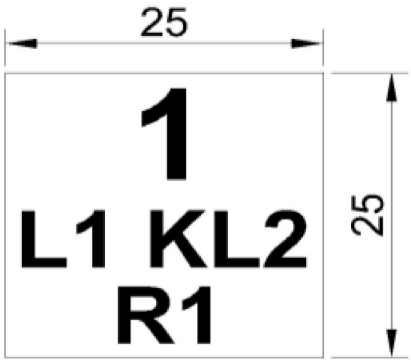


Figura 2.10 - Exemplo de Implementação V6

Figure F.7: Work Instruction - Physical Identification Architecture - Page 7

Appendix G

Work Instruction - Marker Fixation and Positioning

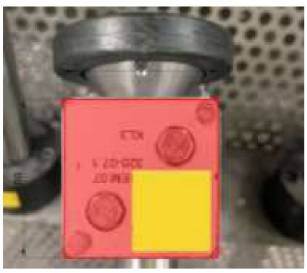
SUPER BOCK GROUP

4. Fixação às Peças de Formato

Definição e descrição da fixação das peças às Peças de Formato

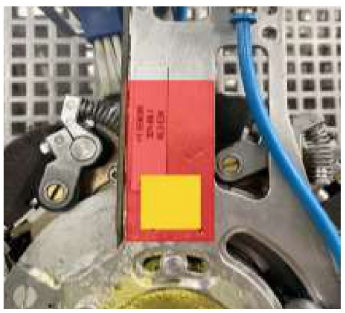
Este capítulo procurar servir de guia à fixação das peças de identificação às Peças de Formato. As zonas a vermelho são os locais passíveis de posicionamento da identificação. A amarelo encontra-se representada uma sugestão de fixação das peças.

4.1 Tomador de Cola



4.2 Cabeça de Pinças (KHS)

Existem, à data, duas variações da Cabeça de Pinças da KHS. De acordo com a peça a tratar, realizar conforme descrito nas figuras.
Ambas as identificações pressupõem a remoção/deslocamento da placa do fabricante, caso contrário não há posição para fixação.



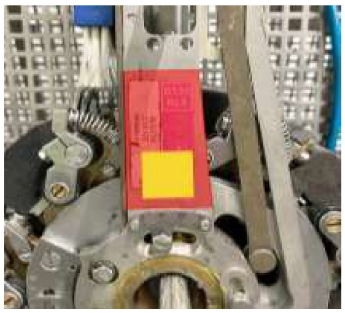
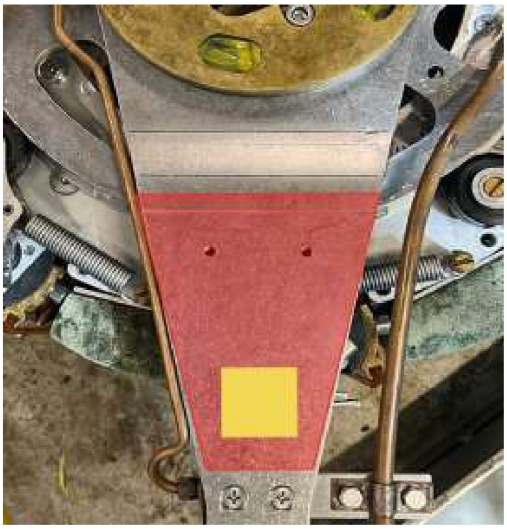


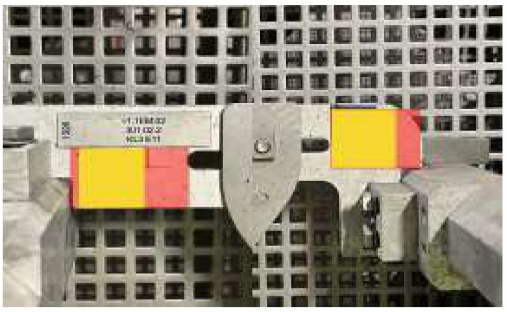
Figure G.1: Work Instruction - Marker Fixation and Positioning - Page 1

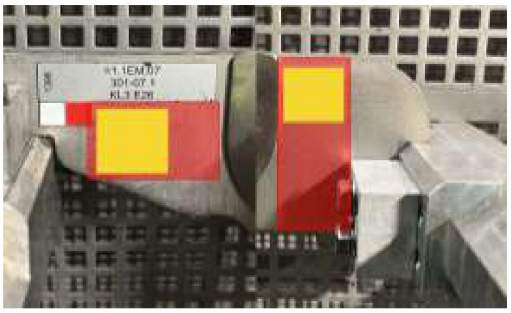
4.3 Cabeça de Pinças (Krones)



4.4 Ponte (KHS)

Semelhante ao sucedido nas Cabeças de Pinças, existem, à data, duas variações de Pontes. De acordo com a peça a tratar, realizar conforme descrito nas figuras.



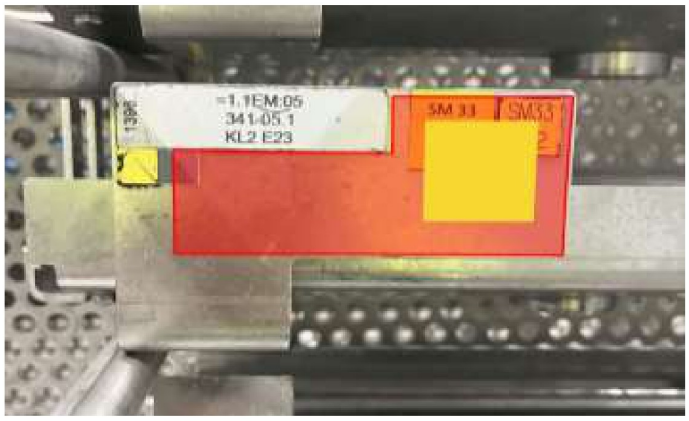


4.5 Ponte (Krones)



Figure G.2: Work Instruction - Marker Fixation and Positioning - Page 2

4.6 Cassete (KHS)



4.7 Cassete (Krones)



4.8 Empurrador (KHS)

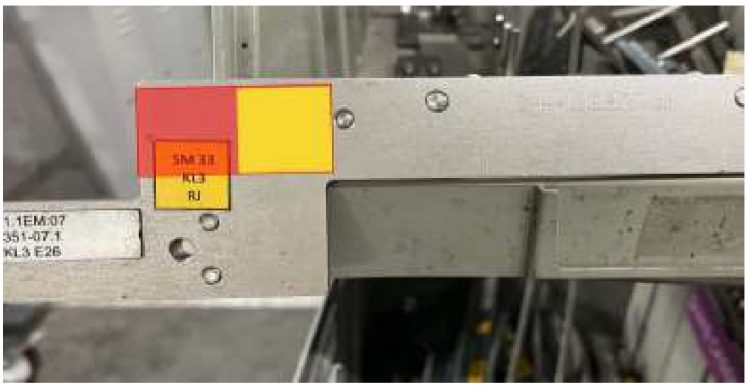
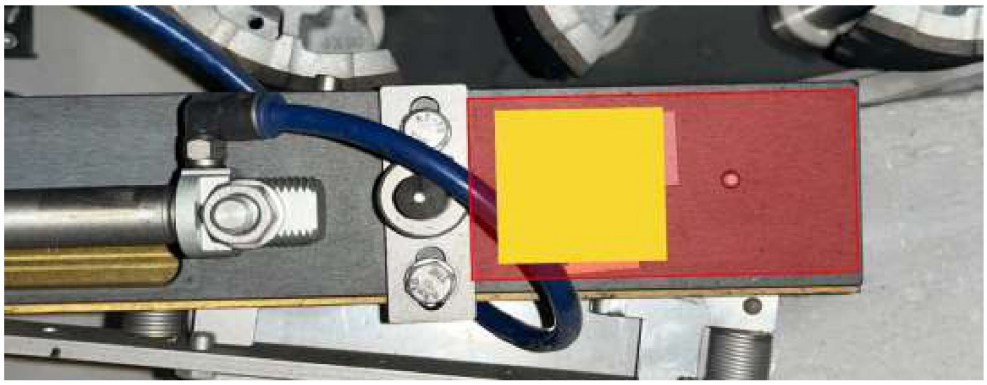


Figure G.3: Work Instruction - Marker Fixation and Positioning - Page 3

4.9 Guias Cassetes (KHS)



4.10 Réguas (Krones)



4.11 Escovas

Tal como explicado no Capítulo 2, a identificação das Escovas dá-se por aperto de uma peça. Não há zona definida para posicionamento. No entanto, recomenda-se que seja próximo do local de encaixe, ficando a posição da Escova na máquina virada para fora.

4.12 Calços

Tal como explicado no Capítulo 2, a identificação dos Calços dá-se por fabrico de novos já com a identificação. Posto isto, não há regras para posicionamento de identificação.

Figure G.4: Work Instruction - Marker Fixation and Positioning - Page 4

Appendix H

Gantt Chart - Labeller

This appendix outlines the macro-steps for a Labeller setup. Figure H.1 displays the process steps, whereas Figures H.2 and H.3 detail their sequence and timings. The case study features a changeover from the "Super Bock 0.20" SKU to the "Super Bock 0.25" SKU. Both configurations require a front label and a wrap-around neck label, differing on the neck label. The letter "E" on a determined step indicates that this task is external, either before or after the internal tasks.

Step ID	Description / Task Name
1	Format Parts Preparation
2	Packaging Material Preparation
3	Format Parts Checkup
4	Stop feed of packaging material in advance
5	Program Change
6	Remove glue system
7	Disassemble the aggregate unit
8	Remove format parts from the carousel and worm screw
9	Assemble format parts for the new reference
10	Assemble the aggregate unit
11	Aggregates collision check
12	Magazines Assembly
13	Assemble glue system
14	On the labeler panel, adjust the height
15	Synchronize the aggregates
16	Adjust height and depth of laser marking
17	Adjust aggregate position relative to the reference
18	Pre-Labeler adjustments
19	Level Inspector adjustment
20	Testing with bottle
21	Cleaning and Tidying up of Format Parts
22	Cleaning and Tidying up of Format Parts (aggregate components)

Figure H.1: Labeller Setup - Macro-Steps

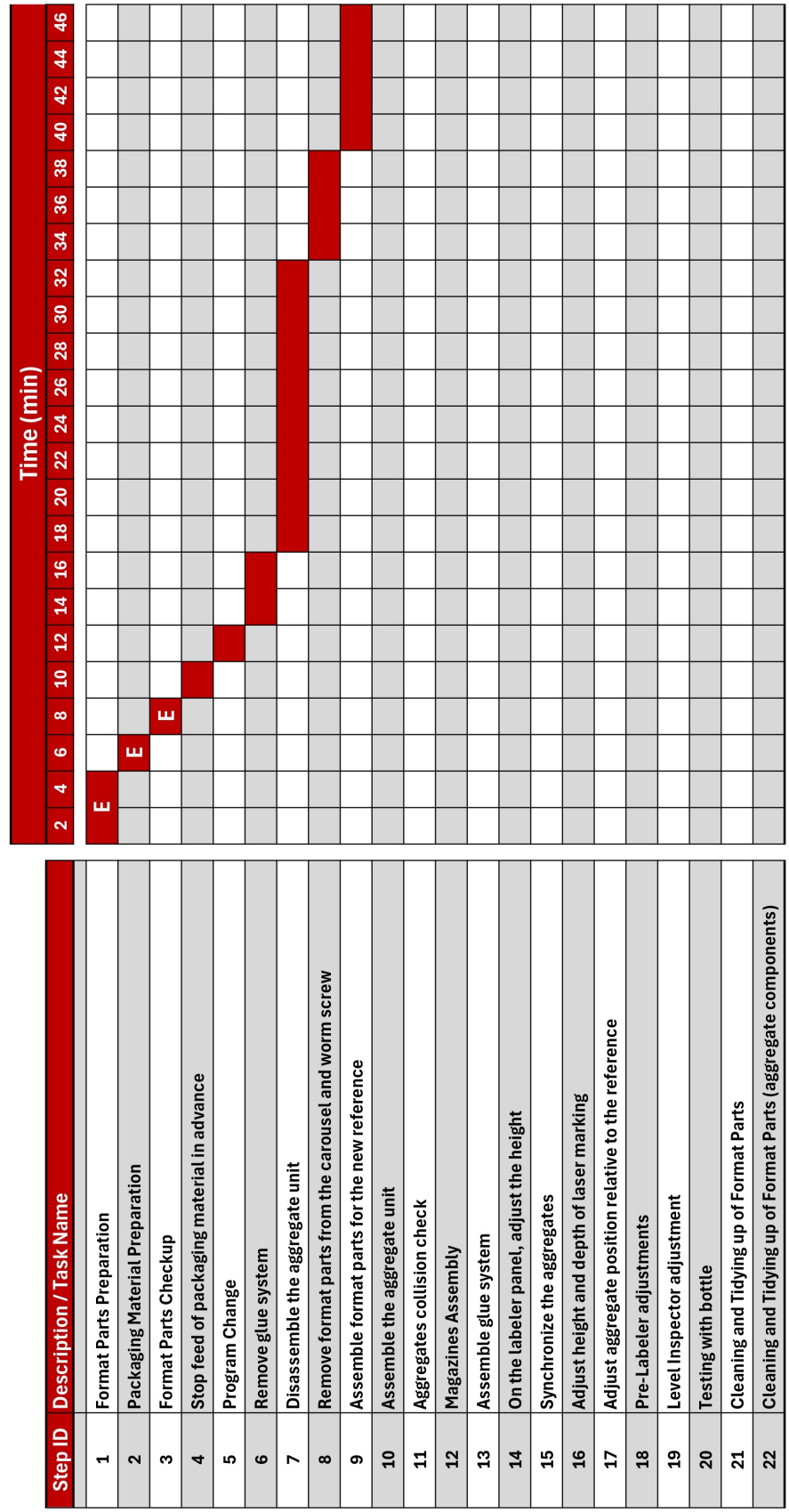


Figure H.2: Labeller Gantt Chart - Part 1

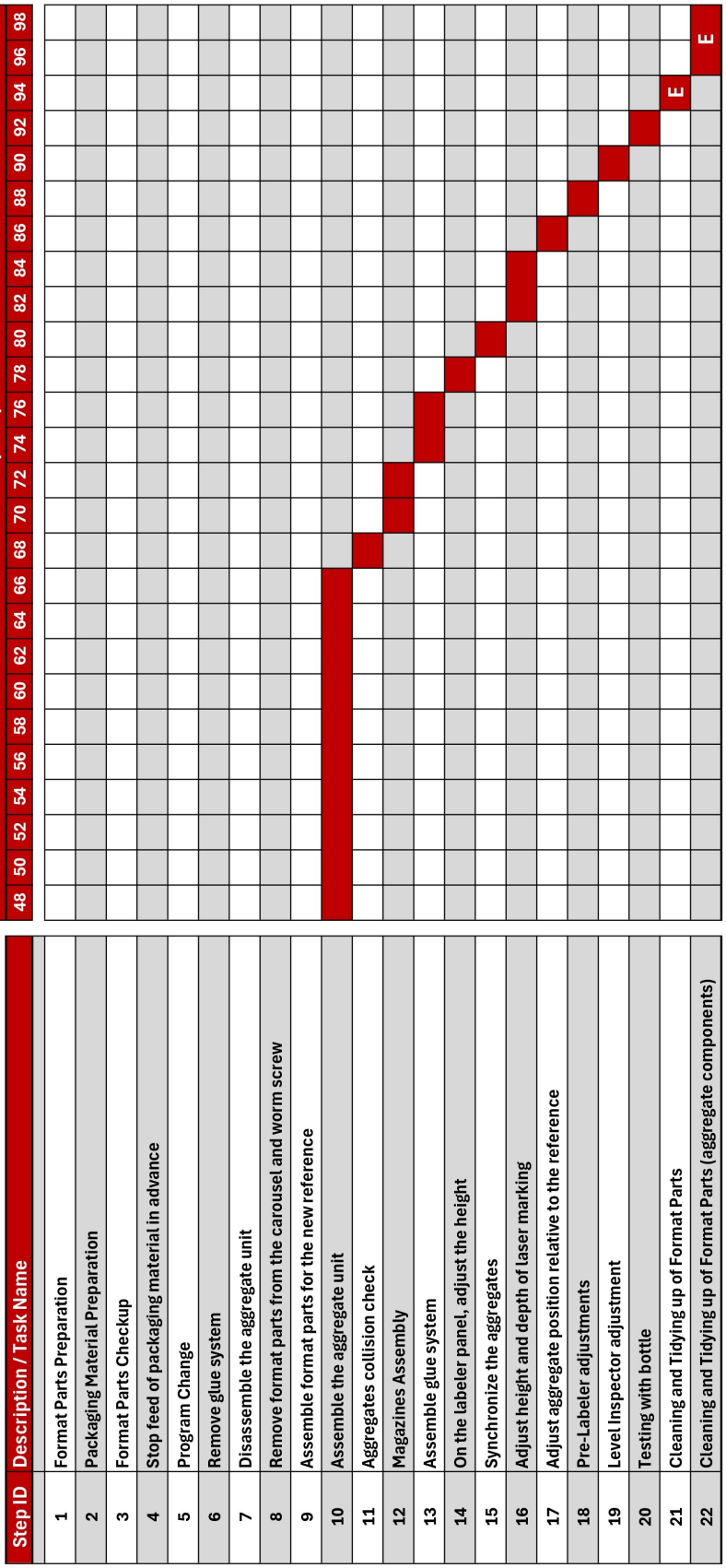


Figure H.3: Labeller Gantt Chart - Part 2

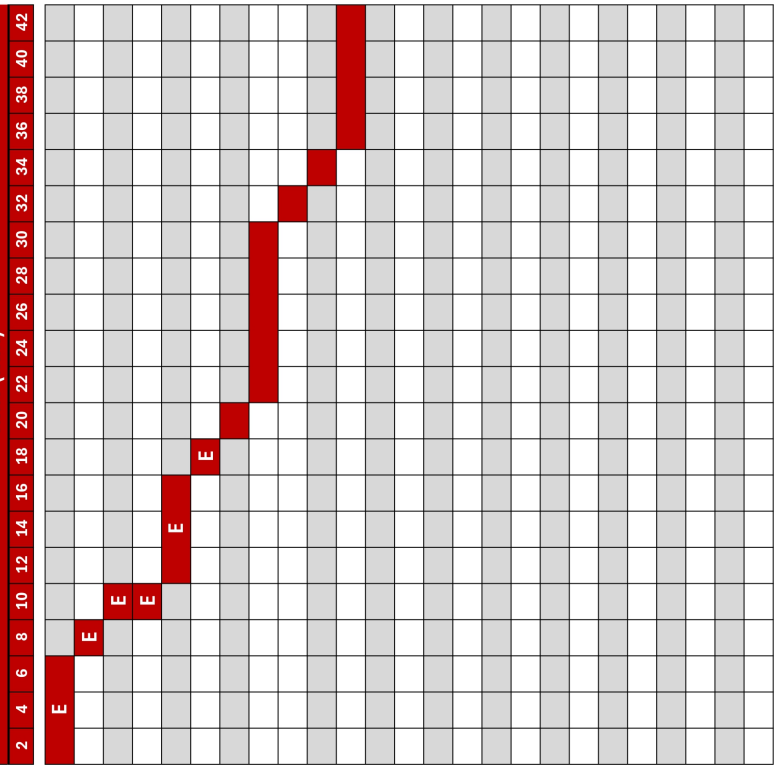
Appendix I

Gantt Chart - Filler

This appendix outlines the macro-steps for a Filler setup. Figure I.1 displays the process steps, whereas Figures I.2, I.3 and I.4 detail their sequence and timings. The case study features a changeover from the "Super Bock 0.20" SKU to the "Somersby 0.33" SKU. This type of change requires a complete change to the Filler and Capper, a crown design change, and CIP. The letter "E" on a determined step indicates that this task is external, either before or after the internal tasks.

Step ID	Description / Task Name
1	Fetch and check the condition of the New Format Parts. In case of an anomaly, create an M2 Note
2	On the Arsopi panel, select the New Order
3	Cut off bottles when the number indicated in the app is missing to finish the order.
4	Cut off crowns/caps as soon as 50,000 bottles are left to be filled (crown or POFF)
5	Start emptying the filler
6	Remove the last three bottles from the previous filling for testing, later taking them to the laboratory
7	After emptying the filler, press the STOP button and turn the button to Open Housing position
8	Empty the capper
9	On the filler panel, change the format to be filled - Type > Selection of types and select the reference to fill
10	Raise the machine to facilitate changing the format parts
11	Wash the Filler
12	Disassemble the Filler and the Capper
13	Wash the Filler
14	Assemble the Filler and the Capper
15	Adjust the height of the Blower, Filler and Capper
16	Adjust the inlet and Inliner guides
17	Install Broken Glass protection and adjust the Foaming Nozzle (5cm height)
18	Close the filler by turning the control buttons to the Production Mode and Cancel positions
19	Perform the synchronization of the format parts on the machine, selecting Service > Servo
20	Register the new cap change, open the octabin and select the desired one
21	Introduce an empty bottle of the new reference into the worm screw to ensure synchronisation
22	On the filler panel, start filling the new reference by selecting Open Blockage.
23	Remove the first three bottles of the current filling for testing, taking them to the laboratory
24	Perform self-control according to IP 1564
25	Wash with Hypofoam and inspect the format parts. In case of an anomaly, create an M1 note

Figure I.1: Filler Setup - Macro-Steps



Step ID	Description / Task Name
1	Fetch and check the condition of the New Format Parts. In case of an anomaly, create an M2 Note
2	On the Arsopi panel, select the New Order
3	Cut off bottles when the number indicated in the app is missing to finish the order.
4	Cut off crowns/caps as soon as 50,000 bottles are left to be filled (crown or POFF)
5	Start emptying the filler
6	Remove the last three bottles from the previous filling for testing, later taking them to the laboratory
7	After emptying the filler, press the STOP button and turn the button to Open Housing position
8	Empty the capper
9	On the filler panel, change the format to be filled - Type > Selection of types and select the reference to fill
10	Raise the machine to facilitate changing the format parts
11	Wash the Filler
12	Disassemble the Filler and the Capper
13	Wash the Filler
14	Assemble the Filler and the Capper
15	Adjust the height of the Blower, Filler and Capper
16	Adjust the inlet and Inliner guides
17	Install Broken Glass protection and adjust the Foaming Nozzle (5cm height)
18	Close the filler by turning the control buttons to the Production Mode and Cancel positions
19	Perform the synchronization of the format parts on the machine, selecting Service > Servo
20	Register the new cap change, open the octabin and select the desired one
21	Introduce an empty bottle of the new reference into the worm screw to ensure synchronisation
22	On the filler panel, start filling the new reference by selecting Open Blockage.
23	Remove the first three bottles of the current filling for testing, taking them to the laboratory
24	Perform self-control according to IP 1564
25	Wash with Hypofoam and inspect the format parts. In case of an anomaly, create an M1 note

Figure I.2: Filler Gantt Chart - Part 1

Figure I.3: Filler Gantt Chart - Part 2

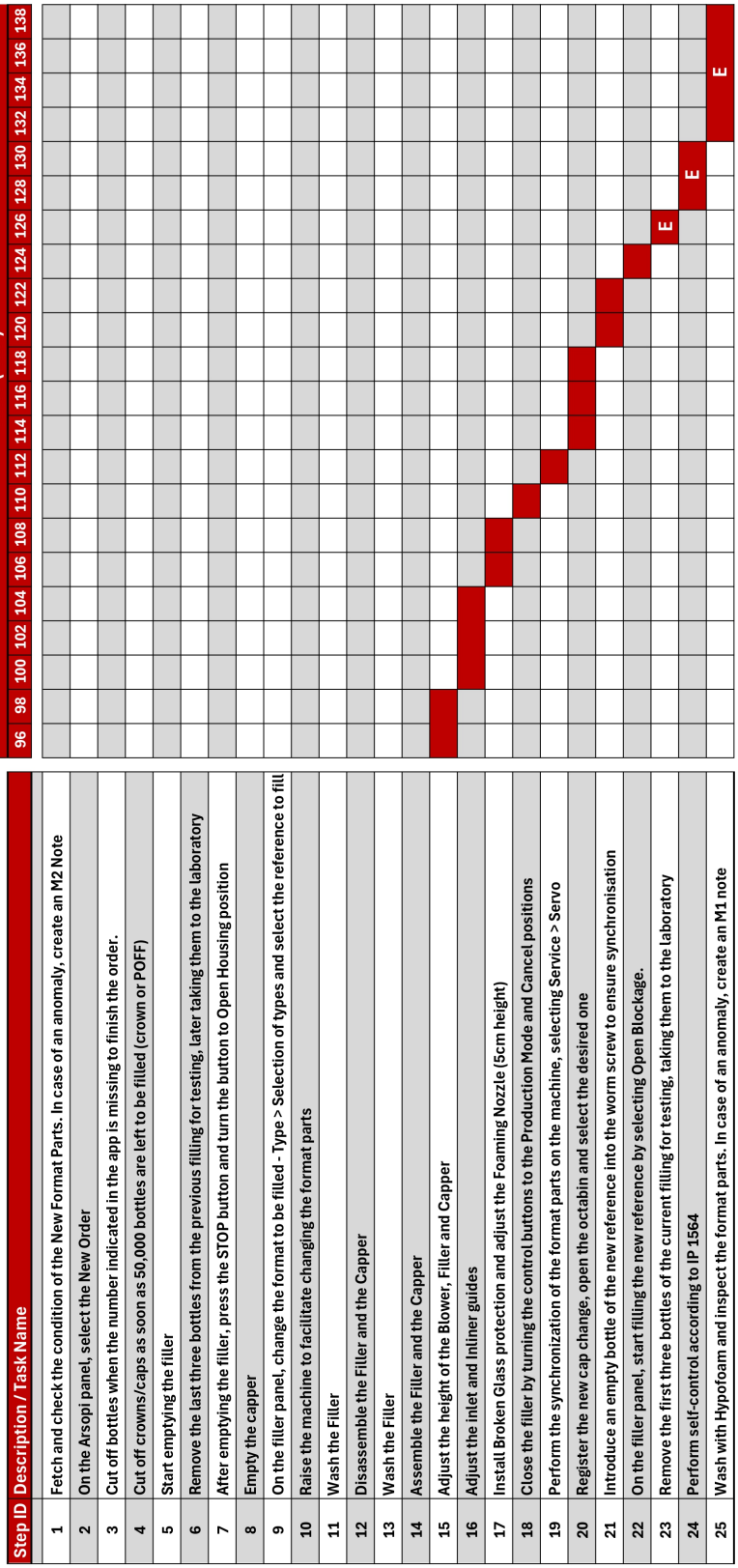


Figure I.4: Filler Gantt Chart - Part 3