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Original Article

Enhancing Operational Effectiveness in a Beverage Bottling SME through SMED, 5S, and TPM Maintenance Practices

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Abstract - *Small and medium-sized enterprises in the Peruvian beverage sector faced persistent challenges of low productivity, frequent machine stoppages, and excessive reprocessing that limited their competitiveness. Previous studies highlighted the effectiveness of Lean Manufacturing and Total Productive Maintenance (TPM), but their combined application in bottling SMEs remained underexplored. This research addressed the urgent need to enhance operational efficiency by proposing an integrated model based on 5S, SMED, and TPM practices. The model was applied to a bottling company in Lima, where effectiveness had reached only 68% of the expected benchmark, generating annual losses equivalent to 34% of sales. Implementation reduced changeover times, improved workplace order, and increased equipment availability, yielding measurable gains in throughput and reliability. These outcomes demonstrated not only academic relevance by filling a gap in industrial engineering literature but also socioeconomic impact by strengthening SME competitiveness. The findings encourage further exploration of dual Lean–TPM strategies in similar contexts.*

Keywords - *SMED Implementation, 5S Methodology, TPM Maintenance, Operational Effectiveness, Beverage Industry SMEs.*

1. Introduction

Bottling carbonated and energy drinks is a big part of the beverage industry today, and Small and Medium-sized Enterprises (SMEs) do much of it. They do more than just make things; they also create jobs, boost local economies, and give consumers more choices as they become more interested in variety and convenience. As lifestyles have changed to include faster consumption habits, their global importance has grown over the past ten years. Latin America has become a lively place in this market, with countries like Peru seeing big growth thanks to both local demand and opportunities to trade with other countries. This situation is a paradox for small and medium-sized Peruvian bottling companies: as consumer expectations and opportunities rise, so do the pressures of competing with multinational giants that have better technology and economies of scale.

Many bottling SMEs have strategic potential, but their production lines keep breaking down, which makes it hard for them to reach their goals. One of the most common problems is that machines are getting slower over time. This is often because the equipment is old, the setups are not standardized, or maintenance is not done on time. On top of that, long repair times after breakdowns stop operations and mess up delivery schedules. Reprocessing bad outputs, whether they are due to wrong carbonation, wrong labelling, or packaging problems, takes up more resources because it requires more labour and raw materials. These setbacks have both financial and strategic effects: companies become less flexible in responding to changing market demands, which could make them less competitive in an industry where timing and consistency are very important.

We need to fix these problems right away. In the bottling industry, customer loyalty depends a lot on the quality of the products and the reliability of the supply. Brand trust can be damaged by a single batch that is not consistent or a delay in restocking shelves. The margin of error is even smaller for smaller players. Every minute of downtime and every unit that needs to be reprocessed cuts into profits, leaving little room to reinvest in new ideas, marketing, or growth. So, fixing these operational problems is not only a technical need but also a way to stay alive. Studies on the productivity of Small and Medium-Sized businesses (SMEs) have shown that companies that use structured improvement programs are better able to handle competition and take advantage of new opportunities.

There are a lot of good ideas in the academic literature about how to improve processes, but most of them focus on big manufacturers. Small and Medium-Sized businesses (SMEs) in the beverage bottling industry have not been studied as much. Big companies have been using advanced systems to improve their operations for a long time, but small bottlers in Latin America often run into problems like not having enough money, not having the right technical skills, or not having the right frameworks for their needs. A lot of the evidence we have about Lean Manufacturing comes from case studies in the textiles, automotive, or general food industries. These studies show that Lean tools like Single-Minute Exchange of Die (SMED) and 5S can help with things like lower defect rates and smoother workflows. However, very few have looked into what happens when these tools are used with Total Productive Maintenance (TPM) strategies like Autonomous Maintenance and Planned Maintenance in the beverage bottling industry. This gap in the research is what this study is based on.

Lean Manufacturing is well-known for being able to cut down on waste and make processes run more smoothly. These are two things that are very important for bottling SMEs. For example, SMED is very useful when frequent product changes cause a lot of downtime. This tool frees up valuable capacity that can be used for production by systematically cutting down on setup times. 5S also helps create organized and standardized workplaces, which reduces mistakes and makes them safer. SMED can cut setup times by more than half, which means more throughput, according to real-world data from SMEs. The 5S method has also been linked to fewer defects and smoother workflows, which are very important in bottling plants where mistakes in packaging happen all the time and hurt productivity.

TPM adds to Lean by shifting the focus from losses that are only related to processes to equipment reliability and giving operators more power. Autonomous Maintenance tells machine operators to do regular checks and small repairs, which lowers the chance of sudden breakdowns. Planned Maintenance, on the other hand, makes sure that preventive actions are scheduled before breakdowns happen, which keeps costs down by avoiding costly delays. Research on Small and Medium-Sized businesses (SMEs) shows that adopting TPM makes machines more available and cuts down on average repair times. This creates a culture where everyone in the company is responsible for operations. TPM has been shown to work well in other industries, but it is still not widely used by small beverage bottlers. This is a missed chance to make equipment more reliable.

This study suggests an integrated production model for Small and Medium-Sized businesses (SMEs) in the beverage bottling industry that combines Lean Manufacturing and TPM. Not only is it new to use these methods, but it is also new to combine them in a smart way to solve the three biggest operational problems: slow machine speeds, long repair times, and high rework rates. Previous studies have shown that using Lean or TPM alone can lead to some improvements, but there is not much evidence that using both together works well in this specific field. The goal of this study is to fill this gap by showing, using a case study from Peru, how combining the two methods produces better results than either one does on its own.

This method also puts the research contribution in context with what has already been found in similar fields. For instance, the use of Lean in small and medium-sized textile businesses has greatly lowered defect rates and increased worker productivity through targeted SMED and 5S programs. In the same way, TPM programs in small and medium-sized food processing companies have worked to improve machine availability and lower repair costs by getting operators more involved. But none of these studies looked at the two methods together in the context of small businesses that bottle drinks, where the problems are both unique and urgent. The study adds new evidence to the field by testing this dual framework in the real world. It also gives managers who are dealing with similar problems useful advice.

In conclusion, small and medium-sized businesses that bottle carbonated and energy drinks are important for economic growth, but they are still at risk because they are not running their businesses efficiently. The current study recognizes their strategic importance, describes the main issues hurting their performance, and presents a model that combines Lean and TPM practices to deal with those issues. The work not only adds to the academic conversation about industrial engineering, but it also gives practitioners useful solutions. Its uniqueness comes from proving that a framework for a specific industry can help small and medium-sized businesses become more competitive in both local and international markets.

2. Literature Review

2.1. Changes in Lean Manufacturing for Small and Medium-Sized Beverage Companies

Lean Manufacturing has become a popular way to come up with new processes, even in fields that are usually very conservative, like food and drinks. A review showed that lean implementation in the food industry was historically limited, with only a few published studies at the time showing that it was not widely used [1]. This is in line with what was found in food SMEs, which had a slow uptake of lean [2]. Even though they were hesitant in the past, recent case studies of small food and beverage companies show that lean tools can lead to big improvements in how they work. For example, two small Portuguese businesses in the food and drink industry used a set of lean practices (5S, Kaizen, etc.) and saw big changes. The lean program created a culture of continuous improvement, made production more flexible, and cut delivery times [3]. A Peruvian maker of carbonated drinks that was dealing with a lot of waste and inefficiency used Lean Manufacturing principles and got amazing results: the rate of product defects dropped by 32%, Overall Equipment Effectiveness (OEE) went from 61% to 81%, and unplanned downtime was cut by 48% after lean-based process improvements [4]. Another study used lean methods and Reliability-Centered Maintenance in a small business that bottles soft drinks. This led to an 8.8% increase in process efficiency by getting rid of waste and making the workflow more efficient [5]. These examples show that Lean Manufacturing, which was first used by big car companies, can also work well for small beverage bottlers, resulting in real improvements in quality, efficiency, and responsiveness [3], [4]. In short, Lean Manufacturing can change the way beverage SMEs make things, allowing them to cut losses and compete with much larger companies [4, 5].

2.2. SMED: Fast Changeovers on Bottling Lines

Changing flavors or package sizes often is a big reason why beverage bottling stops working. In this case, the Single Minute Exchange of Die (SMED) method was used to cut changeover times significantly and increase productivity. One case study showed how a Small Manufacturing company used SMED to get rid of unnecessary steps and activities that did not add value, saving an estimated €360,000 a year (about 2% of sales) [6]. SMED has been shown to work well in beverage packaging lines to make it easier to switch between different flavors or bottle formats. A recent study at a Latin American non-alcoholic beverage company used SMED principles (separating internal and external tasks, doing things at the same time, and making quick changes) to cut the time it took to change flavors from 234 minutes to 170 minutes, which is a 27% improvement. This saved a lot of money on downtime costs [7]. Another Polish food and drink company used SMED and 5S to organize the Workplace. They focused on a filling line that changed over 15 times a month. The company looked at its current procedures (which were different for each operator and were not standardized) and moved some tasks to outside workers. This led to an 11% increase in production efficiency without any capital investment, saving the company over €100,000 a year in time [8]. A Small and Medium-Sized business (SME) bottler in Peru added SMED to its lean toolkit and saw setup and adjustment times drop by 30.8%, which led to more throughput [9]. These studies show that SMED really does shorten changeovers. For example, they show that different crews do changeovers in different ways, that there is no standard work, and that machines are idle while they are not in use [2]. Beverage SMEs can get to changeovers that take less than ten minutes by systematically dealing with these problems, such as staging materials and tools ahead of time, standardizing the changeover sequence, and training operators. In short, SMED methodology has worked well on packaging lines for carbonated drinks and food. It has led to faster changeovers, more machine uptime, and big productivity gains [7], [8].

2.3. 5S for Quality and Order in the Workplace

The 5S method (Sort, Set in order, Shine, Standardize, Sustain) is often the first step for Small and Medium-Sized businesses (SMEs) to become lean. It focuses on keeping the Workplace clean and organized. 5S has been used in Small and Medium-Sized businesses that bottle drinks to make production areas safer and more efficient at a low cost. A Peruvian study used 5S in a food and beverage company's warehouse and production areas. This made the workflow more organized, which improved the flow of materials and cut down on the time it took to complete a process [4]. A case in Bangladesh also used 5S in a beverage production plant and saw many benefits: it freed up floor space, got rid of unnecessary inventory and junk (which saved money), and operators were more productive with fewer defects and rejections after they cleaned and organized their workstations. These kinds of changes are common in 5S. By getting rid of clutter and making tools and materials easy to find, businesses cut down on mistakes and wasted motion. One small business saw a direct effect on quality when it started using 5S and good housekeeping: an Indonesian SME saw its product defect rate drop from 12% to 0% in just one month after starting 5S and a PDCA routine [10]. This defect removal saved the company a lot of money on rework and scrap, and it was done with only a small amount of money spent, showing a high ROI [10]. Research shows that 5S improves many areas of performance in a more general sense. For instance, a case study in a small manufacturing company found that after a 5S program, productivity went up by 87%. This was mostly because workers saved time and worked more efficiently in a newly organized workspace [4]. For small and medium-sized beverage businesses, keeping the bottling line clean and organized is important for both efficiency and product safety and compliance. Evidence from a variety of fields shows that using 5S leads to cleaner, safer work areas, less waste, and more work done [10].

2.4. In TPM, Autonomous Maintenance is Called Jishu Hozen.

Total Productive Maintenance (TPM) is a part of Autonomous Maintenance (AM) that gives machine operators the power to do basic maintenance tasks like cleaning, lubricating, inspecting, and tightening to keep equipment running [11]. Autonomous maintenance has been very useful for Small and Medium-Sized businesses (SMEs) in the beverage industry, where maintenance resources are limited and unplanned downtime can have a big effect on output. A case study from a beer bottling plant showed that operators who were trained to clean and check a critical filler/capper machine increased the Mean Time Between Failures (MTBF) from 87 hours to 113 hours (30% improvement) and the Mean Time to Repair (MTTR) from 1.15 hours to 0.87 hours [12]. This meant that the filler was more reliable during a 12-hour shift, going from 87% to 90% [12]. A beverage company in Indonesia also used a structured FMEA approach to set up an AM regime on a filling line, which cut breakdown rates by 40–60% on the machine they were targeting [13]. AM programs make daily maintenance tasks (Clean, Inspect, Lubricate, Tighten) the same for everyone and help operators form new habits. They also help find signs of wear before they get worse [11]. Studies show that these kinds of practices not only reduce downtime but also make things safer and boost morale, as operators learn new skills and take ownership of their work. For small and medium-sized beverage companies, the result is a big rise in availability and OEE [12, 13].

2.5. Planned Maintenance and Preventive Care in TPM

Operators do autonomous maintenance, but Planned Maintenance, which is another part of TPM, is when dedicated technicians do scheduled preventive maintenance and repairs to keep equipment from breaking down. Small and Medium-Sized businesses (SMEs) in the carbonated and energy drinks sector can greatly improve the reliability and performance of their equipment by putting in place a strong planned maintenance program [14]. In practice, preventive maintenance has worked very well. A Nigerian beverage bottling company put in place a structured maintenance plan and said that OEE rose by 50% within a week of starting TPM [14]. An SME in Peru combined planned maintenance with lean improvements, and after the changes, the OEE went from 62% to 82%, which meant that there were far fewer breakdowns and minor stops [4]. When preventive maintenance was put in place, failures went down by 81% per year, and hours lost to maintenance went down by about the same amount [4]. Another study found that interventions for preventive and predictive maintenance led to a 4.66% increase in MTBF and a 21.6% decrease in MTTR. This means that production went more smoothly and with fewer interruptions [9]. A Peruvian beverage company's lean-TPM program, which included planned maintenance, cut equipment downtime by almost half and increased OEE by 20 percentage points [4]. These cases show that Planned Maintenance is very important for small beverage companies. By scheduling inspections, part replacements, and overhauls during non-production hours, SMEs can avoid major equipment failures and keep their throughput steady [14].

3. Contribution

3.1. Proposed Model

Figure 1 illustrates the proposed production model, which synthesizes Lean Manufacturing precepts with Total Productive Maintenance (TPM) activities adapted for a small-to-medium beverage enterprise committed to the manufacture and wholesale of carbonated and energy drinks. The initial phase deployed the 5S framework, which systematized workplace organization and cleanliness, curbed non-value-adding activities, and institutionalized operation-standard conditions. The second intervention, the Single-Minute Exchange of Die (SMED) technique, targeted minimization of bottling line changeover intervals—an imperative given the pronounced product heterogeneity and the imperative of agile market responsiveness. Third, the TPM program was generalized with a specific focus on the participatory role of operators in preventative, corrective, and predictive maintenance operations. This step sought to heighten equipment availability, curtail unplanned defects, and valorize operator ownership of machinery integrity. Collectively, the three systematic undertakings were articulated to promote a unifying goal of ongoing enhancement, attenuation of systematic and random variability, and fortification of process dependability, thereby positioning the enterprise not only to elevate operational efficiency but also to defend its product and market vitality in an environment defined by pronounced volatility of consumer preferences and recurrent competitive pressures.

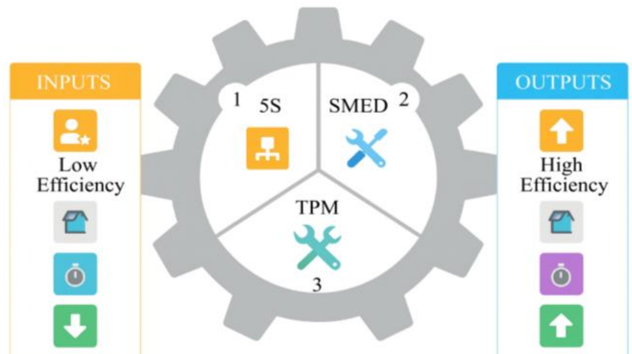

Fig. 1 Proposed model

3.2. Model Components

The proposed model serves as an intentional answer to the systemic obstacles encountered by small and medium-sized enterprises in the beverage industry, focused on operators of bottling lines and wholesale distribution channels for carbonated and energy drinks. Its architectural skeleton is constructed from an integrated blending of Lean Manufacturing doctrines and Total Productive Maintenance tenets, with the explicit targets of curtailing non-value-added activities, heightening agility, and fortifying the dependable flow of production processes. The framework avoids presenting the operational instruments in a piecemeal manner; instead, it unveils them in a seamless and sequential order, in which systematic workplace organization, reduced setup-time methodologies, and the continuous improvement of equipment ultrasonic(s) (vaccine of equipment) mutually reinforce each other. A central representation of the model appears in Figure 1, while the subsequent sections delineate the compelling and purposeful application of each of its distinctive constituents within a typical beverage SME.

3.2.1. 5S as the Foundation for Order and Discipline

The model is anchored by an unwavering commitment to the 5S methodology, the lever through which the workstation achieves and sustains a threshold of operational discipline. Within the beverage bottling context, the uninterrupted throughput of primary and ancillary materials—granulated sugar, concentrated syrups, preformed PET containers, aluminum closures, and assorted wrap stock—insists on an environment where items are always easy to see, easy to reach, When the team extracts chipped hand tools, expired spare part inventories, and empty, mislabeled cleaning-chemical containers, the potential for error is minimized, and the often-estranged footprint on crashed floor space is returned to the shrinking physical resource of the plant.

Upon the successful removal of excess items, the operation enters the phase of logically setting things in order. This stage mandates that every instrument, part, or resource possess an assigned, clearly marked location, enabling operators to retrieve filling valves, calibration weights, or sanitizers without the slightest pause. For instance, changeover kits tailored to diverse bottle configurations are mounted on shadow boards positioned fewer than two steps from the processing station. The persistent visibility of these kits pre-empts the operator from spending unproductive minutes scouting for clamps or resetting wrenches, thereby shrinking the window of downtime attendant to product changeovers. Adopting the same principle, raw material stacking is likewise rationalized: pallets of PET preforms, or syrup cylinders, occupy defined bays, each demarcated with tape and signage, rendering their occupancy and readiness instantly observable.

The subsequent shin, or cleanliness, stage assumes heightened criticality in the beverage sector, where sanitary compliance is not discretionary. The daily cleansing protocols are designed to achieve more than the mere removal of granularity; they comprise an exhaustive purification of conveyors, filling nozzles, and carbonation reactors. By evenly distributing the cleaning work among operators, latent reservoirs of microbial entrance points are brought to light, permitting prophylactic intervention. Concurrently, isolated issues, such as pinhole leaks in infrastructure or unexpected resonance in rotary bearings, are detected while operators are still within the zone of operation. As a result, maintaining cleanliness is transformed from a question of aesthetics to a proactive tool for preventing process errors and preserving product quality.

Goal-driven behaviors are transformed into disciplined habits during the fourth phase, standardization. The facility's organized end-of-shift checklists guarantee that every operational discipline—verifying that tools are returned to shadow boards, carrying out comprehensive line sanitization, and replenishing consumables—occurs in a consistent order. Temporary attention is transformed into permanent practice through this methodical repetition.

On the other hand, the sustain phase never ends and requires constant group focus. Regularly scheduled audits establish a common frame of reference by taking a developmental rather than a punitive approach. Work groups evaluate whether floor markings are being followed, whether cleaning is thorough, and whether storage procedures are being followed. The workforce internalizes a custodial pride ethic as a result of these introspective assessments, viewing a neat workplace as the most obvious indicator of professional identity.

Within the bottling line, the 5S methodology has a discernible impact. Operators minimize redundant motion by moving through their zones with practiced efficiency. Production modules are ready for start-up in hygienic conditions, bulk additives are properly staged, and instruments are located in conspicuous locations. The pedagogical value of 5S is consistently evident beyond operational machine efficiency: each team member understands that disorder spreading from one island of activity may ripple and jeopardize the harmonic flow of the entire bottling cylinder. The reduction of micro-inefficiencies converges into a strategic advantage that increases plant capacity, enabling timely order fulfilment and insulative responses to demand peaks, all without undue and obvious stress on the workforce, for a small-to-medium beverage company operating under the pressure of wafer-thin margins.

Fundamentally, the 5S framework establishes the bedrock upon which the entire operational model balances. Absent sustained discipline of the physical plant, initiatives to compress changeover durations or to nurture asset reliability inevitably confront latent inertia. By cultivating a physical atmosphere in which deviation radiates immediately, the practice renders noticeable and unmistakable no-affordance to deviance, thus enabling subsequent techniques to develop, mature, and contribute in a harmonised and disciplined manner.

3.2.2. SMED as a Lever for Flexibility and Responsiveness

Following the instantiation of workplace order and standard hygiene, project expansion proceeds to the Single-Minute Exchange of Die (SMED) methodology, which confronts a primary constraint within the beverage filling operation: the cumulative duration of transitions between distinct product sizes. At the facility examined, market behaviour dictates rapid cycling among 500-ml carbonated soda, 1-litre energy drink, and 1.5-litre family-format bottles. Each transition introduces mechanical repositioning of filling nozzles and capping heads, a full sanitation cycle, and recalibration of processing parameters.

Under the facility's previous operation, changeover durations frequently surpassed the one-hour benchmark, leaving equipment dormant and pending customer orders growing. Systematic SMED deployment clarifies the distinction between internal and external activities. Assigning the decontamination of changeover kits, preparation of guide rails, and verification of label rolls to "external" tasks permits these to advance concomitantly with product flow. Consequently, the stoppage itself requires the completion of only internal activities, thus minimizing the duration of machinery inactivity.

A representative changeover from 500-ml to 1.5-L packs exemplifies the ongoing improvement. Under the legacy approach, the operator would idle the line, spend valuable minutes gathering unrelated tools, install new guide rails, manually scrub the filler, and laboriously adjust the capper. Application of SMED eliminated non-value-added steps: rails and clamps are now color-coded and stored at the workstation, tools reside on labelled shadow boards, and non-product-contact parts receive preventive cleanings on a designated trolley nearby. Consequently, the line stop is devoted solely to removing and replacing format-specific elements, followed by a well-documented verification of pressure, torque, and speed settings. As a consequence, the overall idle period shrinks to a fraction of its former magnitude.

Standardization sustains the impressive gains. Production sheets prescribe with precision each torque target for capper segments, the specific strokes of syrup-flow ball valves, and the verification order for totalizer scales. Cross-shift operators rehearse the same memorized steps and checks, calming differences in speed and attention fatigue while achieving minimal out-of-tolerance readings. Where expedient, designers substitute quick-disconnect fasteners for conventional bolts and sliding fingers, thus permitting operators to release batching clamps and to reposition guide fingers with the moderate flick of a safety latch rather than a full socket procedure.

Beyond the obvious technical improvements, the Single-Minute Exchange of Die (SMED) methodology cultivates a culture of cross-functional collaboration. No longer is the changeover viewed as the domain of a lone operator; it morphs into a coordinated team operation, with preparatory duties carefully parceled among staff. Consequently, one operator might be responsible for sanitation, a second for adjusting the bottle guider rails, and a third for ensuring that the labeling ribbons are correctly tensioned. The deliberate diffusion of tasks compresses the available changeover interval.

The advantages precipitated by SMED reach well past throughput acceleration. When the method shortens the transition time, the facility gains the latent capability to react instantaneously to demand surges. For example, a retailer may unexpectedly place a large order for energy drinks, and the production line can shift to that format with minimal notice, leaving production schedules intact and inventory lead times unaffected. This rapid responsiveness reassures customers that the manufacturer possesses the operational dexterity to meet evolving market dynamics.

Furthermore, the compression of setup times unintentionally weakens the justification for large production lots. Rather than generating surplus inventories of a single SKU to ration the infrequent changeover, the facility can schedule smaller, more frequent production runs that more precisely mirror actual customer demand. This practice decreases in-process inventory carrying costs, diminishes the danger of product spoilage, and mitigates the risk of having unsaleable energy drinks, which are subject to a diminished shelf life relative to more stable beverage categories.

In conclusion, SMED reframes previously disruptive changeovers as a structured, repeatable procedure. It converts idle time into an orchestrated, time-boxed activity, allowing operations to regain fluidity. Within a high-throughput beverage environment, this disciplined approach yields superior line utilization, synchronizes production rhythms with real-time demand signals, and fortifies Lean's central tenet of maximizing value by minimizing waste.

3.2.3. Total Productive Maintenance (TPM): A Reliable Path Guided by Collective Commitment

The model's third pillar, TPM, focuses on a deliberately narrow but strategically vital remit: autonomous maintenance and planned maintenance. By honing in on these two dimensions, the decision aligns with the resource realities encountered by a medium-sized bottling facility while still safeguarding the overriding imperative of equipment reliability. Autonomy empowers operators to cultivate a preventative culture, and planned maintenance embeds rigorous schedules, thus embedding shared stewardship into the facility's operational DNA.

Autonomous maintenance serves as the enterprise's initial safeguard against equipment deterioration. Operators receive instruction and mandate to execute routine tasks—namely, visual checks, surface cleaning, and low-skill repairs—on a daily schedule. Within the beverage-processing environment, this work encompasses, for instance, the removal of syrup residue from filling-valve surfaces, the intermittent application of lubricant to conveyor bearings, and the visual verification of gaskets inside carbonation tanks. While none of these actions necessitate advanced training, all of them are decisive in curbing the build-up of debris and in postponing the advance of mechanical wear. Daily involvement in these duties yields a perceptible bonus: operators strengthen their instinct for irregular phenomena. Consequently, a variation in the harmonic balance of a filler, or the discovery of a pin-prick leak in a compressor housing, is documented and escalated at the earliest opportunity, thereby forestalling the escalation of a minor abnormality into a production threat or a substantial repair bill.

Planned maintenance enhances the continuous improvement framework by embedding systematic interventions designed by the technical team. Maintenance cycles for each asset are commensurate with its criticality; consequently, technicians draft rotating schedules delineating calibration, part substitution, and comprehensive refurbishments. Carbonation tanks, compressors, and labeling apparatus are serviced per cycles, harmonizing original equipment manufacturer guidance with the idiosyncrasies of the plant's operational profile. Significantly, the schemes are not conceived in isolation; rather, their efficacy is augmented by operational insights accrued from operators in the course of autonomous daily checks, thereby creating a continuous information loop in which minute observations progressively mold the design of larger, periodic interventions.

The interplay of autonomous and scheduled tasks yields an environment of dependable production while restraining the SME's exposure to the full extent of Total Productive Maintenance's eight conceptual pillars. Responsibility for asset condition is thereby distributed: operators tend to anomalies that are overt and imminent, whilst technicians confront those that are intricate and cyclical. The twin-pronged approach concomitantly diminishes the incidence of unanticipated plant halts, prolongs the operational life of the equipment, and stabilises production variability.

By reframing maintenance as a collective cultural commitment, the enterprise shifts how personnel view their daily roles. Operators cease regarding preserving equipment as a specialized, remote activity; rather, they internalize that their continuous watch assures the bottling line's rhythm. Concurrently, technicians move beyond a reactive troubleshooting posture, applying data-driven foresight to schedule interventions that sustain reliability. Within an operational climate where delivery schedules are sacrosanct and the cost of unscheduled stops is measured in both euros and reputation, this consolidated stewardship translates into an effective competitive moat.

The deliberate interjection of maintenance into the plant's procedural heartbeat serves the dual purpose of insulating production from sudden stoppages and reinforcing the membrane of Lean thinking that pervades the model. In that view, each team member is both convener and guardian of efficiency, sources of waste are intercepted before they materialize into events, and process architecture is iteratively renovated in the search for stable, predictable outcomes. By actualizing only two of the total eight TPM pillars, the Organization threads a judicious line between lofty intention and hard operational artifact, preserving reliability despite chronically shallow resource pools while incrementally maturing the model commensurate with the realities of a small enterprise.

3.2.4. Operational Integration: A Drive with No Friction

The interlace of 5S, SMED, and the chosen TPM pillars converts the floor into a cohesive mechanism, with every station and asset devoted to the flow of the next. Observed tidiness and standardized arrangement expose hidden problems, minimized changeover times grant adaptive capacity, and the fundamental robustness of equipment guarantees a steady rhythm. The result is a drive that rotates without backlash: each discipline guarantees the integrity of the next, and systemic friction is diminished. Viewed collectively, the effort transcends discrete initiatives and matures toward a durable operational frontier.

3.2.5. Phased Deployment: The Method of Advance

The rollout proceeds in hypertrophy (commitment to each stage of development and capacity). The starting cycle is to entrench 5S, for only after the Workplace is released from disorder can the next stage prevail. SMED is then activated on the most common and most expensive changeovers, after which TPM is aligned with successive and planned maintenance so that reliability is reinforced with manageable input. Phased acceleration of each of these pairings, and neglecting patterning of the imperatives, ruins each responsibility. The wide framework is relentlessly embedded in the Pace Media, with every initiation of this can.

3.3. Model Indicators

The assessment of the beverage production model for small- and medium-sized enterprises was underpinned by a coherent battery of performance indicators built expressly to gauge the model's holistic effectiveness. Each of the metric categories was concretized to the peculiar working circumstances governing the lines for carbonated and stimulant drinks, thereby anchoring the evaluative toolkit to the empirical realities of the subsector. The ensuing analytically regimented procedure yielded a panoramic, integrative sketch of the production complex, which in turn constituted a durable backbone for real-time surveillance and a compass for judicious deliberation. These conditions have sustained the progressive reinforcement of operational productivity and assured the perpetuation of systemic enhancement across the manufacturing estates of the surveyed firms. In the next paragraph, the indicators applied to assess the proposed model are developed.

Effectiveness

This indicator reflects the alignment between actual and planned production, highlighting the capacity of the plant to achieve its monthly targets and overall operational goals.

$$\text{Effectiveness} = \left(\frac{\text{Actual Monthly Production}}{\text{Planned Monthly Production}}\right) \times 100$$

Transfer Time

This measure captures the efficiency of internal logistics by evaluating the duration between the start and end of material or product transfer within the plant.

$$\text{Transfer Time} = \text{End Time} - \text{Start Time}$$

Trained Workers

This indicator expresses the proportion of the workforce that has received proper training, reflecting the company's efforts in skill development and operational readiness.

$$\text{Trained Workers} = \left(\frac{\text{Number of Trained Workers}}{\text{Total Number of Workers}}\right) \times 100$$

Measurement of Disorder in Plants

This metric quantifies workplace organization based on 5S audits, indicating the extent of order and discipline achieved in the production environment.

$$\text{Disorder Measurement} = \left(\frac{\text{5S Audit Result}}{5}\right) \times 100$$

4. Validation

4.1. Validation Scenario

The validation scenario was carried out in a case study corresponding to a Small and Medium-Sized enterprise (SME) in the beverage sector, located in Lima, Peru, with additional operations in another region of the country. The company specializes in the production and commercialization of carbonated and energy drinks, sustaining more than twelve years of market presence. Its products were regularly supplied to supermarkets, which reinforced its position in the modern trade channel. The organizational structure consisted of a small administrative team, a plant workforce, and interns who provided direct support to the production process. All stages of beverage manufacturing, from ingredient preparation to final bottling, were developed internally. Despite this capacity, the enterprise faced constraints in production efficiency, which translated into losses in operational capacity and difficulties in meeting overall demand. These challenges highlighted the need for structural improvements in its management approach to strengthen competitiveness and ensure long-term sustainability.

4.2. Initial Diagnosis

The diagnostic investigation of the production system, as articulated in the accompanying case study, established that the principal constraint is the inadequate operating effectiveness of the manufacturing process, which attained only 68% of the established benchmark of 95%. This disparity has materialized as a pronounced economic detriment, conservatively projected at PEN 76,146 per annum, equivalent to 34% of yearly sales losses. Detailed decomposition of the shortfall reveals that parasitic machine velocity losses exert a 47% share on ineffective output, protracted repair durations 34%, and the necessity for product reprocessing 19%.

Further analysis of the contributory determinants disclosed that excessively lengthy changeover and calibration intervals, insufficiently advanced operator skills, recurrent exigent technical recalibrations, a disorderly workplace configuration, and sporadic product spillages at the capping stage act concurrently, amplifying the erosion of operational efficiency. Together, these realized and realized condition indices signal the inadequacies in both the preventive and corrective asset management protocols and in the spatial and procedural layout of the production locale. Collectively, these failings circumscribe the firm's capacity to achieve streamlined throughput, system permanence in the face of demand variability, and the attainment of its mandated operational economic goals.

4.3. Validation Design

The produce management framework, which integrates Lean methodologies alongside Total Productive Maintenance (TPM) pillars, was subjected to empirical validation during a four-month pilot within a craft beverage bottling firm specializing in aerated and energy drinks. The operational design sought to amplify overall manufacturing effectiveness by operationalizing three primary interventions: standardizing the Workplace through a disciplined 5S deployment, compressing changeover durations via SMED to smooth processing continuity, and embedding a dual-maintenance regime—comprising operator-led and Scheduled interventions—aimed at reinforcing machinery reliability. Performance appraisal was corroborated through a meticulously defined set of quantitative indicators, guaranteeing that discerned enhancements were simultaneously aligned with strategic productivity gains and substantiated economic merit.

4.3.1. Introductory Context

The adoption of the proposed model for the case-study company functions as a multifaceted remedy to the operational inefficiencies that had constrained both productivity and competitive positioning. The firm, a small-to-medium-sized beverage bottler, typically experiences unstable demand patterns, constrained capital for high-end technologies, and reliance on the quality of its personnel. Within this operational envelope, the model combined Lean techniques with Total Productive Maintenance (TPM) tools to eliminate the sources of waste, dampen operational variability, and enhance reliability in the most critical production functions. The intervention extended beyond superficial technical modifications and employed a systemic lens, uniting workplace organization, quick-changeover methods, and disciplined maintenance. By interrelating these elements, the design aimed to elevate not only tactical performance metrics—such as setup duration and defect frequency—but equally, to secure the enduring viability of the production system through the cultivation of preventive and autonomous behaviors among employees.

The methodological framework was intentionally designed to balance analytical rigor with pragmatic applicability, acknowledging that small and medium enterprises frequently contend with constrained resources that preclude the adoption of elaborate and costly solutions. The model consequently leveraged established, yet flexible, management mechanisms—5S, Single-Minute Exchange of Dies (SMED), and Total Productive Maintenance (TPM)—whose conceptual underpinnings were rigorously recalibrated to suit the distinctive dynamics of the beverage-bottling domain. The selection of these techniques is derived from their demonstrable efficacy in mitigating the critical discontinuities unveiled during the initial diagnostic phase: pervasive disarray at workstations, protracted and variable changeover times, elevated breakdown rates, and the inadequate dependability of production and packaging machinery. In addition, measurable, quantitative performance indicators were assigned to each methodological element, thereby furnishing evaluative criteria that tether outputs to predetermined, empirical thresholds and conferring transparency and replicability upon the resultant assessments.

The ensuing sections of this report systematically catalogue the application of each aforementioned tool. For each item, we elaborate on the methodological recalibration executed within the specific plant environment, document the resultant performance outcomes, and contemplate the larger ramifications for both operational efficiency and competitive posture. By interweaving descriptive and analytic elements, we illustrate the mechanisms by which established Lean and TPM paradigms, when judiciously tailored to the contours of the carbonated and energy beverage bottling subsector, may be recalibrated into adaptive and potent instruments for performance enhancement.

4.3.2. 5S: Workplace Organization and Process Stability

The initial component of the intervention focused on the deployment of the 5S methodology, a framework acknowledged for its capacity to instill order, cleanliness, and procedural discipline within operational environments. Within the setting of a beverage bottling small- and medium-sized enterprise, the lack of an organized workplace had resulted in protracted searches for tools and materials, congested movement corridors, and repeated workflow interruptions precipitated by the misplacement of equipment. These chronic inefficiencies produced aggregate delays that eroded both daily operational output and staff morale.

The rollout of 5S took place in a sequenced manner that commenced with the removal of excess items from production zones, advanced to the logical arrangement of tools and materials, and culminated in the installation of visual cues and standardized procedures. Focused instructional sessions reinforced not only the procedural tasks but also the anthropological component of 5S, articulating the imperative of workstation stewardship. Supervisorial personnel complemented this educational exposure with periodic assessments, the results of which became essential metrics for gauging implementation trajectory. Statistically, the improvements were pronounced. The overall audit score rose from 42 to 82, signifying a marked enhancement in adherence to established organizational standards. Search durations fell by 65%—a metric closely tied to reduced cycle times—enabling operators to obtain the required instruments and materials with minimal delay. Correspondingly, workflow disruptions narrowed by 18%, a measure that correlates with both process streamlining and augmented employee efficiency.

Analytically, the gains confirmed the suitability of the 5S methodology as a baseline practice that readies the workspace for subsequent, more profound process refinements. However, the extent of the advantages was directly proportional to ongoing operator participation. In small and medium-sized enterprises, perpetuating such participation obligates management to continual instructional reinforcement and to the systematic incorporation of audits into routine activity. Although the data presented evident productivity improvements, the longevity of those benefits hinges on the ingraining of the 5S principle into the organizational ethos rather than relegating it to a limited-session, discrete project.
Deploying a structured 5S programme across the bottling facility of the SME yielded a suite of ancillary advantages that extended well beyond the traditional operational metrics. Systematic Organization curbed opportunities for product contamination, a primary concern within the beverage sector, thereby creating an indirect but essential layer of quality assurance. The likelihood of defects arising from improper handover or suboptimal storage environments diminished appreciably. Consequently, the methodology assumed a proactive role in supporting not only the facility's efficiency indices but also the observance of regulatory standards and the safeguarding of consumer health. Given that quality and hygiene serve as unequivocal determinants in the sector, the applicability and strategic relevance of the 5S framework attain a broader and more imperative dimension.

4.3.3. SMED: Reducing Changeover Time and Increasing Flexibility

The initiative's second strategic thrust was the adoption of Single Minute Exchange of Die (SMED), a structured framework designed to compress setup and changeover intervals. In the SME under review, excessively prolonged changeover periods constituted a pronounced bottleneck, particularly within the context of a product mix encompassing both carbonated and energy beverages. The production lines were routinely necessitated to alternate between multiple container formats and flavor variants, and conventional procedures for such transitions yielded not only extended idle states but also pronounced stocks of in-process materials and frequent breaches of promised delivery deadlines.

Implementation of SMED commenced with a detailed examination of the current changeover procedure, clearly delineating internal from external tasks. All operations not demanding machine interruption were systematically converted to external activities, whereas internal operations were codified and rationalized. Tool and component organization was enhanced via shadow boards and clearly marked storage zones, a continuation of the prior 5S programme. Concurrently, quick-release devices were introduced to curtail the need for manual tuning, and operators attended targeted training sessions to practice the newly standardized routines until proficiency was achieved.

Results substantiated the applicability of the SMED philosophy. Total changeover duration decreased by eightyfive minutes, representing a thirty-one percent gain against the original benchmark. This time, the gain effectively elevated machine utilization and facilitated a closer match between production and actual customer requirements. Concurrently, buffer inventory was diminished by twelve percent, liberating resources that were previously allocated to excessively large safety stock. The company was able to absorb market volatility with greater velocity thanks to the newly improved scheduling agility, which is a crucial capability in the modern beverage industry. Although the initiative resulted in a significant decrease in the changeover lead time, the goal metric was still slightly above 100 minutes, the cutoff point typically adopted by globally recognized standards. Such a result obviously calls for ongoing optimization and suggests that funds may be allocated in the future to more advanced enabling technologies. The documented trajectory, however, demonstrated that businesses with limited resources can still gain a great deal by strictly following well-defined changeover procedures.

The absolute and relative value of SMED increased in the bottling industry because of both increased consumer-mandated customization and acute product proliferation. Fluid reaction capability is necessary because the beverage market is still characterized by quick changes in consumer preferences for identically packaged products. The process simultaneously increased throughput, freed up productive buffer capacity, and—most importantly—provided the strategic Flexibility to launch newly developed offerings with little idle buffer by methodically reducing changeover duration. The resulting operational agility significantly reduced strategic exposure to sporadic fluctuations in channel demand while strengthening market position.

4.3.4. TPM: Enhancing Reliability through Preventive and Autonomous Maintenance

The strategic initiative's linchpin, the third one, focused on Total Productive Maintenance (TPM), which aims at maximising throughput by defining preventative steps, allowing operators autonomous maintenance, and using their deep understanding of the machine. In the context of the bottling plant, enduring breakdowns of machinery and overlong cycles to repair machinery were already established as the dominant factors inhibiting the output. Workflow was interrupted by unscheduled stoppages, causing a direct and indirect financial impact, which included costs associated with the employee not working, overdue shipments, and a breach of the set quality standards.

Implementing TPM seemed to the team like a step-by-step system that would be less daunting. Step one involved the tedious battle of paperwork by converting maintenance activities into documented standard operating procedures. As part of the operating schedule, the reenlistment of the foundational activities, which included routine inspections, timely lubrication, and the removal of particles, was incorporated, thus eliminating the need to rely on irregular servicing. The advanced cohorts of operators received training focused on taking responsibility for maintenance and servicing, thus allowing maintenance technicians to focus on advanced technical maintenance. Rule-based plans of activities, which had been preventive, were executed simultaneously based on previous analysis of reliability, thus allowing the allocation of resources at points of recurrence.

The observed quantitative metrics were compelling. The Mean Time Between Failures (MTBF) increased by 31%, indicating a prolonged duration over which machinery operated without fault. The Mean Time to Repair (MTTR) decreased by 25%, signifying enhanced effectiveness in the identification and resolution of faults. The incidence of breakdowns decreased by 68%, thereby fortifying the reliability of the overall network. Consequently, Overall Equipment Effectiveness (OEE) rose from 61% to 79%, and the defect rate experienced a 22% contraction.

Although these outcomes substantiate the capacity of Total Productive Maintenance (TPM) to effect transformation, the gradual decay of performance gains remains a significant risk in the absence of sustained management sponsorship and routine performance checks. Small and medium enterprises often confront resource constraints and the dynamism of strategic objectives, both of which can attenuate the durability of TPM gains. Unless corrective discipline is reinforced systematically, operators are likely to revert to quasi-reactive maintenance, thereby eroding performance and risk milestones.

Within the beverage bottling segment, TPM further delivered a measurable impact on both product integrity and regulatory compliance. Unplanned stoppages can heighten the probability of contamination and can disrupt the precision of carbonation, both of which compromise safety and patron confidence. The reliability gains from TPM not only decreased the duration of asset inactivity but also concurrently preserved product quality. The convergence of these operational and reputational outcomes positioned TPM as an indispensable pillar of the overall intervention framework.

4.3.5. Integrated Outcomes and Critical Reflection

When 5S, SMED, and TPM were implemented simultaneously, operational performance improved in several ways. TPM strengthened equipment reliability, SMED introduced rate-flexible behaviours, and 5S created an orderly baseline. When combined, these strategies successfully blocked off established silos and significant status quo inertia, fostering a long-lasting platform of increased throughput and competitive agility.

The integrated architecture was convincingly verified quantitatively. Changeover batch swaps decreased to two-thirds of the previous average, production interruptions decreased by 40%, internal audit results nearly doubled, time spent on physical searches was cut in half, and the empirical measure of manufacturing inventory showed a correspondingly streamlined appearance. Measured Overall Equipment Effectiveness increased, getting close to but not quite over the invisible cutoff point of global best practices.

However, a frank assessment revealed the necessity of retrofitting. Despite being noticeably tighter, top-notch artifacts, quintains, and changeover clocks still instantiate Organization. Gross throughput, the independence rule, and unstructured physical inefficiency led to acceptable timelines that did not reach the approved 85-closure threshold. Two percent, coaching and management insistence, forward-process trickle-through, and a management ego aligned with transformative ambitions are seen in the installation of structures required for continuous performance preservation. Lastly, internal sales and related logistics revealed the patient's address, even though the delivered program achieved significant internal advancement. Vertebrate, future stewardship will now allow supply-match and specialist match.

The results, in the context of the beverage industry, show that small and medium-sized businesses can effectively implement advanced management frameworks without having to make significant upfront financial commitments. Disciplined methodology, active shop floor staff involvement, and clear alignment with larger institutional goals are critical success factors. Consequently, the proposed model achieves quantifiable performance gains while furnishing a scalable blueprint for extending Lean and Total Productive Maintenance principles across analogous firms.

4.4. Results

Table 1 displays a side-by-side comparison of the starting metrics, forecasted performance targets, and post-validation outcomes obtained by applying Lean and Total Productive Maintenance (TPM) instruments within the bottling Small-to-Medium Enterprise (SME). The analysis reveals a marked enhancement in overall process effectiveness, advancing from 68% to 90%, corresponding to a relative augmentation of 32.35%. Concurrently, the transfer time for the bottling line contracted from 275 minutes to 148 minutes, achieving the anticipated benchmark and yielding a 46.18% reduction; this advancement has been shown to accelerate operational throughput. Concerning the workforce, the proportion of personnel who received training rose from 35% to 60%, affording a relative gain of 71.43% beyond the baseline. A complementary indicator of shop-floor clutter demonstrates a 106.67% gain, suggesting a substantial minimisation of non-value-adding activity and a more efficient operating environment.

Table 2. Validation Results of the Lean-TPM Maintenance Model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Effectiveness	%	68%	95%	90%	32.35%
Transfer Time	minutes	275	148	148	-46.18%
Trained Workers	%	35%	65%	60%	71.43%
Measurement of Disorder in Plants	%	30%	65%	62%	106.67%

5. Discussion

The reported gains—5S audit scores increasing from 42 to 82, changeover time decreasing by approximately 31%, and OEE rising from 61% to 79%—align with findings from food and beverage SMEs adopting Lean–TPM hybrids. Small food businesses still do not all use Lean, but where 5S is a standard practice, it is common to see fewer defects and delays [2]. Additionally, when toolsets are combined (like 5S with Kaizen), they show real benefits [3]. The size of the OEE increase is in line with recent beverage cases that use Lean practices and reliability routines together [4].

In terms of changeover, the reduction achieved is consistent with SMED case studies in SMEs, although it falls short of the "world-class" single-minute targets observed when internal–external task conversion is advanced and facilitated by straightforward fixtures [6]. Finally, the big drop in breakdowns and repair times shows how well-documented TPM is for making process industries more stable and available, especially when autonomous and planned maintenance are used together, and layout/order enablers (5S/SLP) help with sustainment [14].

5.1. Study Limitations

The analysis is limited to a single case with a four-month validation period, which constrains external validity and renders long-term sustainability uncertain. Some indicators, like OEE, come close to world-class benchmarks but do not quite reach them. This suggests that there are limits to how much they can improve.

The intervention focused on two pillars of TPM (autonomous and planned maintenance), so it does not show how the other pillars (like focused improvement and early equipment management) worked. The lack of a randomized or multi-site design makes it easier for contextual biases like demand seasonality and learning effects to affect the results. This is because the data is not granular enough to show which actions (5S, SMED, TPM) caused which effects.

5.2. Practical Implications

The results show that SMEs can get a lot more done without spending a lot of money by using low-cost enablers (5S), time-compression methods (SMED), and reliability routines (TPM) in a certain order. In bottling situations where the flavour or format changes often, shorter changeovers give you more mix flexibility and let you make smaller, demand-paced lots. Better housekeeping and visual control cut down on sanitation-related micro-stops, and operator-led care increases MTBF while lowering MTTR, stabilizing carbonation, fill accuracy, and label integrity. For managers, the implication is operational and strategic: disciplined routines at the shop-floor level are sufficient to improve service level and unit economics in markets dominated by larger rivals, echoing prior findings that integrated Lean–TPM frameworks strengthen SME competitiveness in process sectors [2], [3], [4].

5.3. Future Works

Future research can enhance generalizability by conducting multi-plant, multi-region studies with extended observation periods, monitoring the sustainability of routines and fluctuations in audit scores. A quasi-experimental design—implementing tools in staggered waves across lines—would enhance causal inference. To get the OEE above 85%, we need to do phased testing on more pillars (focused improvement, quality maintenance) and simple predictive elements (sensor-based condition checks on fillers and cappers). Lastly, applying Lean methods to suppliers and customers (for example, getting ready for a supplier changeover or ensuring that returnable packs are delivered on time) could help prove that the in-plant improvements we have seen lead to better service and lower costs throughout the beverage supply chain.

6. Conclusion

The results of this investigation substantiate that the concurrent deployment of Lean Manufacturing and Total Productive Maintenance methodologies delineates a reliable trajectory for bolstering operational efficiency in small- and medium-sized beverage bottling enterprises. Utilization of 5S techniques, Single-Minute Exchange of Dies, and structured maintenance programming enabled the targeted facility to curtail changeover intervals by over 30%, elevate the 5S audit indicator from 42 to 82, and improve Overall Equipment Effectiveness from 61% to 79%. These gains operate as mutually reinforcing variables, signifying a coherent, systemic architecture inherent in the proposed intervention framework.

The present study's contribution resides in its capacity to illustrate that substantial improvements remain attainable within the severe resource constraints commonly observed in beverage SMEs featuring aged infrastructure. Systematic attention to workplace order, expedited set-ups, and anticipatory maintenance emerges as a determining competitive lever, reinforcing the view that sustained industry performance rests more on disciplined operational and design principles than on introducing advanced technological solutions.

The academic value of this research arises from its documentation of a methodology that marries Lean and TPM within an SME milieu, eschewing major capital expenditures. Evidence is advanced confirming that the synergistic interplay of the two programs cultivates increased manufacturing agility, curbs intrinsic waste, and stabilizes production oscillation, thereby validating the model as a viable mechanism for operational enhancement in resource-constrained contexts.

The study's final observation emphasizes that lasting sustainability of the observed throughput improvements hinges upon the ongoing commitment of leadership and the sustained involvement of operational personnel. Subsequent investigations might profitably extend the evaluation of digital instruments that can augment the core principles of Lean and Total Productive Maintenance. Alternatively, comparable analytical frameworks could be applied to additional beverage sector segments characterized by pronounced demand variability and stringent quality constraints, both persistent sources of operational complexity.

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