Integrated Lean Operational Model to Increase Efficiency in a Winery Company

Jassir V. Carbajal-Macedo[1]; Gabriel N. Serrano-Rossado[2]; Rafael Chavez-Ugaz[3]; Claudia C. Leon-Chavarri[4]
[1,2,3,4]Universidad de Lima, Perú, *20200398@aloe.ulima.edu.pe, 20212566@aloe.ulima.edu.pe, rchavezu@ulima.edu.pe, cleon@ulima.edu.pe*

Abstract– The pisco industry plays a key economic and cultural role in Peru. This study develops an operational model for the small Peruvian winery, dedicated to pisco production, with the objective of reducing the end-of-line cycle time through the application of Lean Manufacturing tools. The model comprises two integrated components: first, the stabilization of operations in the quality control and labeling stations through the application of 5S; and second, the physical redesign of critical activities using Poka Yoke and Slotting to improve workflow and reduce human error. Validation was conducted using a hybrid approach combining a pilot test and discrete-event simulation in Arena. The simulation demonstrated a 31.8% reduction in end-of-line time from 48.97 to 33.40 seconds per bottle, a 27% decrease in material search time, and a 76% reduction in the deviation of quality defects. These results suggest the effectiveness of the proposed solution in improving operational efficiency and highlight its potential for replication across other micro and small wineries in Peru's wine sector.

Keywords—Operational efficiency, 5S, Poka-Yoke Slotting, Winery.

I. INTRODUCTION

The Peruvian winery sector, 98.1% of which is composed of micro and small enterprises (SME's) constitutes an economic activity of growing national importance [1]. Likewise, the production of the traditional spirit pisco embodies a Peruvian cultural expression [2]. Nevertheless, the sector faces technical constraints, a low level of professionalization, and scant adoption of continuous-improvement methodologies, especially in the final stages of the pisco production process: bottle washing, filling, capping, quality inspection, labelling, and warehousing, collectively referred to as the end-of-line. These shortcomings result in cost overruns derived from internal inefficiencies, lengthy processing times, and recurring errors in end-of-line activities [3].

The principal challenges these MYPEs encounter lie in the end of line stage, encompassing washing, filling, quality control, labelling, and storage. This phase can account for as much as 63 minutes of production time owing to non-productive periods caused by warehouse disorganization, variability in inspection activities, and the absence of standardization in manual tasks [4]. Such inefficiencies compromise the quality of the final product and the ability of the company to meet demand in a timely manner.

Lean manufacturing tools including 5S, the Poka Yoke system, and Slotting have demonstrated improvements in operational performance across manufacturing industries. Prior studies indicate that Poka Yoke can reduce human errors by up to 75% [5], [6], whereas implementations of 5S have reported 26% enhancements immaterial flow within industrial processes [7]. Slotting, in turn, has been highlighted for optimizing warehouse layouts and cutting operating times by up to 23%. However, significant gaps persist in literature, particularly in designing operational models that integrate these tools simultaneously and validate them within the sector [8], [9]. This gap offers an opportunity to develop proposals tailored to the specific conditions of these enterprises and to contribute empirical evidence to the existing body of knowledge. Accordingly, the present work sets forth solutions aimed at shortening operating times, improving quality, and bolstering market competitiveness.

In response to this scenario, the study proposes the design, development, and validation of an operational model that integrates the 5S, Poka Yoke, and line Slotting methodologies within a Peruvian MYPE dedicated to producing and bottling pisco in the winery sector.

II. LITERATURE REVIEW

A. *Relation of wasting time and winery*

Research has identified that unproductive times, high variability in critical stations, and human errors are recurring issues in artisanal manufacturing plants [2], [9]. In labor-intensive sectors such as the winery industry, where automation is limited, these factors directly impact productivity and quality. As highlighted in [10], bottling and storage are critical processes not only due to their energy consumption but also because of their contribution to inefficiencies. Furthermore, the lack of established procedures in bottling leads to manual scheduling, resulting in up to 24% of unproductive time [4].

Winery SMEs in particular face difficulties in implementing advanced planning and organizational systems, which cause delays and low operational efficiency [4]. Some solution techniques have begun to be implemented, primarily to address specific issues. In this sector, it has been found that up to 30% of total costs are concentrated in the bottling stage, highlighting the urgency of adopting problem-solving techniques [11].

B. *Application of 5S to address disorder and operational variability*

Industrial companies have shown that the implementation of 5S and SLP in manufacturing plants has led to a 34% reduction in space usage and a 26% improvement in material flow [7]. Additionally, productivity increases of up to 68% have been achieved by eliminating waste through this methodology [12]. These experiences demonstrate that implementing 5S not only optimizes the physical work environment but also contributes to standardization and operational discipline, which are key elements in environments with high levels of manual work [13], [14].

C. *Poka Yoke as a tool for preventing human errors*

The use of Poka Yoke enables a reduction on human errors ranging from 35% to 75%, minimizing operational variability and rework [6], [13]. In a study involving an SME facing quality issues, this technique was shown to reduce defects and enhance overall process efficiency. Poka Yoke is particularly useful in processes where visual inspection or repetitive tasks create inconsistencies in final product quality, offering physical or visual mechanisms that reduce dependence on human judgment [15], [16].

D. *Slotting for efficient warehouse reorganization*

The Slotting technique has been widely applied in industrial firms with notable results. Following an ABC analysis, operational times were reduced by 19.24% after reorganizing the warehouse layout [8]. Additionally, the application of Slotting led to a 23% improvement in total process efficiency and significantly decreased travel distances [17]. When combined with spaghetti-diagram-based movement analysis, Slotting achieved a 98% reduction in distances traveled with mobile containers [9]. These practices validate Slotting as a key tool to minimize search times, improve ergonomics, and reduce unnecessary efforts in disorganized or poorly designed warehouses [12].

Most of the literature focuses on individual applications of these tools and lacks proposals that simultaneously address multiple root causes under a unified model. While individual benefits have been identified for each technique, there is no documented evidence of validated operational models that combine 5S, Poka Yoke, and Slotting in artisanal manufacturing settings such as the wine sector, where working conditions and resources differ substantially from those of industrial plants.

This study aims to help close this gap by designing, applying, and validating an integrated operational model to reduce inefficiencies in end of line processes. The proposed model seeks to leverage the synergies among complementary Lean tools while adapting to the technical and budgetary limitations of SMEs, contributing empirical evidence to an under documented field.

In response to this scenario, the study proposes the design, development, and validation of an operational model that integrates the 5S, Poka Yoke, and line Slotting methodologies within a Peruvian MYPE dedicated to producing and bottling pisco in the winery sector.

III. METHODOLOGY

A. *Conceptual Model*

The proposed operational model is based on the Lean Manufacturing philosophy and aims to reduce inefficiencies in end-of-line processes within artisanal manufacturing environments. It is specifically designed for SMEs in the winery sector, characterized by high manual workload, limited resources, and low standardization. Unlike approaches that apply tools in isolation, this model proposes an integration of 5S, Poka Yoke, and Slotting, acting on root causes identified in the technical diagnosis.

The model design consists of two components: (i) Stabilization and standardization of the process, and (ii) Physical redesign of activities. According to studies, there is synergy in using 5S alongside Slotting to enhance the impact on space organization. Likewise, 5S complements Poka Yoke in reducing errors and fostering continuous improvement. This structure aligns with findings that independently support the benefits of these tools [5], [6], [7].

Once errors are minimized, greater operational predictability is achieved, which is essential for implementing Slotting based on efficiency criteria such as frequency of use and proximity.

Research demonstrates the utility of these tools as key success factors in implementing a Lean model that integrates techniques to achieve better results [18]. In addition to support in the literature, the design has been adapted to be replicable in companies with budgetary and operational constraints, providing a systemic guide for continuous improvement in critical artisanal manufacturing processes.

Considering this research, the operational model unfolds through two sequential components that directly respond to the root causes diagnosed in end-of-line operations. Both are grounded in Lean Manufacturing principles validated in labor-intensive SMEs and comply with the technical and normative guidelines cited in the conceptual framework [5], [6], [7].

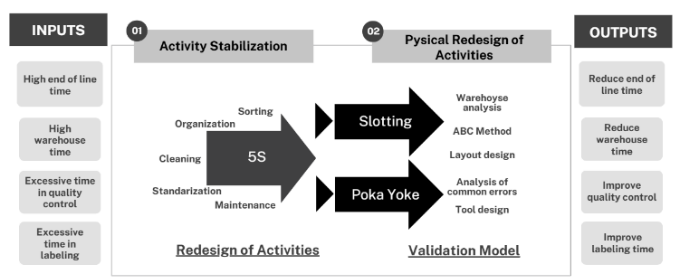

Fig. 1 Proposed Model.

B. *Component 1: Stabilization of activities through 5S*

The purpose of the first component is to reduce initial operational variability and create controlled working conditions at inspection and labeling stations. The 5S methodology (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) is applied, recognized as a fundamental pillar in standardization processes since it eliminates sources of mode such as disorder, unnecessary movements, and waiting times [19]. The deployment includes classifying supplies using red tags, assigning fixed tool locations with shadow boards and signage, establishing a sustained cleaning program with weekly control cards, and implementing visual instructions that standardize the step-by-step activity sequence. All of this is reinforced by periodic internal audits. This intervention directly addresses material search times and task execution variability, measured through indicators such as seconds per bottle for searching, standard deviation in visual inspection, and average labeling time. Thus, environmental stabilization provides a reliable operational basis for applying subsequent controls.

C. Component 2: Physical redesign of activities (Slotting +Poka Yoke)

The second component jointly addresses the physical flow of materials and error prevention through the application of Slotting in the storage area and the development of Poka Yoke devices at quality and labeling stations. First, redistribution is carried out based on the behavior of each element and an ABC analysis considering rotation, weight, and criticality of inputs. Based on this data, warehouse layouts are designed using digital tools. Frequently used materials are then relocated to high-accessibility zones, applying ergonomic criteria according to NTP 339.010-1 and using metal racks compliant with UNE-EN 15635 and NTP 1029 [20], [21], [22]. This intervention aims to reduce the seconds per bottle spent searching for by at least 20%.

In parallel, Poka Yoke devices are implemented to eliminate defects caused by human error. Among these, for quality control, a white light is used as an improvement mechanism for standardized visual verification during bottle inspection. Finally, for labeling, a 3D model is designed for a semi-automatic labeler tailored to the type of bottles used by the company. The improvements implemented are analyzed using the following indicators:

TABLE I
INDICATORS

Tool	Indicators		
	Name	***Unit***	***Formula***
Slotting	Average time spent searching in the warehouse	s / bottle	Σ Time spent searching for materials in a batch / Number of bottles in batch
5S	Standard deviation in quality control	s / batch	Reduction in standard deviation
Poka Yoke	Time out of the actual mode in quality control	s / batch	Σ (Activity times - mode time before applying the tool)
Poka Yoke / 5S	Average time in labeling	s / bottle	Σ Time at labelling station in a batch / Number of bottles in batch

It is important to highlight that both components of the model were designed to operate jointly. The progressive implementation of the 5S methodology generated initial conditions of order and standardization at the workstations, which facilitated and enhanced the impact of subsequent physical changes. In turn, the reorganization of the layout and the incorporation of error-proof mechanisms reinforced the standards established by 5S, consolidating sustainable operational practices. The combination of operational order with an efficient plant layout translates into concurrent improvements in both time and quality [7]. In this case study, it was demonstrated that 5S acted as a key enabler for the effectiveness of Slotting and Poka Yoke by ensuring that the new physical conditions remain functional.

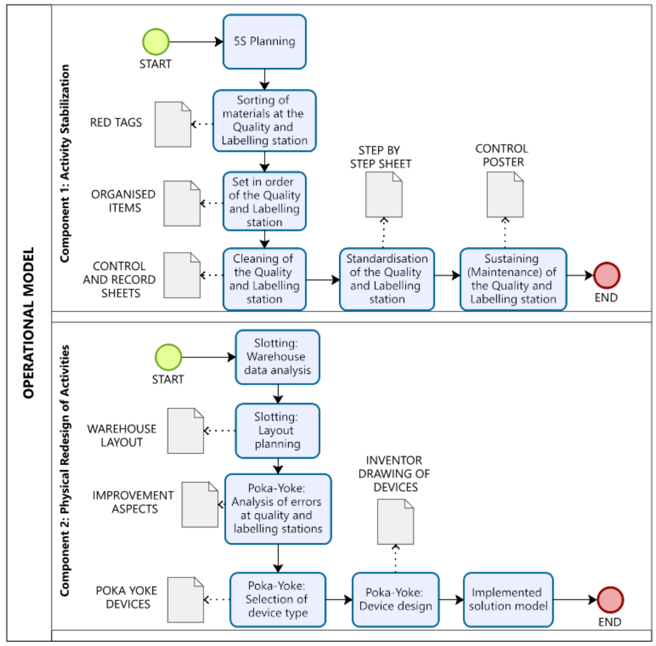

Fig. 2 Bizagi Operational Model.

IV. RESULTS

A. Initial Diagnosis (As-Is)

The root causes directly influenced the high end-of-line time were identified, enabling the definition of key performance indicators (KPIs) to measure improvements (Fig #3). Based on a study previously conducted by the company, the initial values of these indicators were established.

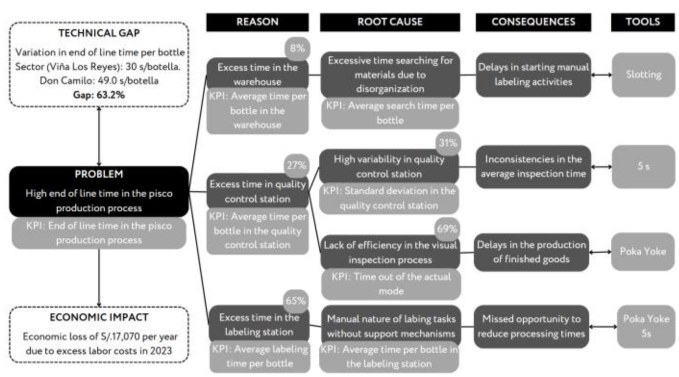

Fig. 3 Problem Tree.

The end-of-line process at Don Camilo exhibited an average time of 48.97 seconds per bottle. Four main causes were identified: delays in material search (4.73 s), high variability in quality control (standard deviation of 4.26 s), prolonged visual inspection times (6.53 s outside the mode), and elevated times in the labeling station (4.07 s). These indicators were used to model the current scenario (As-Is) in Arena and compare it with the improved proposal.

B. Validation of the proposed model

A hybrid validation approach was applied, combining pilot testing with simulation techniques. A sample of 380 bottles was selected, representing a statistically valid subset of the company's annual production volume of 40,000 bottles. This sample size was determined to ensure representativeness while maintaining a 95% confidence level and a 5% margin of error. Both the pilot test data and simulation results were analyzed under these statistical parameters to evaluate the performance of the proposed model.

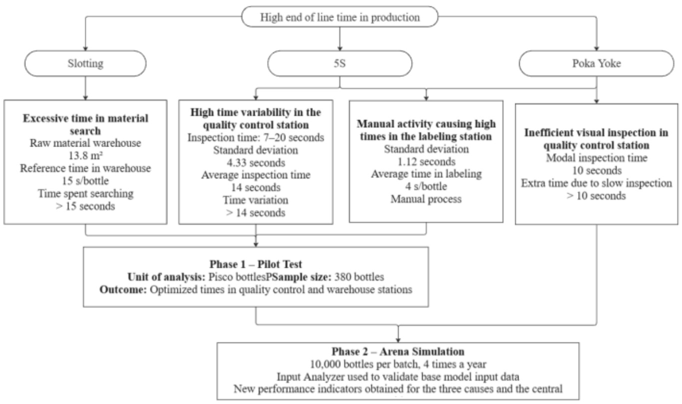

Fig. 4 Validation Model.

1) Pilot test

Due to time constraints, the 5S and Slotting tools were partially validated through a pilot test. In the quality control station, the implementation of 5S reduced the standard deviation of inspection times from 4.26 to 1.42 seconds, while in the labeling station, it decreased from 1.12 to 1.04 seconds. In parallel, the reorganization of the warehouse using Slotting reduced the average time spent searching for materials from 18.6 to 14.3 seconds per bottle, achieving a 23% improvement. The results obtained from the pilot test were used as input for the simulation of the improved scenario.

2) Arena Simulation

The validation of the improved model was conducted through a comprehensive simulation in Arena, incorporating the proposed tools, including Poka Yoke, which could not be physically implemented due to budget constraints. The model design was based on real operational data collected by the company and statistically distributed using the Input Analyzer module.

The unit of analysis was the bottle, and a sample of 380 observations was used, calculated for a finite population with a 95% confidence level and a 5% margin of error. The simulation included all end-of-line subprocesses (washing, bottling, capping, quality inspection, labeling, and final storage), allowing for the analysis of the system's behavior in both its current (As-Is) and improved states.

3) Results obtained

One of the most relevant findings of the study was that the sequential combination of 5S, Slotting, and Poka Yoke suggest more effective than their isolated application. For instance, the order and standardization created through 5S enabled the Slotting intervention to generate consistent benefits, while the organized physical environment was essential for the proper functioning of the Poka Yoke mechanisms. This tool interaction effect allowed improvements made in one station to positively influence the next, producing a systemic reduction in end-of-line time and reinforcing the importance of integrated Lean implementation in artisanal manufacturing environments.

TABLE II
RESULTS OBTAINED AFTER SIMULATION

Indicators	Values			
	As Is	***Piloto***	***Simulation***	***Improvement***
Average time spent searching in the warehouse	4.73	3.66	3.47	- 27%
Standard deviation in quality control	4.26	1.42	2.36	- 45%
Time out of the actual mode in quality control	6.53	-	2.25	- 66%
Average time in labeling	4.07	3.8	2.07	- 49%

V. DISCUSSION

In terms of result interpretation, the average time spent on warehouse searching was reduced from 4.73 to 3.47 seconds, representing a 27% improvement. This reduction is a direct consequence of applying the Slotting tool, which allowed for reorganizing material locations based on rotation criteria, minimizing unnecessary operator movements and improving access to supplies. A study realized in 2022 reported improvements of 15% and 23% after implementing Slotting and redesigning the storage layout [17]. In contrast, other studies observed a 19.24% improvement in operational time, which is 8 percentage points below the improvement achieved with the simulated model [8]. This difference may be attributed to the initial conditions of the plant studied, where inventory levels were limited (no more than five items) and no formal organizational system existed. Thus, the absence of an initial structured setup allowed the Slotting intervention to generate a more significant impact by optimizing internal flow and further reducing search time beyond what was reported in previous studies.

These reductions compared with isolated applications reported in prior studies; these effects are consistently larger. For Slotting, typical improvements range ≈15–23% [17], below the 27% achieved once the process had been stabilized first. For 5S, studies on industrial SMEs document 26% material-flow gains and up to 68% productivity increases, while here the main stability outcome is a 45% cut in inspection variability evidence that 5S functions as a variability reducer in labor-intensive settings rather than a mere flow accelerator [7], [12]. For Poka-Yoke, error reductions are around ~35–75% in our case the 66% reduction in out-of-mode inspection time is within the upper bound, which is attributed to deploying error-proofing on an already standardized and structured station [6], [13]. Taken together, the data supports the claim that the sequence yields compounded effects that exceed those reported for isolated tools

Regarding quality control, two key indicators were analyzed. First, the standard deviation of inspection time, which measures the dispersion between samples, was reduced from 4.26 to 2.36 seconds, achieving a 45% decrease. This improvement resulted from the use of Poka Yoke and 5S tools, which help reduce human error. Second, the time outside the current mode in quality control dropped from 6.53 to 2.25 seconds, representing a 66% improvement. Additionally, the average time in the labeling station significantly improved from 4.07 to 2.07 seconds, yielding a 49% reduction over the base model. This overall decrease not only reflects the proper implementation of the selected tools but also their contribution to establishing a more disciplined organizational culture, focused on error prevention, operational efficiency, and workplace order.

When comparing these results with previous studies, improvements of up to 68% in productivity have been reported through the implementation of 5S, primarily by eliminating waste and adding value to the process [13]. Additionally, reductions of 8% in material search time and 18% in retrieval time have been achieved in similar settings [14]. In the case of Poka Yoke systems, documented applications have shown improvements of up to 35% in assembly time, highlighting their effectiveness in minimizing human error in repetitive tasks [6].

As can be observed, the percentage improvements in indicators such as standard deviation, time outside the mode, and average time exceed those found in the reviewed literature. This is primarily because most referenced studies implemented only a single tool per station, whereas in this study, both 5S and Poka Yoke were applied in the quality and labeling stations, significantly reducing cycle times in each process.

Finally, when these findings are contrasted with the theoretical and practical background reviewed, the results suggest the potential effectiveness of the conceptual model that was proposed. In contrast to previous approaches where Lean tools were applied in isolation, the sequential integration of these methodologies, combined with a hybrid validation method (simulation and pilot testing), appears to offer a more comprehensive approach to address both operational variability and structural inefficiencies. Furthermore, the low cost required for implementing the model (S/ 5,726), compared to the estimated annual savings of S/ 17,070, indicates promising technical, economic, and regulatory feasibility, particularly when fully implemented across other micro and small winery enterprises.

VI. Conclusions

The study addressed the problem of excessive end-of-line time in a microenterprise dedicated to pisco production, identifying four root causes that were systematically tackled through the proposed operational model.

First, the disorganization in the warehouse was resolved through the implementation of Slotting, which reorganized materials based on rotation and accessibility. This intervention reduced the time spent on material searching by 27 percent and demonstrated the potential of spatial redesigning in small-scale facilities with limited inventory systems.

Second, the high variability in quality control activities was addressed using the 5S methodology, resulting in a 45 percent reduction in standard deviation. This indicated a significant gain in operational stability and consistency in inspection tasks, especially in processes that rely heavily on manual execution.

Third, the inefficiency in visual inspection was mitigated by introducing visual aids and light-enhanced inspection procedures under the Poka Yoke principle. This led to a 66 percent reduction in time outside the mode, revealing the importance of error-proofing in artisanal quality control environments.

Fourth, excessive time in the labeling station was reduced by 49 percent through a combination of standardized procedures and the design of physical aids, which simplified manual tasks and improved reproducibility across batches.

In general terms, the implementation of the integrated model resulted in a 31.8 percent reduction in average end-of-line time per bottle. This confirms that a sequential application of Lean tools, supported by a hybrid validation strategy, can effectively address both technical inefficiencies and structural limitations in artisanal manufacturing processes.

VII. Recommendations

For future full implementations of each tool included in the model, it is essential to consider the seasonality of production and the order-based demand dynamics. Executing the improvements during periods of lower demand will enable progressive implementation, reducing the impact on operations and ensuring that each stage, such as 5S or warehouse reorganization, is adequately consolidated before moving forward. This type of planning will facilitate a comprehensive, efficient, and sustainable application of the model.

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