

Improving Fresh Egg Waste Levels in a Lima Warehouse of a Producer and Distributor Company Using Lean Six Sigma Tools and EOQ Method

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Abstract

The management of perishable products poses critical challenges in supply chains due to their short shelf life and the risk of economic losses caused by inadequate storage conditions. In the poultry sector, egg production, renowned for its nutritional value, affordability, and versatility, faces high levels of waste. In Peru, where egg production grew by 142.93% between 2005 and 2023, with an annual growth rate of 5.2%, improving storage practices is essential to ensure economic sustainability. This study examines a case in a Peruvian egg production and distribution company, which reported losses of S/.308,181 in 2022 wastes due to overstock and improper storage conditions. Lean Six Sigma tools were implemented to maximize customer value and reduce waste. An EOQ-based inventory policy optimized supply management, while an acceptance sampling strategy reduced the rejection of non-compliant batches in the company's five main sales channels. The application of these tools was validated using Arena Simulator. The results showed a 49.97% reduction in damaged trays, achieving an accurate calculation of the reorder point (ROP) and the optimal replenishment quantity. Additionally, rejected trays for failing quality standards decreased by 44.44%. Overall, the implementation of these tools resulted in a 39.4% reduction in economic impact. This study highlights the effectiveness of integrating EOQ and acceptance sampling to optimize the management of perishable products, offering replicable solutions for similar challenges in the supply chain.

Keywords

Waste, Inventory Management, Warehouse Management, Lean Manufacturing, Quality Management, Perishable Product.

1. Introduction

According to Singh and Verma (2018), the warehouse is a critical part of the supply chain, as it directly influences the success of the company through proper management from the sourcing of raw materials to the delivery of the final product. So much so that they must operate efficiently and effectively to avoid high percentages of waste (Shah et al., 2017). In the food sector, and especially in the handling of perishable products, waste is a critical problem. Hertog et al. (2025) indicate that up to 50% of fresh produce can be lost due to microbial decomposition or insect damage.

Furthermore, inadequate warehouse design can lead to slow inventory turnover, increasing the risk of obsolescence and economic losses (Alstrom, 2001). In the case study analyzed, it was identified that the percentage of decrease with respect to net sales was 0.21% during 2022, having an economic impact of S/. 308,180.95 (Figure 1).

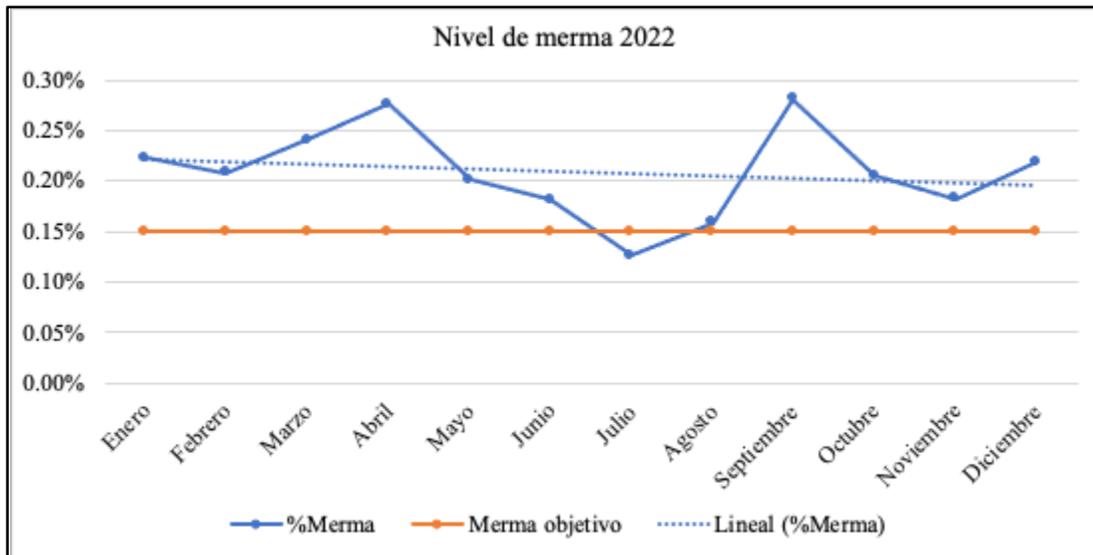


Figure 1. Monthly Waste Level Throughout 2022 for the Case Study, Compared with the Sector's Waste Level.

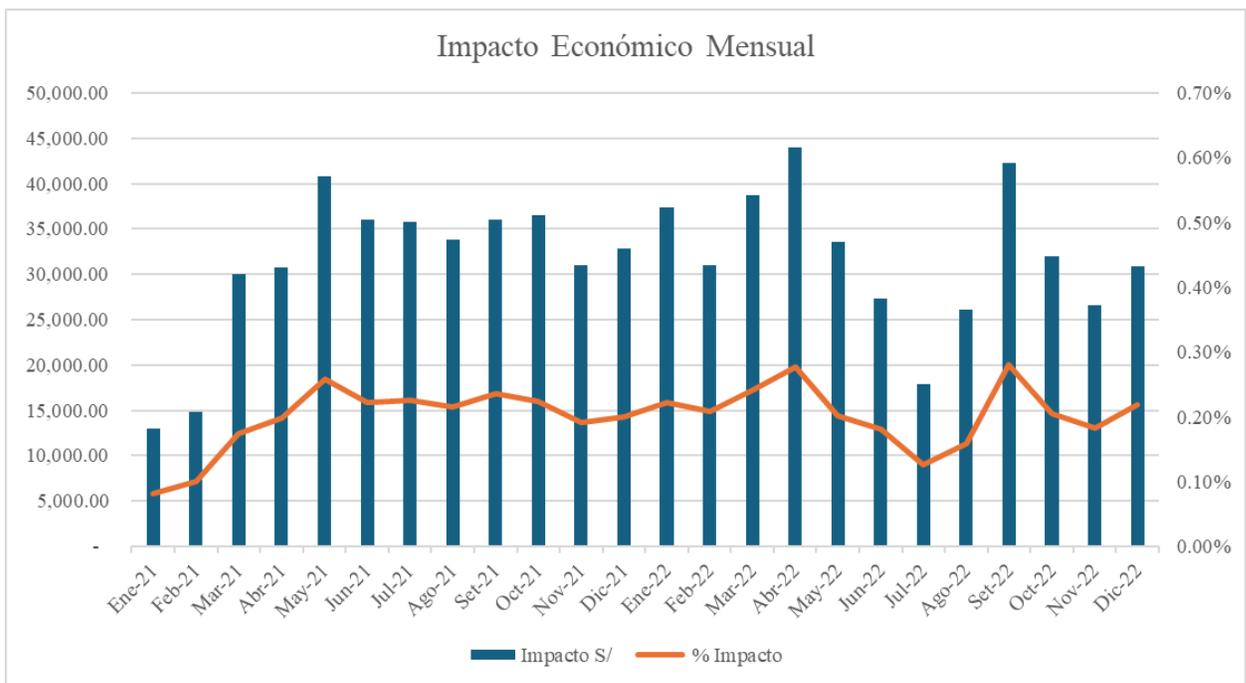


Figure 2. Economic Impact in Sales and Percentage of the Waste Level Identified Period of 2022 and 2021.

Piva et al. (2022) highlight the importance of having management indicators that help minimize product unavailability and reduce costs from inefficient transactions. In the case study (Figure 2), it is shown that the application of the Lean Six Sigma methodology with a DMAIC approach revealed the need to adjust certain warehouse parameters to improve turnover, stock, and satisfied demand KPIs through implementing an EOQ-focused inventory management system and attribute-based quality sampling to significantly reduce defective product levels within the supply chain.

Currently, eliminating non-value-added activities is essential for companies to offer high-quality products at low cost (Çalışkan, 2022). Baby et al. (2018) note that inadequate storage and high picking costs can negatively impact operational and economic efficiency.

Standardization in storage procedures and the implementation of precise forecasting and monitoring systems are crucial to avoid human errors and reduce waste (Christensen et al., 2021). In this regard, a good inventory management policy for perishable products—which minimizes losses and waste—is critical for logistical success (Luo et al., 2022). Somkun et al. (2024) conclude that optimizing the sourcing policy and applying the EOQ method can reduce food waste by up to 46%. The case study identifies a weekly sourcing batch of 60,000 crates transported from the hub to the warehouse, noting that replenishment was not based on an accurate forecast but rather on the average quantity that left the warehouse weekly, without a prior evaluation of market demand and behavior. Moreover, fieldwork and interviews revealed that the only quality control points in the supply chain occurred once when the crates left the hub and once when they reached the final customer. Regarding quality, Rodriguez and Urrutia (2023) demonstrate that using tools such as the Ishikawa diagram, Pareto analysis, and the Six Sigma DMAIC cycle can lower production costs and improve operational efficiency. Additionally, the acceptance sampling technique—based on pre-established criteria to determine batch quality—is fundamental for ensuring product safety and quality, thereby avoiding the distribution of defective batches (Ciccarelli et al. 2023).

1.1 Objectives

The main objective of this research is to reduce the level of fresh egg waste in the warehouse of a company in Lima, which will positively impact profitability and supply chain efficiency. Two critical factors have been identified: commercial replenishment, where batches are discarded for failing to meet quality standards, and physical damage in the warehouse due to inadequate handling and deficiencies in inventory management. The proposed strategy was formulated using the Lean Six Sigma tool with a DMAIC approach, identifying in each case the sourcing parameters that need adjustment as well as implementing and controlling an attribute-based acceptance sampling station. It is expected that the implementation of these measures will reduce the current waste level from 0.21% to a target of 0.15%, improve inventory turnover and other management indicators, and contribute to increased operational efficiency and market competitiveness.

2. Literature Review

In the food industry, losses and waste are a problem that affect not only the environment, but also lead to a decrease in income for producers and, consequently, an increase in prices for consumers (Torres, G et al. 2021). Throughout the entire production and distribution process, waste occurs, so an analysis is essential since it directly impacts productivity (Celis et al., 2017). According to Singh, D. and Verma, A. (2018), one of the most critical parts of any supply chain is the warehouse. The success or failure of a company depends significantly on the structure of its supply chain, which consists of multiple stages: from the procurement of raw materials, their transformation into the final product, the storage of the finished product, and its transportation to final delivery.

The objective of warehouses is to meet customers' needs through the efficient use of resources, delivering the right product, in the right place, and in good condition (Shah et al., 2017). Various documents suggest that developing an Economic Order Quantity (EOQ) model can help increase the overall benefit in a warehouse (Tuan et al. 2021). It also helps address the problems present in inventory management by using the EOQ method to reduce excess stock in the warehouse (Lopez and Matta, 2022). For the practical use of an inventory control system, EOQ values are fundamental, given the cost implications of using different approximate models as well as for the development of a practical model. Since statistical inventory control involves a large number of products, it is necessary to use an inventory control model that directly determines the value of the control variables (Alstrom, 2001).

The proposed solution focuses on introducing a quality management and food safety system in the case study's warehouse, using Lean Six Sigma with a DMAIC approach. Additionally, the Reorder Point (ROP) and the Economic Order Quantity (EOQ) will be calculated. The combination of these two tools will help reduce the number of product boxes damaged due to excess inventory, low inventory turnover caused by the lack of adequate management policies for perishable products, and a high percentage of commercial replenishments resulting from the delivery of defective boxes.

Effective inventory management is critical for minimizing losses in perishable goods. Several experimental studies demonstrate that adapting traditional EOQ models to incorporate product shelf-life considerations enhances inventory accuracy and minimizes overstocking. For instance, Caliskan (2022) introduces closed-form solutions that account for exponential deterioration, while Tuan et al. (2021) develop an EOQ model tailored for items with a fixed shelf life under non-increasing demand conditions. These innovations provide robust tools for setting optimal order quantities and reordering policies that are responsive to the unique challenges of perishable items. Central to this integrated approach is the application of the DMAIC framework, a cornerstone of Lean Six Sigma, which systematically drives process standardization and continuous improvement. Akkas and Honhon (2023) illustrate, through experimental research, how establishing maximum shipping age requirements using a “Ship-Oldest-First” strategy—though akin to FIFO—is vital for refining inventory policies under the DMAIC process. Moreover, Lopez-Yamunaque and Matta-Cruz (2022) demonstrate that coupling multi-criteria ABC analysis with EOQ and PDCA (a precursor to DMAIC) cycles effectively reduces excess stock and lowers warehouse costs. These studies affirm that Lean Six Sigma methodologies can be seamlessly integrated with EOQ models to identify, quantify, and mitigate inefficiencies in inventory systems. Additional research by Vahdani et al. (2021) extends the EOQ framework by applying metaheuristic algorithms, such as the Binary Dragonfly and Genetic Algorithms, to solve complex lot-sizing problems. Meanwhile, Christensen et al. (2021) propose a novel forecasting accuracy measure that accounts for the asymmetric impact of shelf life on product availability, thereby enhancing demand forecasting and stock replenishment strategies.

Quality management also plays a pivotal role in this integrated approach. Hertog and Uysal (2014) illustrate that incorporating shelf-life modeling for First-Expired-First-Out (FEFO) management—though a brief consideration relative to DMAIC—can add significant value by aligning warehouse practices with downstream supply chain requirements. Complementary quality control techniques, including acceptance sampling, Ishikawa diagrams, and Pareto analysis, further ensure that process improvements lead to reduced production and storage costs while maintaining high product quality. Collectively, the literature demonstrates that integrating EOQ models with Lean Six Sigma’s DMAIC framework provides a comprehensive strategy to optimize inventory management, reduce waste, and enhance operational efficiency in perishable supply chains. This approach not only addresses the dynamic challenges of inventory control but also supports a sustainable and competitive advantage in the global food industry—a finding that holds significant implications for industrial engineering practice.

3. Methods

This research has an explanatory scope, as its purpose is to establish the causes behind why a warehouse for perishable products exhibits a high spoilage rate, which not only affects the business’s profitability but also the product’s quality and added value. Moreover, our research design is experimental with a quantitative focus, since we altered the variables, parameters, and/or processes in the warehouse in order to achieve a reduction in the number of spoiled egg crates in the case study design and to propose an analysis methodology that provides results in line with the research objectives.

To begin the process of identifying the problem and evaluating the risk level of the activities, it is crucial to define the scope of the research and specify the activities on which it will focus. The tools employed are centered on the Lean Six Sigma methodology with a DMAIC approach, as it provides a systematic structure that allows identifying and eliminating the root causes of variability and waste (Rodriguez-Alza et al., 2023). After applying the steps of define, measure, analyze, improve, and control, the application of techniques is suggested to improve both inventory management and the quality control of the product leaving the warehouse.

First, we validated that the problem in the case study was significant and had a truly negative impact on the warehouse's profitability. For this purpose, data collection and fieldwork were crucial in order to obtain real-time data and KPIs to conduct the problem diagnosis and identify its root causes.

We initially defined the root causes of the research problem using a root cause tree diagram, which identified that 24% of the spoilage in 2022 originated from damages within the warehouse and, secondly, that 57.09% was due to commercial returns resulting in spoiled crates. On the other hand, sourcing and inventory methodologies were applied using the EOQ method and the implementation of quality controls in the warehouse layout before merchandise loading for subsequent distribution. It was decided to apply the EOQ method to reduce the replenishment lot size, which in turn led to better inventory management where the entire product received was sold, thus increasing the inventory turnover rate and reducing overstock levels. Applying the EOQ method required making a sales forecast based on the average sales of previous years from the warehouse in order to avoid stockouts and excess inventory. Similarly,

considering the EOQ formula shown in Table 1, it was necessary to know the ordering costs and the storage cost of the fresh egg crates. Finally, to decrease the number of spoiled crates due to commercial returns, in order to improve the dispatch indicator and the quality of the finished product, a random attribute-based acceptance sampling process will be implemented as part of the warehouse logistics process for the rejection or acceptance of evaluated batches.

$$EOQ = \frac{\sqrt{2 * D * S}}{i * H}$$

D = Annual Demand
 S = Cost Per Order
 C = Cost Per Unit
 I = Holding Cost (%)

Subsequently, we measured the warehouse parameters, such as storage capacity, stock levels, the number of spoilage events originating within the warehouse, the number of spoilage events due to commercial returns, inventory turnover, and the reorder point; in addition to measuring and establishing the parameters for acceptance sampling, such as sample size, the sampling unit (eggs), and the number of eggs required for accepting or rejecting the lot to be evaluated.

Table 1. Logistics and Storage Conditions of the Warehouse Inventory.

KPIs	Value
Warehouse Capacity (egg box)	60,000
Supply Lot (egg box/day)	8,600
Waste Level (%)	0.21%
Waste due to Warehouse damage (egg box)	1,433
Number of Commercial Returns (egg box)	3,409
Average Stock Level (%)	105.5%

As a third step, the warehouse design is analyzed—first under the current conditions observed in the case study to validate that our design is functional. For this phase, we applied simulation methods using Arena V2 software. The validation test consisted of comparing the simulator’s results with the data collected in the case study and ensuring that the KPIs obtained are similar. The following results and deviations from 30 runs of the design confirmed that the initial design was valid according to Table 1. After validating the case study model, the new replenishment lot obtained from the EOQ method was applied, and a sampling activity was implemented, considering an NCA (Acceptance Sampling Normalized Criteria) of 2.5% with a sample size differentiated for each sales channel. This allowed for the identification of batches that do not meet the hypothesis, so that they can be shrunk before the merchandise is loaded (Figure 3 and Figure 4).

ARENA Simulation Results
 USER - License: STUDENT

Output Summary for 30 Replications

Project: Unnamed Project
 Analyst: USER

Run execution date : 6/22/2024
 Model revision date: 6/22/2024

OUTPUTS					
Identifier	Average	Half-width	Minimum	Maximum	# Replications
Jabas Merma Almacen	1462.5	6.7674	1433.0	1502.0	30
Jabas Despachadas	3.1159E+6	179.67	3.1150E+6	3.1170E+6	30
Jabas Reposicion Comercial	3281.5	16.970	3162.0	3360.0	30
InicioOperacion.NumberIn	2191.0	.00000	2191.0	2191.0	30
InicioOperacion.NumberOut	2190.0	.00000	2190.0	2190.0	30
System.NumberOut	2190.0	.00000	2190.0	2190.0	30

Figure 3. Results from the 30 simulated replications in Arena Simulator of the analyzed variables.

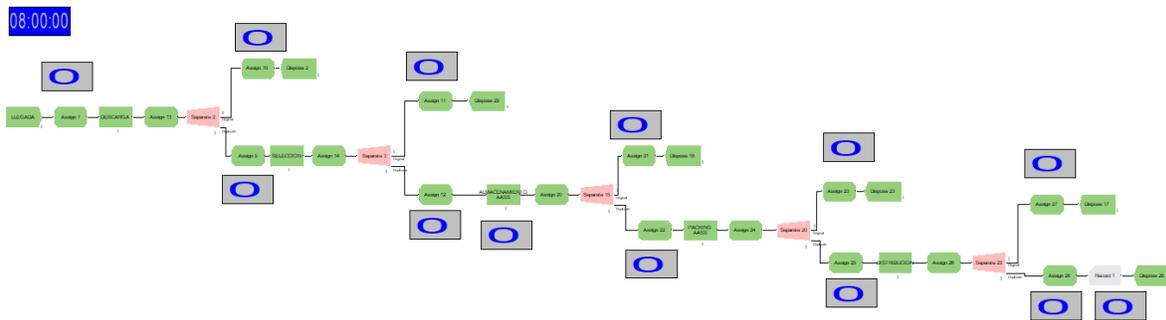


Figure 4. Initial Model in the Arena Simulator.

This solution design must be continuously controlled and improved. First, by adjusting the demand for eggs, since it is fluctuating and can experience sales spikes or shortages in the market, which in turn requires adjustments in the replenishment lot and the reorder point. Second, it is important to measure the sampling conditions, constantly adjusting the parameters to achieve a lower margin of error and variability, so that the process of accepting or rejecting a lot is more effective, given that historical data is available for statistical analysis.

4. Data Collection

In order to apply the methodology outlined in the chapter—specifically in the measurement phase—it was crucial to collect logistics and sales data of the merchandise entering and leaving the warehouse to establish the research objectives and expect optimal results from the solution design. The case study provided us with the raw database of crate sales for the period 2021 and 2022, along with the number of spoiled crates per month during the analyzed periods. The collection and analysis of data revealed that the months with increased demand also experienced a rise in the total number of spoiled crates, as indicated by Figure 5 and Table 3. Additionally, after interviews with the warehouse manager, we found that between 8,500 and 8,600 crates arrived daily.

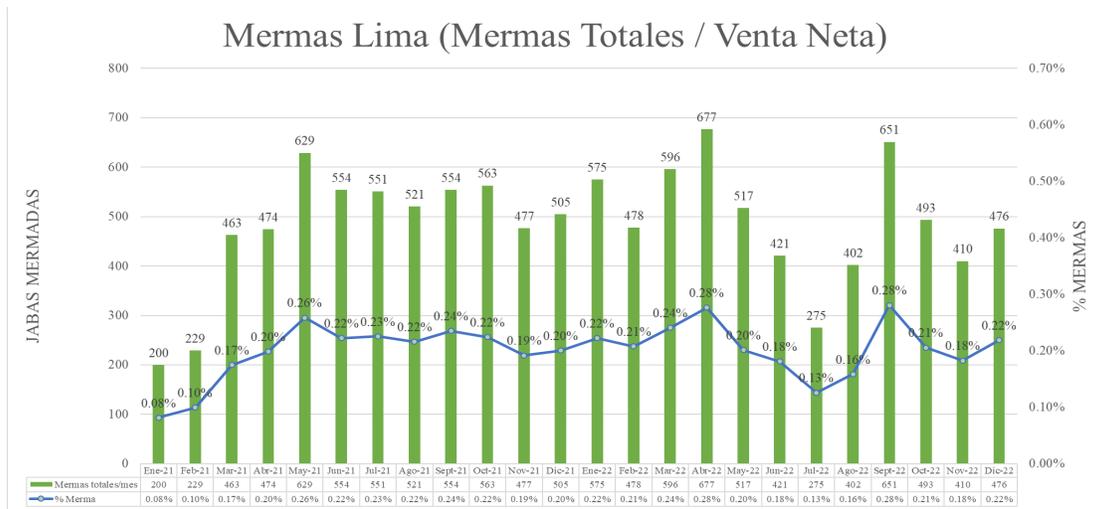


Figure 5. Total waste level for the period 2021 - 2022 of the warehouse in Lima.

The implementation of the EOQ inventory management model goes hand in hand with precise demand planning that meets market needs. Upon receiving the case study, it was identified that the warehouse was being overstocked, with daily replenishments ranging between 8,500 and 8,600 crates, resulting in excessively high levels of inventory coverage. This situation clearly did not benefit the warehouse, as it increased the risk of overstock. Therefore, collecting sales data—as shown in Table 1—was essential to apply the triple exponential smoothing forecasting methodology, which achieved a MAPE of 0.27% in the forecast. Once the forecasted quantities for each month were determined, the EOQ formula was applied, taking into account the costs provided by the case study, as detailed in Table 2.

Table 2. Net sales in crates during the period 2021 - 2022 in Lima. Name of the table

Month	Net Sales 2021 (Egg box)	Net Sales 2022 (Egg box)
Jan	245,477	258,287
Feb	230,031	229,930
Mar	265,062	247,613
Apr	238,502	244,860
May	243,093	256,648
Jun	248,876	232,340
Jul	244,362	218,548
Aug	241,120	253,481
Sep	235,319	231,943
Oct	251,077	239,917
Nov	248,846	224,334
Dec	251,836	217,694

Table 3. Costs

Type of Cost	Value
Cost Per Order	1,500 Soles/order
Holding Cost	360 Soles / egg box

Additionally, to enable an accurate diagnosis of the case study, as described in the previous chapter, two types of spoilage that significantly affect the warehouse's profitability were identified (spoilage due to sanitation was not

considered because the spoiled eggs were reprocessed to produce derivative products such as egg flour), as shown in Table 4.

Table 4. Results obtained from the root causes of the problem.

KPIs	Results 2021 (egg/box)	Results 2022 (egg/box)
Waste due to Warehouse damage (egg box)	1,134	1,433
Number of Commercial Returns (egg box)	3,128	3,409

Thanks to the literature review, we identified that high levels of overstock in perishable products such as fresh eggs increase the probability that they become defective and are subsequently spoiled (Arzum and Dorothee 2023). Therefore, considering that the warehouse has a capacity of 60,000 crates of fresh eggs, the monthly stock levels for the analyzed periods were collected from the warehouse database and the percentage stock level was calculated as shown in Table 5. Several months were identified where the stock level exceeded 70% (the standard used by the company for inventory management), corresponding to the same months in which high quantities of spoiled crates were observed.

Table 5. Data Stock of periods 2021-2022

Month	Stock 2021 (egg box)	Stock 2022 (egg box)	Stock Level 2021 (%)	Stock Level 2022 (%)
Jan	34,983	56,230	58%	94%
Feb	41,455	44,591	69%	74%
Mar	34,245	48,125	57%	80%
Apr	34,822	57,862	58%	96%
May	40,686	60,528	68%	101%
Jun	38,353	46,293	64%	77%
Jul	44,334	67,040	74%	112%
Aug	51,436	72,800	86%	121%
Sep	52,616	68,878	88%	115%
Oct	43,016	74,184	72%	124%
Nov	38,819	65,845	65%	110%
Dec	50,567	70,049	84%	117%

Finally, the solution design was validated using Arena V2 simulation software in a one-year run. Initially, the model was executed with 30 replications, yielding the results shown in Figure 6, but this run displayed a deviation of 6.76 for physically damaged crates and 16.97 crates for returns. An optimal number of replications was calculated to ensure that the average metric for the number of dispatched crates had a lower margin of error at a 50% confidence level. As a result, the design was subsequently run with 120 replications, since the standard deviations of the model variables were much lower than those observed in the 30-replication run.

ARENA Simulation Results
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Output Summary for 120 Replications

Project: Unnamed Project Run execution date : 6/22/2024
 Analyst: USER Model revision date: 6/22/2024

OUTPUTS					
Identifier	Average	Half-width	Minimum	Maximum	# Replications
Jabas Merma Almacen	1460.3	3.4523	1407.0	1503.0	120
Jabas Despachadas	3.1160E+6	90.445	3.1149E+6	3.1178E+6	120
Jabas Reposicion Comercial	3283.9	8.9852	3162.0	3407.0	120
InicioOperacion.NumberIn	2191.0	.00000	2191.0	2191.0	120
InicioOperacion.NumberOut	2190.0	.00000	2190.0	2190.0	120
System.NumberOut	2190.0	.00000	2190.0	2190.0	120

Figure 6. Results obtained from 120 simulated replications of the initial model in Arena Simulator.

5. Results and Discussion

5.1 Numerical Results

Initially, using sales data from the Lima area for the period 2021 and 2022, it was proposed to use forecasting models to determine the projected demand and use that value to calculate the optimal and economical replenishment lot. Three forecasting models were employed: additive triple exponential smoothing, multiplicative triple exponential smoothing, and averaging-based forecasting. The model was chosen based on having the lowest Mean Absolute Deviation (MAD).

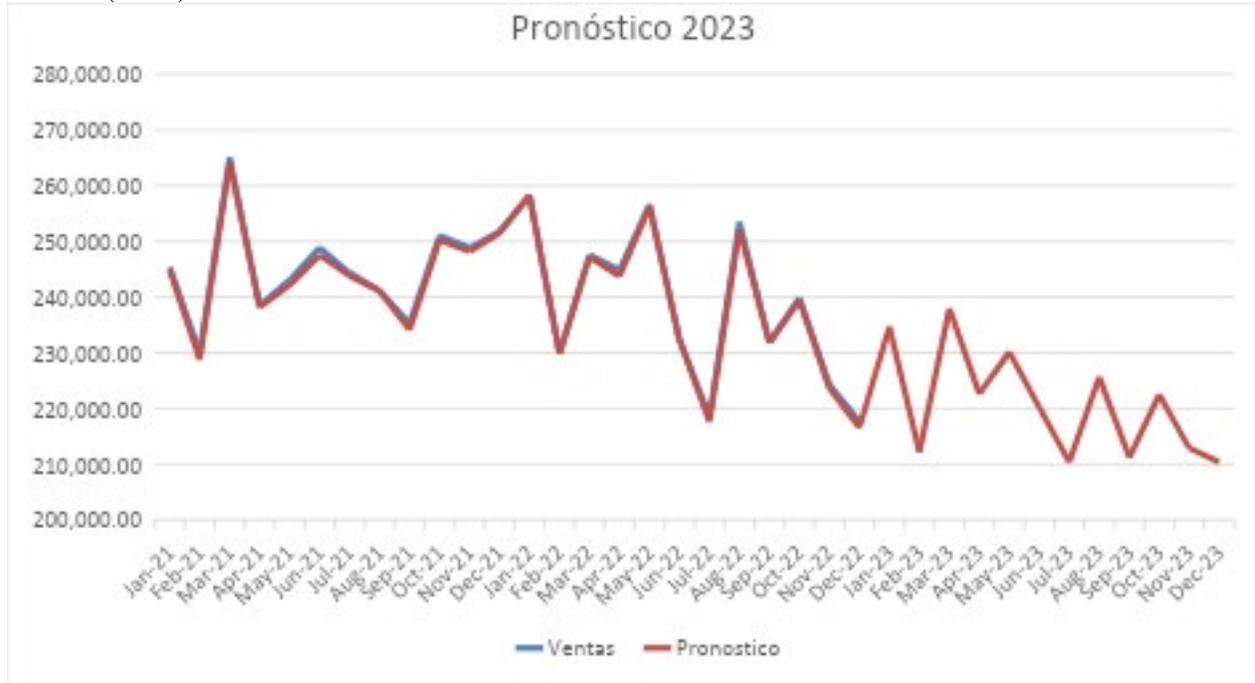


Figure 7. Forecast performed using triple exponential smoothing with additive seasonality.

Table 6. MAD results of the different forecasting models

Forecasting Model	MAD (egg Box)	Projected sales
Exponential smoothing triple additive seasonality	654.5	2,530,855.00
Exponential smoothing triple multiplicative seasonality	7,178.14	2,406,056.15
Simple Average	16,961	2,899,583.00
Moving Average	16,585	2,727,780.00
weighted moving average	9,962	2,698,917.00

Applying the formula from Figure 7, using the data obtained from the case study as shown in Table 6, along with the number of crates forecasted from the selected forecast model, resulted in a new daily replenishment lot of 5,135 crates, with a standard deviation of 215 crates. Additionally, with the new replenishment lot, it was identified that the Reorder Point (ROP) was 21,252 crates, yielding an annual cost of S/739,367.76 for the year.

The attribute acceptance sampling plan, based on ISO 2859-1 and statistical control fundamentals, guarantees the quality of the daily egg batches ($\approx 8,055$ crates, ~ 2.9 million eggs) by inspecting 500 randomly selected units. Any egg that is infected, rotten, or broken is considered defective, and an Acceptable Quality Level (AQL) of 2.5% is established; batches with up to 21 defects are accepted, whereas those with 22 or more are rejected. This method balances the risks for both the supplier and the customer, enabling the identification of issues and process improvements through record-keeping, trend analysis, and feedback. The plan ensures traceability, compliance with international standards, and a reduction in returns, contributing to a consistent delivery of high-quality products with guaranteed effectiveness and efficiency.

Once the theory was applied, the parameters were set using the selected engineering tools for improving the spoilage indicator, and these parameters were transferred to the simulation model. The arrival rate of crates changed to 5,135 crates as the daily replenishment, and the sampling activity was implemented in the warehouse flow, configured with the probability criteria for a batch to be classified as spoiled. The simulation model results, according to Figure 8, yielded the following outcomes as presented in the comparative Table 7.

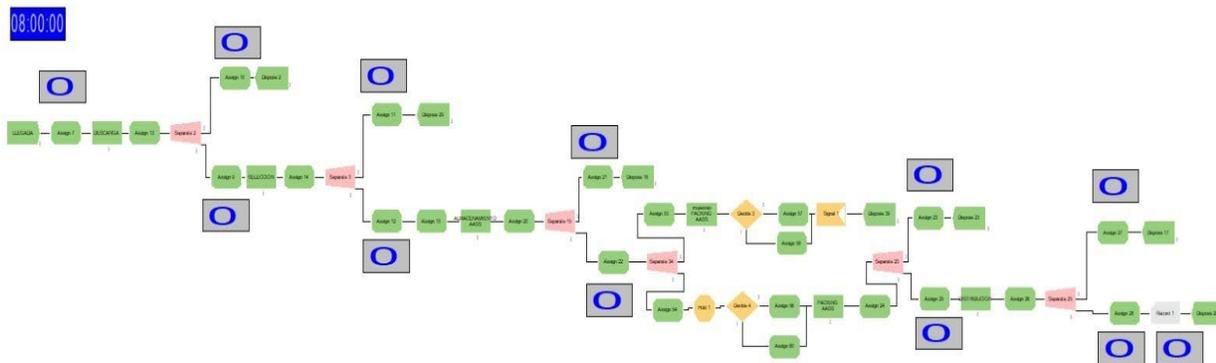


Figure 8. Solution model modeled and simulated using the tools provided in Arena Simulator.

Table 7. Comparison of the results of the initial model and the final model.

KPIs	Initial Scenario	Final Scenario	Δ Egg Box	Benefit S/.
Waste due to Warehouse damage (egg box)	1,460	731	729	47,427.39
Number of Commercial Returns (egg box)	3,284	1825	1459	94,785.94

5.2 Graphical Results

The numerical results aimed at reducing spoilage caused by damages within the warehouse and reducing commercial returns are presented in the following Table 8. Additionally, the variation of the following variables that correlate with the overall spoilage indicator for the research problem was identified, with the simulation results showing a 0.14% spoilage rate throughout the warehouse.

Table 8. Comparison of all variables analyzed from the initial model and the final model in Arena Simulator.

KPIs	Initial Scenario	Final Scenario
Waste due to Warehouse damage (egg box)	1,460	731
Number of Commercial Returns (egg box)	3,284	1825
Supply Lot (egg box)	8,572	
Waste Level (%)	0.21%	0.14%
Annual Demand (egg box)	2,855,595	2,530,855

5.3 Proposed Improvements

The proposed improvements created a Lean approach to inventory management that not only reduces the waste of crates caused by damages in the warehouse or returns, but also decreases the error variability in the calculated parameters, such as forecasted demand and acceptance criteria during sampling. This approach allowed us to determine the optimal and economical daily replenishment quantity for merchandise delivery without overstocking the warehouse. Furthermore, the proposed approach enabled the identification of the analysis and implementation model of the methodology (as shown in the Figure 9).

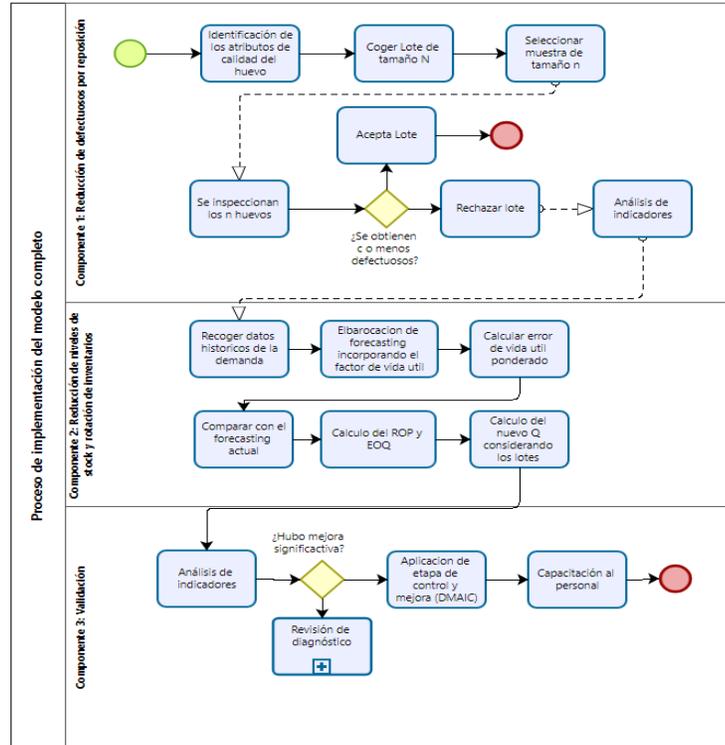


Figure 9. Implementation process of the solution model.

Commercial replenishments originating from the poor quality offered to the channels were corrected by implementing a food quality system in the warehouse. To improve the warehouse quality system, we proposed the use of Lean Six Sigma tools, specifically through its DMAIC approach (Define, Measure, Analyze, Improve, and Control), whose main objective is the continuous improvement of processes and activities and the reduction of waste. This translates into greater efficiency, quality, and profitability in warehouse management and its operations. As a result of implementing this lean approach—specifically before loading the crates onto secondary transportation—a quality control is planned to be implemented, which applies acceptance sampling techniques; if more than c defects are found in the sample, the crate is discarded, and this process is continuously repeated to reduce the number of defective units distributed to the channels.

The application of the EOQ method alongside a demand forecast—while calculating the forecast accuracy—to reduce warehouse stock (avoiding overstock situations) and increasing inventory turnover is directly related to the probability that the eggs will not be damaged or completely lose their properties from the time of storage until they are prepared, loaded, and dispatched to the sales channels. The most important decision in managing inventory is determining how large the replenishment lot should be and when to execute it (Nagib, Ahmad Najhan Mohd, 2016), without undersupplying your potential demand or compromising your sales forecast and objectives. In order to implement the EOQ method in the case study, the following assumptions must be considered:

- The holding cost is known and constant.
- The ordering cost is known and constant.
- The annual demand rate is known.
- The unit price is known and constant.
- Replenishment occurs instantaneously.
- Stockouts are not permitted.

Regarding demand, we reinforce the view of Christensen et al. (2021), who suggest that forecasting methods are fundamental for inventory control and discuss how forecast accuracy affects the effectiveness of replenishment planning, as well as the subsequent levels of waste and quality. Similarly, forecast accuracy will be measured by the magnitude of the deviations between the actual and forecasted demand when implementing the model, comparing the MAD and MAPE to evaluate the model’s impact on warehouse inventory and availability. This research will provide an understanding of the evaluation of asymmetric forecasts according to the shelf life of eggs and its relationship with the demand in the following days, ensuring a high level of freshness and a low level of waste.

However, this inventory control policy will not be functional unless it goes hand in hand with a food quality system. For this case, we decided to apply the Lean Six Sigma tool—specifically the DMAIC approach—to define the research objectives, measure the model indicators, analyze these indicators, and improve and control the process through acceptance sampling techniques. The concept of Lean Six Sigma is more efficient than Lean and Six Sigma separately (Flores, Javier, 2020). Therefore, we will use DMAIC as a tool to investigate food waste and thereby reduce this indicator in the stage prior to consumption (Kolawole, Olushoola, and Hussain, Zahid, 2021). In the Improve and Control stage, an acceptance sampling plan has been decided upon; according to the results of the inspection of a random sample taken from the lot, a decision is made as to whether the lot is accepted or not. However, since the entire lot is not inspected, sampling always carries a certain risk. The first error would be rejecting a lot that should be accepted, while the second error would be accepting a lot that should have been rejected (Ciccarelli et al. 2023).

5.4 Validation

The validation of our improvement design was carried out, as explained earlier, using the Arena V2 simulation tool by comparing the real data obtained from the case study with the data generated from 120 replications of the design. The results were as follows, leading to the conclusion that the model designed in the simulation tool was valid and functional.

Table 9. Comparison of actual results versus the results from the final Arena Simulator model

KPIs	Results 2022 (egg/box)	Results Arena Simulator (egg/box)
Waste due to Warehouse damage (egg box)	1,433	1,460
Number of Commercial Returns (egg box)	3,409	3,284

Once the design was validated and after implementing the proposed improvements both in the inventory management model using the EOQ methodology and in the attribute acceptance sampling process, a notable reduction was observed in the types of spoiled crates as indicated in Table 9. Specifically, spoilage due to warehouse damage decreased by 56% and commercial returns dropped by 40%. Overall, the total spoilage—including that due to sanitation—reached 0.14%, which is in line with the research objective of 0.15% (a percentage typically maintained by the industry).

Finally, after validating the reduction in spoilage, an economic evaluation was carried out to confirm the viability and profitability of the proposed design. It was found that the retail price of the crates was S/64.9 and the cost was S/33.76, resulting in a margin of 39%. The solution model led to a reduction of 730 crates spoiled due to warehouse damage and 1,459 crates spoiled due to commercial returns. This decrease in spoilage, in turn, reduced the economic impact since the crates remained fit for regular daily sale, yielding total gross sales of S/142,161.37 (plus an additional S/44,641.39 from crates spoiled by sanitation issues and subsequently reprocessed). Thus, an additional annual sale of S/186,802.76 was achieved as a result of the reduction in warehouse spoilage. On the other hand, the total investment for the entire model—including the new hires for the sampling personnel and the training costs related to the solution design—was S/159,000 as initial outlay (Figure 10).

	Periodo 0	Periodo 1	Periodo 2	Periodo 3	Periodo 4	Periodo 5
Ingresos		S/ 186,802.76				
Costos	-S/159,000.00	-S/ 124,159.27	-S/ 124,186.28	-S/ 124,186.28	-S/ 124,186.28	-S/ 124,186.28
Utilidad Bruta		S/ 62,643.49	S/ 62,616.48	S/ 62,616.48	S/ 62,616.48	S/ 62,616.48
IGV		-S/ 11,275.83	-S/ 11,270.97	-S/ 11,270.97	-S/ 11,270.97	-S/ 11,270.97
Flujo	-S/159,000.00	S/ 51,367.66	S/ 51,345.52	S/ 51,345.52	S/ 51,345.52	S/ 51,345.52

Figure 10. Economic evaluation of the solution model.

Performing an economic evaluation to assess the project's viability, we obtained the following financial indicators. Our Net Present Value (NPV) came out at S/185,108.87, which means that the project will generate profitability by increasing the company's value after considering an investment of S/159,000. In addition, the Internal Rate of Return (IRR) was calculated at 18% against a discount rate of 12%, indicating that the project is attractive and economically viable (Table 10).

Table 10. Project Profitability KPIs.

KPIs	Results
TIR	18%
VAN	185,108.87 S/.
Rate	12%

6. Conclusion

This study presents an innovative combination of tools, including the Lean Six Sigma methodology with a DMAIC approach, inventory management using the Economic Order Quantity (EOQ) model, and attribute-based acceptance sampling. The primary objective of this integration is to reduce the level of defective products in the supply chain and optimize inventory control.

The implementation of the Lean Six Sigma methodology with a DMAIC approach allowed for the identification and elimination of process variability, providing superior service value to the customer and significantly contributing to reducing operational waste. The EOQ method proved effective in optimizing supply management, ensuring that inventory remained within optimal levels while simultaneously reducing the risk of overstocking. Furthermore, the use of attribute-based acceptance sampling complemented these strategies by significantly reducing the number of rejected batches, ensuring that only products that met quality standards reached the end customer. As a result of this synergy of methods, operational efficiency was improved and the amount of waste in the warehouse was significantly reduced.

This combined approach not only provides a valuable framework for continuous improvement in perishable product management, but also offers a replicable model for other companies facing similar challenges in their supply chains. As a future action, we suggest exploring additional predictive analytics techniques to complement this methodology, which could further boost the effectiveness of the implemented strategies.

However, certain limitations are recognized in the scope of the study, especially in the generalization of the results to other companies in the sector. Therefore, additional research is recommended, focusing on the application of predictive and demand forecasting techniques, which could further enhance inventory management strategies in the poultry industry. In essence, the findings of this work present a replicable framework that could be implemented in companies with similar challenges in managing perishable products.

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