Improving a Bakery's Service Level Using Machine Learning, Process Standardization, and Packaging Redesign

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Received: August 15, 2025 / Accepted: October 15, 2025 / Published: 5 June, 2026
doi: https://doi.org/10.26439/ciii2025.8655

ABSTRACT—This paper proposes a model to improve the service level of a pastry shop that faced issues such as incomplete deliveries, product damage, and delivery delays. The proposed solution integrates three components: (i) a machine learning (ML) model for delivery route optimization, (ii) standardization of the order dispatch process through manuals and checklists, and (iii) a packaging redesign incorporating internal supports and waterproof liners. As a result, the fill rate (FR) increased from 89.81% to 94.28%, the damaged delivery rate (DDR) decreased from 5.58% to 3.61%, and late deliveries were reduced from 5.07% to 1.26%. In addition, the proposed model avoided the emission of 574 kg of CO_2 per year. This model is applicable to small and medium-sized enterprises (SMEs) seeking to improve their logistics, reduce operating costs, and increase customer satisfaction through more efficient and sustainable processes.

Index Terms—Confectionery, machine learning, packaging, service level, standardized processes.

I. Introduction

The pastry sector has experienced sustained growth at the regional level, driven by an increasingly demanding consumer who values not only the quality of the product, but also its presentation, sustainability and punctuality in delivery [1], [2]. In Latin America, annual growth of 5.8% is projected for the premium segment, associated with increased purchasing power and a growing preference for tailored experiences [3]. This environment has placed increasing pressure on companies' operational capacity, requiring greater logistical efficiency, assurance of product integrity during transport, and minimization of order-picking errors [4], [5]. Likewise, the need to adopt responsible practices has prompted a re-evaluation of packaging material usage, optimization of resource consumption, and reinforcement of process traceability. The accelerated digitalization of the sales channel has exposed the limitations of traditional distribution schemes, making it essential to incorporate technological solutions that allow predictive planning and the maintenance of consistent service levels in highly competitive contexts [6].

However, many bakeries continue to face structural deficiencies in their logistics operations. The case analyzed exhibits a service level of 89.81%, below the recommended standard of 95%, along with a damaged delivery rate (DDR) of 5.58%, a preparation error rate (PER) of 4.61%, and a delivery inaccuracy (DI) of 5.07%. Unlike previous studies that address isolated solutions, this work integrates technological, operational and structural components to jointly address logistical failures, which represents an original contribution to the artisanal bakery sector.

In response to this problem, a comprehensive solution based on three main components is proposed: an intelligent dispatch system using machine learning (ML), process standardization through visual tools, and the redesign of technical packaging. Previous studies have addressed similar problems in bakery supply chains, primarily focusing on waste reduction or delivery time improvements through specific technological approaches [3], [15]. However, unlike these works, this study addresses a comprehensive operational challenge by integrating logistical precision, real-time traceability, and packaging structural redesign under sustainability criteria. This convergence of logistical, human, and environmental dimensions increases the complexity of the problem and requires multidisciplinary solutions that extend beyond the isolated approaches proposed in the literature [7], [8]. This combination seeks to improve logistical accuracy, reduce transit times, and ensure product integrity. Similar studies have shown that these strategies can reduce waste in bakery supply chains by up to 30% [3], [4], while also increasing customer satisfaction through reduced service variability [5].

The artificial intelligence component was developed using a multiple regression model based on historical data and real-time traffic information, following approaches aimed at route optimization and emission reduction [6], [9]. In parallel, operational standardization—based on visual control mechanisms and role definition—reduces human errors, improves traceability and increases employee performance [10], [11]. Finally, the packaging redesign considered the NTP 209.027:2012 and ISO 18601:2013 standards, prioritizing stackability, structural strength and sustainability, in accordance with guidelines related to the use of active packaging in bakery products [12].

The results were validated through pilot tests and simulations, showing an increase in the fill rate (FR) to 94.28%, a reduction in the DDR to 3.61%, and a decrease in the DI to 1.26%. In addition, the avoidance of 574 kg of CO_2 per year was achieved through waste reduction, demonstrating that the proposed approach is not only operationally viable, but also environmentally sustainable.

II. Literature Review

A. Outbound Logistics

Outbound logistics represents one of the greatest challenges in the food industry, particularly for companies handling perishable products such as pastries. Issues such as poor route planning, delivery delays, and inefficient dispatching increase operational costs negatively affect customer satisfaction. Studies indicate that these issues directly affect service quality, highlighting the need for smarter logistics systems [13]. In this context, Bei *et al.* [14] developed an intermodal transport model for perishable goods that reduces both costs and product deterioration, improving delivery efficiency by up to 18% for temperature-sensitive items.

B. Implementation of Advanced Technologies

The use of technologies such as ML has become essential to make food supply chains more efficient and reliable. These tools assist in predicting delivery times, managing unexpected changes, preventing logistical issues, and optimizing resource utilization [15], [16]. Recent research has also demonstrated how technology can support more sustainable operations. For example, Nannar *et al.* [17] created a model that combines efficiency measurement with sustainability goals, improving logistics performance and resource use by up to 20% in perishable food systems. Likewise, Nikseresht *et al.* [18] reviewed over 150 studies and found that ML models combining prediction and optimization can reduce emissions and process variability by up to 25%, demonstrating their strong potential to link efficiency with sustainability.

C. Quality of Service

The quality of service in the food sector is a key factor for competitiveness. It is determined not only by the quality of the final product but also by the accuracy of order preparation, delivery punctuality, and the condition in which products reach the customer. Standardization of operational processes is a fundamental strategy that reduces variability, minimizes errors and ensures consistent service levels, positively impacting customer perception and loyalty [19].

D. Food Waste

Food waste represents a critical problem in the bakery and pastry industry. A significant portion of these losses results from product damage during handling and transport, primarily due to inadequate packaging or suboptimal handling processes. Research emphasizes the importance of implementing strategies such as packaging redesign to provide greater protection during distribution, as well as improving logistics practices to mitigate both economic and environmental losses [20].

E. Sustainability

Sustainability plays a key role across all company activities, influencing both operations and their environmental and social impact. Optimizing routes, reducing product damage, and improving packaging not only save costs but also reduce CO_2 emissions, lower material usage, and minimize waste—supporting business models aligned with the Sustainable Development Goals (SDGs) [21]. Likewise, Prayitno and Wicaksono [22] introduced a framework that uses artificial intelligence to enhance collaboration among logistics partners in cities, showing that AI-based coordination can reduce CO_2 emissions by nearly 30%, while improving transparency and flexibility in shared logistics systems.

III. Methodology

This study applied a continuous improvement methodology, combining industrial engineering techniques, data science and product redesign, with the aim of increasing the service level in a pastry shop. The proposal was structured around three main axes as shown in Fig. 1:

Logistics optimization using ML for delivery time prediction and route sequencing.

- Standardization of operational processes in order preparation and dispatch activities.
- Redesign of packaging, aimed at reducing damage to the product and improving logistics efficiency.

Each axis included the analysis of operational data, the technical design of the solution and its implementation under an engineering approach tailored for SMEs.

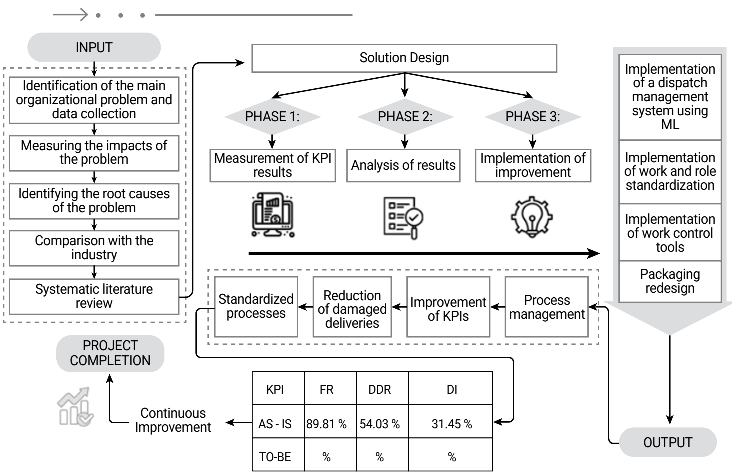

Fig. 1. Macro model of the solution proposal.

A. Logistics Optimization Through ML

The ML model was developed with the aim of reducing delivery times and improving accuracy in logistics planning. The CRISP-DM (Cross Industry Standard Process for Data Mining) methodological model was followed, structured into six phases: business understanding, data understanding, data preparation, modeling, evaluation and implementation.

1) *Data Collection and Analysis*: Historical operational data from the company's management system were used, considering the following variables:

- Destination store
- Departure date and time
- Charging time
- Download time
- Transit time
- Day of the week
- Traffic condition

2) *Predictive Model:* A supervised regression model using Random Forest was applied to predict transit times based on multiple factors. The model was trained on a structured dataset containing 1,153 records.

3) *Representation of the Predictive Function:* Although the Random Forest model does not generate an explicit equation, conceptually the prediction follows the function:

$$T_{transit} = f\ (Destination, H, Day_{week}, T, Load)$$

Where:

- f = Function generated by decision trees
- *Destination* = Destination store
- H = Departure times
- *Day* = day of the week
- T = Traffic
- *Load* = Operational load

4) *Optimal Route Sequencing*: Transit time prediction was integrated into a comprehensive search algorithm that calculates all possible permutations of stores to visit. The optimal sequence corresponds to the one that minimizes the total travel time subject to the constraint of point-to-point routes (departure from and return to the plant):

$$min \sum_{i=1}^{n} T_{traffic_i}$$

B. Standardization of Operational Processes

The second axis of improvement consisted of the standardization of critical processes related to order preparation and dispatch.

1) *Analysis of the Current Process (AS-IS)*: A detailed mapping of the AS-IS process was carried out, identifying tasks with high operational variability and risk of errors, mainly in:

- Armed with requests
- Product verification
- Vehicle charging

2) *TO-BE Process Design:* Standard operating procedures were defined for the following activities:

- Standard order assembly sequence
- Quality control and dispatch checklist
- Standardization of in-vehicle load criteria

Visual tools were implemented and tasks were redistributed to ensure operational traceability.

3) *Ergonomics and Operational Safety*: Criteria were applied according to NTP 399.010:2004 and ISO 11228, prioritizing the reduction of physical efforts in handling and loading tasks.

C. Packaging Redesign

The packaging redesign focused on reducing the DDR and improving transportation efficiency.

1) *Diagnosis of Damage*: The following were identified as the main causes of product damage:
   - Internal movement of products during transport
   - Strong vibrations on the road
   - Insufficient material impermeability
2) *Technical Packaging Design*: The new packaging was designed according to three fundamental criteria:
   - Structural protection: Lateral reinforcements and internal dividers.
   - Waterproofing: Incorporation of laminates resistant to moisture and grease.

The new packaging structure includes internal reinforcements and a waterproof layer that protects the product from movement and moisture during transport. The unfolded layout (bottom left) illustrates how the structure was adapted to enhance stability and facilitate stacking.

D. Calculation of Operational Indicators

The following indicators were defined to quantify operational performance:

- Fill rate (FR)

$$FR = \frac{Complete\ and\ on\ time\ products}{Total\ ordered\ products} \times 100$$

- Damaged delivery rate (DDR)

$$DDR = \frac{Damaged\ products}{Total\ ordered\ products} \times 100$$

- Preparation error rate (PER)

$$PER = \frac{Errors}{Total\ ordered\ products}$$

- Delivery inaccuracy (DI)

$$DI = \frac{Extra\ working\ minutes}{Schedule\ working\ minutes}$$

E. Environmental Assessment

Environmental evolution was carried out considering three main factors: emission reduction, waste minimization, and material savings.

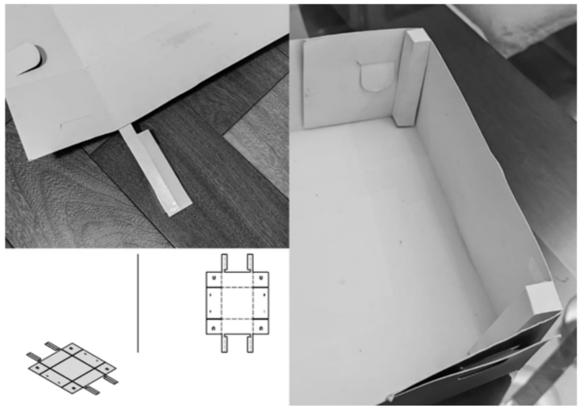

Fig. 2. Redesigned packaging model.

1) *Reduced Emissions Calculation:* The CO_2 emissions avoided by the reduction in vehicle operating hours were estimated.

$$Emissions_{CO_2 ed} = (H_{before} - H_{after}) * FUELConsumption_{vehicle} \times Factor_{CO_2}$$

Where:

- H_{before} = Total delivery hours before upgrade
- H_{after} = Total hours of delivery after upgrade
- $Consumption_{vehicle}$ = Liters of fuel per hour
- $Factor_{CO_2}$ = Kg CO_2 emitted per liter of fuel

2) *Reduction of Waste Generated:* The reduction of damaged units was calculated

$$Waste_{reduced} = Units_{damaged\ before} - Units_{damaged\ after}$$

3) *Savings in Packaging Materials:* Material savings resulting from the more efficient packaging redesign were estimated:

$$Material_{savings} = (M_{before} - M_{after}) \times added\ units$$

Where:

M_{before} and M_{after} represent the weight of packaging material per unit before and after.

IV. Results and Validation

The validation of the proposal was carried out as shown in Fig. 3, through pilot tests in real operations over four weeks, as well as simulations using historical data. The results demonstrate significant improvements in the primary service level indicators.

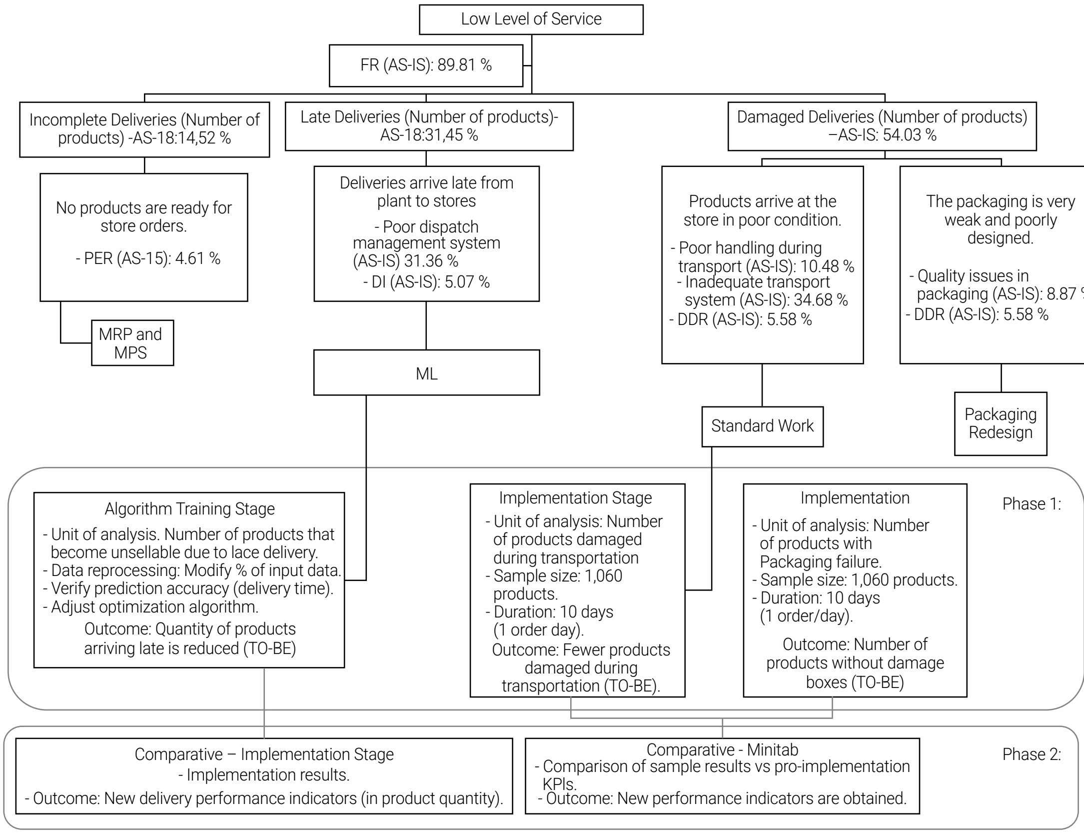

Fig. 3. Macro-level validation model diagram.

A. Results

The results listed in Table I were obtained through a 10-day implementation in the company's real operations, complemented by simulations using historical data from the management system. Operational indicators, including FR, DDR, PER, and DI, were measured before and after implementing the proposed improvements. Each value corresponds to the average observed during the test period, verified through field records and daily monitoring reports.

The improvement in the FR and the significant reduction in the DI reflect the positive impact of the ML model applied to logistics optimization. On the other hand, the reduction of DDR and PER demonstrates the effectiveness of process standardization and packaging redesign.

B. Validation of the ML Model

The Random Forest–based predictive model achieved a coefficient of determination (R^2) of 0.91 and a root mean square error (RMSE) of 3.74 minutes, demonstrating high accuracy in predicting transit times by considering variables such as traffic, departure time, day of the week, and operational load.

The application of the model, combined with the exhaustive route-sequencing algorithm, reduced total daily travel time by 17.8% and decreased variability in delivery times.

TABLE I

Results Before and After Improvement

Indicator	Results		
	Initial situation	*Improved situation*	*Change (%)*
FR	89.81%	94.28%	+4.98%
DDR	5.58%	3.61%	-35.3%
PER	4.61%	2.11%	-54.23%
DI	5.07%	1.26%	-75.14%

C. Process Standardization Validation

The validation of the standardization was carried out through an operational pilot test, with the following results:

- PER was reduced by 54.23%.
- Assembly and dispatch times improved by 12%.

- Recurring errors in the verification, loading, and assembly processes were eliminated through the implementation of checklists, visual controls, and task redistribution.

D. Packaging Redesign Validation

The packaging redesign was validated through the same pilot test, focusing on transport resistance and the ability to protect the product. The results were as follows:

- Reduced the DDR from 5.58% to 3.61%, equivalent to a 35.30% improvement.
- Elimination of damage caused by vibration, shock, or internal displacement.

V. Discussion

The results indicate that the improvement proposal significantly reduced the main operational failures affecting the bakery's service level. The combined implementation of three initiatives—logistics optimization via ML, standardization of operational processes, and packaging redesign—enabled a comprehensive approach to addressing DIs, product damage, and partial order fulfillment.

The increase in the FR, from 89.81% to 94.28%, confirms that the comprehensive solution significantly improved the company's ability to fulfill orders in quantity and timeliness, approaching the 95% standard recommended for efficient logistics operations in the sector [18].

The DI, reduced from 5.07% to 1.26%, demonstrates the effectiveness of logistics optimization via the ML model. This result surpasses the 22% waste reduction reported by Aljohani [13], who applied route optimization techniques without integrating real-time traffic or validating with actual data. Instead, our approach used supervised prediction with Random Forest, incorporating real-time traffic, which resulted in a 17.8% reduction in total daily travel time.

The PER decreased from 4.61% to 2.11%, representing a 54.23% improvement. This result aligns with the findings of Quiroz-Flores et al. [14], who reported a 13% service level improvement through task standardization, although their approach did not include an ergonomic task redistribution phase as proposed in this study. The combination of checklist, visual control and task distribution improved assembly times and eliminated recurring errors, reinforcing the findings of Burgess *et al.* [19] on the importance of traceability in food supply chains.

The DDR decreased from 5.58% to 3.61%, representing a 35.30% improvement. This result confirms the effectiveness of the new packaging design and aligns with the recommendations of Qian *et al.* [12], who emphasize that packaging with active elements can prevent damage from moisture and vibrations. Unlike Qian, our redesign incorporated internal support elements and waterproof sheets within the same current material, achieving an improvement without the use of external or specialized materials.

Analytical Flowchart	PRODUCTS			
Diagram number: 2 Page: 1af 1	SUMMARY			
Object: Dispatch of bakery products	ACTIVITY	CURRENT	PROPOSED	ECONOMY
Activity: Complete dispatch process	Operations	09	12	-
	Tranports	03	03	-
Method: PROPOSED	Delays	01	01	-
	Inspections	02	02	-
Place: Plant- "La Crocante" Store	Storages	01	01	-
Form number: 2	Distance (meters)	28	26	-
	Time (minutes)	40	38	
Prepared by: Sergio Mercado, Santiago Vásquez				
Date: 09302025				

DESCRIPTION	C	D(m)	T (min)	SYMBOL ○	⇨	D	□	▽	OBSERVATIONS
1. Make requirement			2				×		Store administrator
2. Send requirement to production			1		×				
3. Plan production			5				×		Production manager
4. Produce products							×		
5. Generate route with ML model			3				×		Warehouse chief
6. Prepare transfer guide			3				×		
7. Load cart with products			2				×		Operator
8. Verty products with guide			2	×					
9. Wait for missing products			5			×			
10. Inform operator			1				×		Dispatcher
11. Prepare checklist									
12. Verity with checklist			2	×					
13. Take products to elevator			2		×				Operator
14. Load van			2				×		Dispatcher
15. Drive to store					×				Driver
16. Receive products			2				×		
17. Record condition			2				×		Store administrator
18. Separate products			1				×		
19. Store products			1					×	End of flow
Total			38	02	03	01	12	01	

Fig. 4. Process analysis diagram (PAD).

At a comprehensive level, the study proposes a multidisciplinary solution impacting five key dimensions: logistics precision, operational ergonomics, environmental sustainability, organizational standardization, and customer experience. Unlike studies such as Lahane *et al.* [11], which address barriers to technological adoption theoretically, this proposal demonstrates how these barriers can be overcome in a real SME through gradual implementation, internal training, and monitoring using accessible tools such as Minitab and Python.

Finally, validation through pilot testing confirmed that the improvements are viable and sustainable under real operating conditions. This positions the proposal as a replicable model for SMEs in the food sector facing similar problems.

VI. Conclusions

The implemented proposal managed to significantly improve the service level of the pastry shop through three key actions: ML, standardization of processes and redesign of the packaging.

The ML model reduced the DI from 5.07% to 1.26%, improving logistics accuracy. Process standardization decreased the PER from 4.61% to 2.11%, while packaging redesign reduced the DDR from 5.58% to 3.61%. As a result, the FR increased from 89.81% to 94.28%.

In conclusion, the integration of these tools is effective and replicable in SMEs facing similar challenges, provided it is accompanied by training and continuous operational monitoring.

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