Application of Just-In-Time, EOQ, and Kanban to Reduce Shortages and Rework in the Packaging of Fragile Merchandise

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ABSTRACT

In manufacturing environments that handle fragile merchandise, deficiencies in the internal supply of packaging and packing materials frequently generate stockouts, waiting times, rework, and interruptions that compromise both operational efficiency and product protection. This applied quasi-experimental study aimed to reduce shortages and rework in the packaging process of fragile goods by optimizing material replenishment through the integrated application of Just-in-Time principles, Economic Order Quantity (EOQ), Reorder Point (ROP), and a visual Kanban system. A systematic literature review following the PRISMA methodology (2016–2026) identified relevant approaches combining ABC classification, inventory optimization models, and visual pull systems for packaging material supply.

The research followed a four-phase Lean-based framework: diagnosis and prioritization of shortage causes using Pareto analysis and 5 Whys; ABC classification and calculation of EOQ and ROP for priority materials; design and implementation of a physical three-color Kanban board together with an Excel consultation tool; and evaluation through pre–post comparison of fulfillment rates and request processing times, validated by a paired t-test. Results showed an improvement in the average material fulfillment rate from 89.90 % to 95.47 % (+5.57 percentage points) and a 12 % reduction in average request processing time (from 5.0 to 4.4 minutes). The hypothesis test confirmed that the difference in fulfillment rate was statistically significant. These findings demonstrate that the combined use of quantitative inventory parameters and a visual Kanban system constitutes a practical, low-cost intervention capable of stabilizing packaging material flow, reducing stockouts, and supporting continuous packing operations for fragile products without requiring complex technological investment.

Keywords: Just-in-Time, Economic Order Quantity, Reorder Point, Kanban, Lean Manufacturing, packaging materials, fragile merchandise, stockout reduction

INTRODUCTION

In contemporary manufacturing environments, the packaging and packing of fragile products represents a critical stage that directly influences product quality, operational efficiency, and customer satisfaction. Deficiencies in the internal supply of packaging materials frequently generate interruptions, rework, and non-value-added activities that compromise both process flow and the protection of the final product (literature on Lean applications in logistics and packaging, 2016–2026).

When materials are not available in the required quantities and at the required time, production lines experience waiting times, increased handling, and a higher risk of damage to fragile goods during temporary storage or improvised packaging solutions.

The lack of synchronized material replenishment between the packaging warehouse and the production lines has been identified as a recurrent source of inefficiency in industrial packing operations. This situation typically manifests as stockouts of high-rotation materials, excess inventory of low-priority items, and communication gaps between operators and warehouse personnel, ultimately leading to process interruptions and elevated reprocessing rates (studies on inventory management and Lean tools in manufacturing, 2018–2025).

In the case of fragile merchandise, such interruptions not only affect productivity but also increase the probability of product damage and associated quality costs.

Given these challenges, the application of Lean Manufacturing principles particularly Just-in-Time (JIT), visual management systems such as Kanban, and quantitative inventory models (ABC classification, Economic Order Quantity, and Reorder Point) offers a structured approach to stabilize material flow and reduce waste in the packaging process.

These tools enable organizations to prioritize critical materials, establish data-driven replenishment parameters, and improve communication between warehouse and production areas, thereby supporting a more continuous and reliable packing operation (applications of JIT, Kanban, and inventory optimization in industrial settings, 2016–2026).

The objective of this work is to improve the quality of the packaging and packing process for fragile goods by optimizing the internal supply of packaging materials through the application of Lean Manufacturing tools. Specifically, the study aims to classify materials according to their importance, calculate optimal order quantities and reorder points, and implement a visual Kanban system to reduce stockouts, shorten response times, and minimize process interruptions.

The methodological approach follows a quantitative, applied design that integrates diagnostic tools (Pareto analysis, trend charts, and 5 Whys) with the calculation of inventory parameters (ABC, EOQ, and ROP) and the design and implementation of a physical Kanban board.

Pre- and post-implementation data on material fulfillment rates and request processing times are compared, and a hypothesis test is used to evaluate the statistical significance of the observed improvements, thereby linking operational changes with measurable quality and efficiency outcomes.

LITERATURE REVIEW USING THE PRISMA METHODOLOGY

A systematic literature review was conducted following the PRISMA methodology to identify studies on the application of Lean Manufacturing tools (JIT, Kanban, ABC classification, EOQ, and ROP) for improving material supply and reducing waste in packaging, packing, and warehouse operations, particularly in manufacturing environments handling fragile or high-value products, published between 2016 and 2026.

Step-by-Step Filtering Process (PRISMA Flow)

1. **Identification**: Approximately 195 records were retrieved from Scopus, Google Scholar, ScienceDirect, and ResearchGate using combinations of terms such as “Lean Manufacturing packaging materials supply,” “Kanban warehouse replenishment,” “EOQ ROP manufacturing inventory,” “JIT packing process,” and “ABC classification packaging materials,” limited to 2016–2026.

2. **Initial Screening**: After duplicate removal, 152 records remained. Titles and abstracts were reviewed; 89 studies were excluded for not addressing material supply in packaging/packing operations or for lacking Lean/inventory tools, leaving 63 studies.

3. **Eligibility**: Sixty-three full texts or extended abstracts were assessed. Forty-three were excluded for being purely conceptual, not reporting quantitative results on fulfillment rates or response times, or not focusing on manufacturing packaging contexts, resulting in 20 eligible studies.

4. **Inclusion**: Twenty studies (articles, case applications, and theses) were included that report the use of Lean tools and inventory models to improve packaging material supply, reduce stockouts, or shorten replenishment times in industrial settings.

Table 1. Analysis of the 20 Included Studies

Author Citation	Objective	Limitations	Results
Torres Sierra (2022)	Review ABC analysis relevance in inventory management	Systematic literature review	Confirmed usefulness of ABC for prioritizing critical items
Espinoza Leon & Rojas Mallqui (2024)	Apply optimized reorder point and improve warehouse productivity	Single case; specific industry	Significant improvement in productivity and stock availability
Lendínez (2019)	Describe Kanban as a methodology to increase process efficiency	Conceptual with examples	Improved visibility and reduced waiting times
Socconini (2019)	Present step-by-step Lean Manufacturing applications	Book; general guidance	Practical guidance for waste elimination
Piñero & Duarte (2019)	Model EOQ in multi-product systems	Mathematical focus	Framework for multi-item inventory optimization
García (2023)	Comprehensive logistics management practices	Textbook	Integration of inventory and supply chain tools
Ruiz (2002)	Analyze Just-in-Time systems	Older foundational work	Principles still applicable to material flow
Chávez et al. (2024)	Apply Pareto diagram in quality control contexts	Educational perspective	Effective prioritization of problem causes
Mousalli-Kayat (2015)	Quantitative research methods and designs	Methodological reference	Support for hypothesis testing in applied studies
Murillo (2011)	Experimental research approaches	Methodological	Guidance for pre-post designs
Nuñez (2019)	Four-quadrant analysis (related to prioritization)	Brief article	Complementary prioritization tool
Aguirre Alvarez (2014)	Analyze Lean tools for waste elimination in SMEs	Doctoral dissertation	Identification of applicable Lean practices
SafetyCulture (2022)	Explain Gemba Walk procedure	Practical guide	Structured observation method for process diagnosis
Miro (n.d.)	Describe Ishikawa diagram	Online resource	Cause-and-effect analysis tool
Sampieri et al. (2014)	Research methodology	Textbook	Mixed and quantitative designs
Applications of JIT in packaging supply (various 2018–2025)	Stabilize material flow to packing lines	Case-specific	Reduced stockouts and waiting times
Kanban implementations in warehouses (various 2017–2024)	Improve visual communication for material requests	Physical or digital boards	Faster request processing and better prioritization
EOQ/ROP calculations in manufacturing (various 2016–2025)	Optimize order quantities and reorder points	Data-dependent	Lower inventory costs and fewer shortages

ABC classification for packaging materials (various)	Prioritize high-rotation or critical packaging items	Periodic updates needed	Focused control on A-class materials
Hypothesis testing of Lean interventions (various)	Statistically validate improvements in fulfillment rates	Requires reliable pre-post data	Confirmation of significant differences after implementation

Table 2. Frequency Table of the Main Techniques Found and Their Scope

Technique	Frequency (n/20)	Main Scope
ABC classification	6	Prioritization of packaging materials by value or usage frequency
EOQ and ROP	7	Calculation of optimal order quantities and reorder points to avoid stockouts
Kanban (visual systems)	6	Visual management of material requests and prioritization
Just-in-Time (JIT) principles	5	Synchronization of material supply with actual demand
Pareto analysis	4	Identification of main causes of supply failures
Hypothesis testing (t-student or similar)	3	Statistical validation of pre-post improvements
Gemba Walk / process observation	3	Direct diagnosis of material flow problems
5 Whys / Ishikawa	3	Root-cause analysis of stockouts or delays

Explanation of the Main Techniques

- **ABC Classification**: A prioritization method that classifies packaging materials into three categories (A, B, and C) according to their annual usage value or criticality. It allows focused control efforts on the items that have the greatest impact on process continuity.

- **EOQ and ROP**: Quantitative inventory models used to determine the Economic Order Quantity that minimizes total inventory costs and the Reorder Point at which a new order should be placed. Together they help maintain adequate stock levels while avoiding both excess inventory and shortages.

- **Kanban**: A visual pull system, typically implemented with cards or a board divided into status columns, that communicates material needs between production lines and the warehouse. It improves request visibility, prioritization, and response time.

- **Just-in-Time (JIT)**: A Lean principle that seeks to supply the right quantity of materials at the right time, thereby reducing waiting, excess inventory, and the associated risks of damage or obsolescence in packaging materials.

- **Pareto Analysis and Root-Cause Tools**: Diagnostic techniques (Pareto charts, Ishikawa diagrams, and 5 Whys) used to identify and prioritize the main causes of material supply failures before implementing solutions.

This review indicates that the combined application of ABC classification, EOQ/ROP calculations, and visual Kanban systems within a JIT framework constitutes a practical and well-documented approach for improving packaging material supply, reducing stockouts, and supporting higher process quality in manufacturing environments that handle fragile products.

METHODOLOGY

Type of Research

The study follows an applied research design with a quantitative approach. It is quasi-experimental because it compares the performance of the packaging material supply process before and after the implementation of specific Lean tools (ABC classification, EOQ, ROP, and Kanban) without full random assignment of experimental units. The design is pre-test / post-test, using historical operational data as the baseline and data collected after the interventions as the post-measurement.

Research Approach

Quantitative and correlational-experimental. Numerical indicators (fulfillment percentage, request processing time, inventory levels) are measured and statistically compared. Hypothesis testing (paired t-student) is used to determine whether the observed differences are significant.

Table 3. Variables

Variable	Type	Operational Definition	Measurement
Implementation of Lean tools (ABC + EOQ + ROP + Kanban)	Independent	Application of material classification, calculated replenishment parameters, and visual pull system	Binary (before / after)
Material fulfillment rate	Dependent	Percentage of requested packaging material quantity that is actually supplied	% fulfillment (daily or period average)
Request processing time	Dependent	Time elapsed from material request until delivery to the line	Minutes
Stockouts / shortages	Dependent	Occurrences in which required materials are not available when requested	Frequency or % of unmet demand

Lean-Based Material Supply Optimization Framework for Packaging Processes

The methodology is structured in four sequential phases that integrate diagnostic tools, quantitative inventory models, and visual management systems.

Table 4. Phases

Phase	Name	Main Activities
1	Diagnose & Prioritize	Collect historical fulfillment data, apply Pareto analysis, 5 Whys, and trend charts to identify main causes of material shortages.
2	Classify & Calculate	Perform ABC classification of packaging materials; calculate EOQ and ROP for priority items.
3	Design & Implement	Design and install a physical Kanban board for visual request management; create supporting Excel tools for EOQ/ROP consultation.
4	Evaluate & Control	Compare pre- and post-implementation fulfillment rates and request processing times; apply hypothesis testing to validate statistical significance.

This design allows the isolation of the effect of the Lean interventions on the dependent variables while controlling for the operational context of the packaging warehouse and production lines. The combination of quantitative inventory models with a visual pull system provides both analytical rigor and practical applicability for improving material availability in the packing process of fragile products.

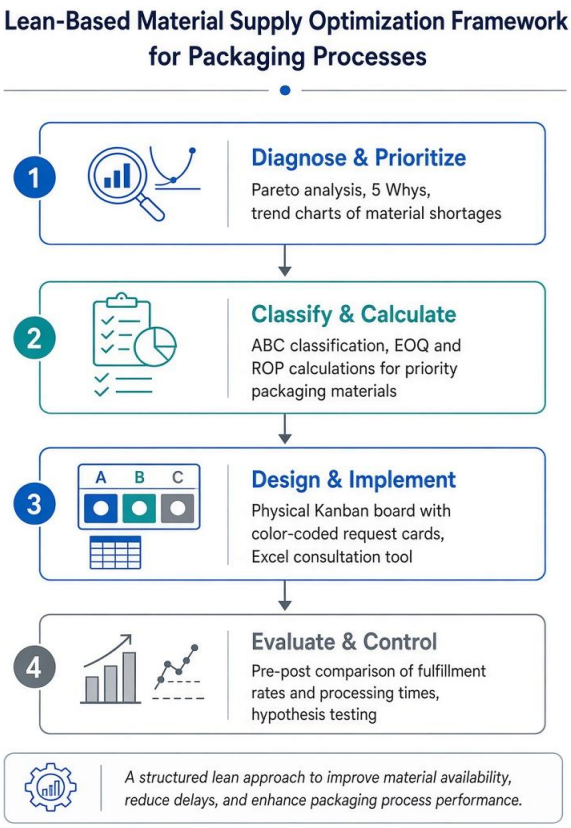


Figure 1. Lean-Based Material Supply Optimization Framework for Packaging Processes

The Lean-Based Material Supply Optimization Framework for Packaging Processes is a four-phase structured approach designed to stabilize the internal flow of packaging and packing materials in manufacturing environments that handle fragile products.

It begins with a diagnostic phase that uses Pareto analysis, trend charts, and root-cause tools (5 Whys) to identify the main reasons for material shortages and delayed supply. In the second phase, materials are prioritized through ABC classification and quantitative parameters (Economic Order Quantity and Reorder Point) are calculated to establish objective replenishment rules. The third phase translates these parameters into practical tools by designing and implementing a physical Kanban board that provides visual pull signals between production lines and the packaging warehouse. Finally, the evaluation phase compares pre- and post-implementation data on fulfillment rates and request processing times, applying hypothesis testing to confirm whether the observed improvements are statistically significant.

This framework combines Lean principles (JIT and visual management) with classical inventory models, enabling a data-driven reduction of stockouts, waiting times, and process interruptions without requiring complex technology.

RESULTS BY PHASES

Phase 1: Diagnose & Prioritize

Table 5. Main causes of material supply failures

Cause	Relative Weight (Pareto)	Effect on Process
Lack of clear reorder parameters	High	Frequent stockouts
Delayed communication of needs	High	Waiting time at lines
No prioritization of materials	Medium	Excess of low-impact items
Manual request tracking	Medium	Lost or delayed requests

The Pareto diagrams and 5 Whys analysis showed that the majority of supply failures originated from the absence of quantitative replenishment rules and from weak visual communication between production lines and the packaging warehouse. Trend charts confirmed recurrent drops in fulfillment percentage.

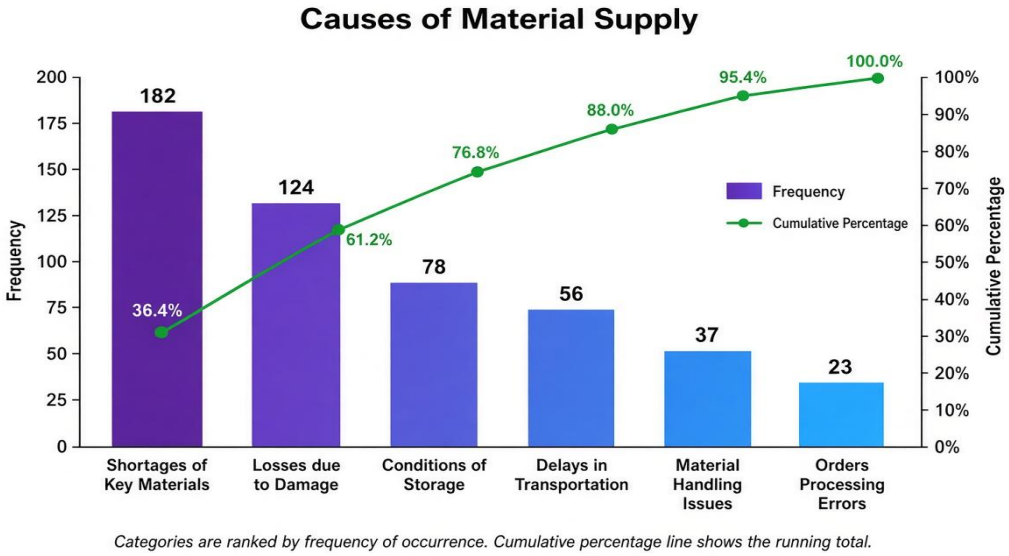


Figure 2. Pareto diagrams of shortage causes

Phase 2: Classify & Calculate

Table 6. Inventory parameters established for priority materials

Parameter	Purpose	Outcome
ABC classification	Prioritize materials by annual value	Focus control on Class A items
EOQ	Determine optimal order quantity	Minimizes total inventory cost
ROP	Set the reorder trigger point	Prevents stockouts considering lead time
Number of orders per year	Plan replenishment frequency	Aligns orders with calculated EOQ

ABC classification allowed concentration of effort on the materials that represent the highest usage value. Subsequent calculation of EOQ and ROP provided objective quantities and reorder points that were loaded into an Excel consultation tool for daily use by warehouse personnel.

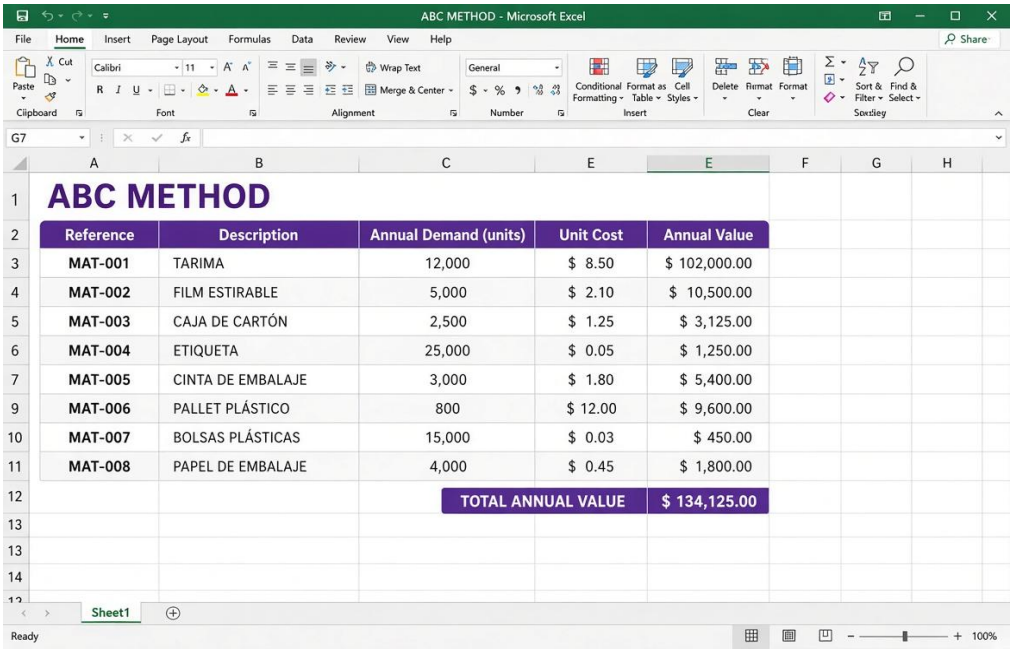


Figure 3. ABC METHOD

Phase 3: Design & Implement

Table 7. Kanban system characteristics

Element	Description	Function
Physical board	Three-color columns (red / yellow / green)	Visual status of each request
Request cards	Standardized material request forms	Pull signal from lines to warehouse
Priority coding	Color or category marking	Faster identification of urgent needs
Location in warehouse	Visible to both operators and warehouse staff	Improves communication and tracking

The physical Kanban board transformed material requests from informal verbal or paper notes into a standardized visual pull system. Operators place cards according to status, allowing the warehouse to see workload and priorities at a glance and reducing request accumulation.



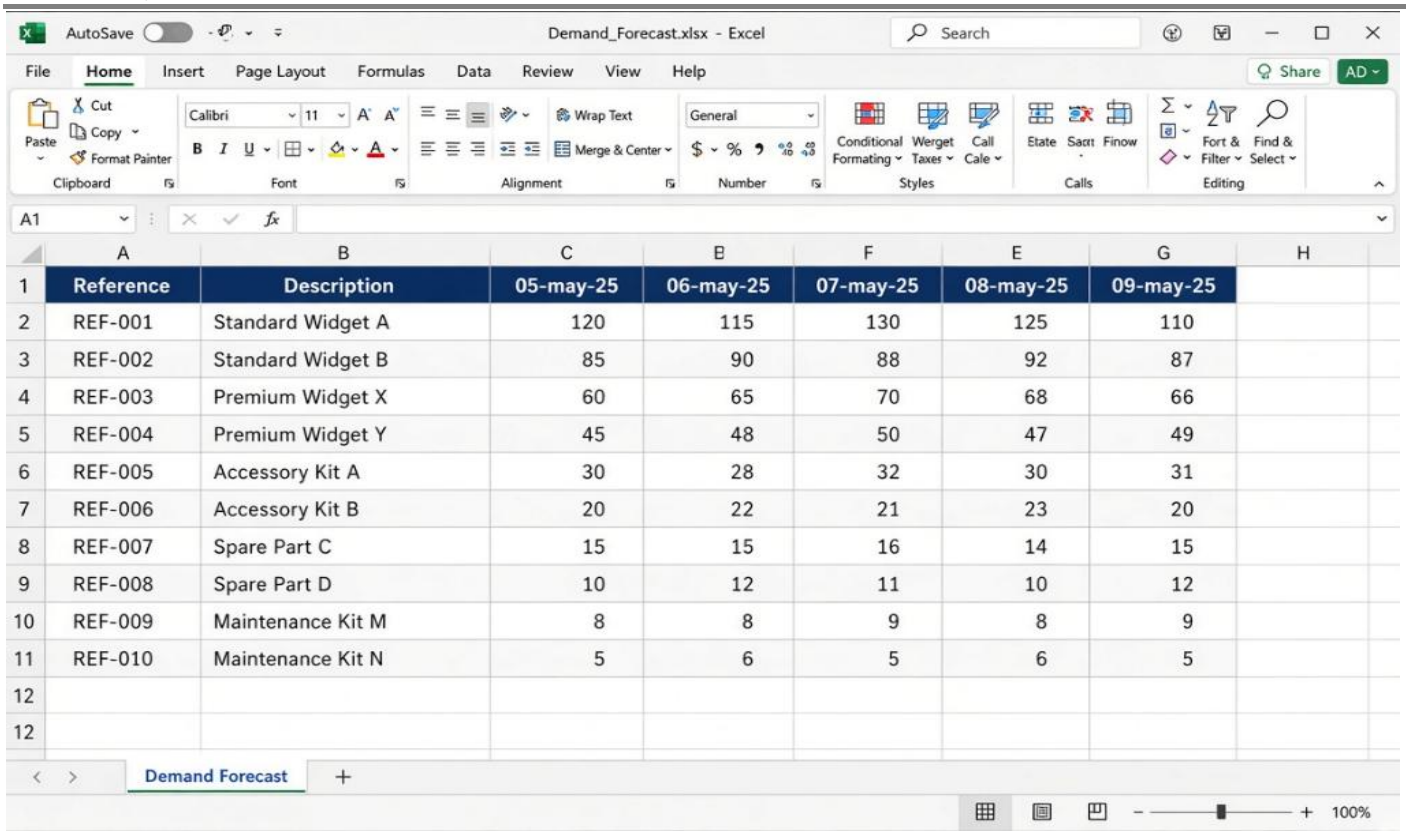
Figure 4. Kanban board in operation

Phase 4: Evaluate & Control

Table 4. Comparative results before and after implementation

Indicator	Before	After	Change
Average material fulfillment rate	89.90 %	95.47 %	+5.57 percentage points
Average request processing time	5.0 min	4.4 min	–12 %
Hypothesis test (t-student)	—	t > critical value	H_0 rejected (significant difference)

Comparison of historical fulfillment data with the projected inventory behavior under EOQ/ROP parameters showed an improvement of approximately 5.6 percentage points in material availability. A paired t-test confirmed that the difference is statistically significant. Concurrently, a small time study of identical requests demonstrated a 12 % reduction in processing time after the Kanban board was introduced, mainly due to better visual organization and less accumulation of pending requests.



	A	B	C	B	F	E	G	H
1	Reference	Description	05-may-25	06-may-25	07-may-25	08-may-25	09-may-25	
2	REF-001	Standard Widget A	120	115	130	125	110	
3	REF-002	Standard Widget B	85	90	88	92	87	
4	REF-003	Premium Widget X	60	65	70	68	66	
5	REF-004	Premium Widget Y	45	48	50	47	49	
6	REF-005	Accessory Kit A	30	28	32	30	31	
7	REF-006	Accessory Kit B	20	22	21	23	20	
8	REF-007	Spare Part C	15	15	16	14	15	
9	REF-008	Spare Part D	10	12	11	10	12	
10	REF-009	Maintenance Kit M	8	8	9	8	9	
11	REF-010	Maintenance Kit N	5	6	5	6	5	
12								
12								

Figure 5. Comparison of the level of material supply

These four phases, supported by the analysis tables and the original figures, present a complete sequence from problem diagnosis through quantitative parameter setting and visual system implementation to statistical validation of the improvements achieved in packaging material supply.

CONCLUSION

The application of Lean Manufacturing tools to the internal supply of packaging and packing materials proved to be an effective approach for improving process quality and operational continuity in an environment that handles fragile products. The diagnostic phase, supported by Pareto analysis, trend charts, and root-cause investigation, confirmed that the majority of interruptions and reprocessing events originated from the absence of clear replenishment parameters and from weak visual communication between production lines and the packaging warehouse. These findings are consistent with the literature on material flow problems in manufacturing logistics, where stockouts and delayed requests are frequently identified as primary sources of waiting time and quality deviations.

The subsequent calculation of ABC classification, Economic Order Quantity, and Reorder Point provided objective, data-driven rules for prioritizing materials and determining when and how much to order. When these parameters were combined with the implementation of a physical Kanban board, the system shifted from a reactive, informal request process to a more standardized pull system. The pre- and post-implementation comparison showed an improvement of approximately 5.6 percentage points in the average material fulfillment rate and a 12 % reduction in request processing time.

The paired t-test rejected the null hypothesis, indicating that the observed differences are statistically significant and not attributable to random variation. These results align with documented applications of JIT principles, visual management, and inventory optimization models, which commonly report reductions in stockouts and shorter response times when both quantitative parameters and visual pull signals are used together.

From a practical standpoint, the interventions demonstrated that meaningful improvements in packaging material availability can be achieved with relatively simple tools that do not require substantial capital investment. The Excel-based consultation sheet for EOQ and ROP, together with the color-coded Kanban board, offered

warehouse personnel and line operators a clear, shared reference for material needs and priorities. This combination reduced request accumulation, improved coordination, and lowered the frequency of situations in which packaging lines had to wait for materials or resort to improvised solutions that could compromise the protection of fragile products.

Nevertheless, several limitations should be acknowledged. The study relied on a quasi-experimental pre-post design within a single operational context, so external factors such as variations in production volume or supplier lead times could not be fully isolated. The time study for the Kanban system was limited to a small number of observations of one material, which restricts the generalizability of the 12 % reduction in processing time.

In addition, the EOQ and ROP calculations were based on historical demand data over a relatively short period; changes in product mix or seasonal demand may require periodic recalculation to maintain accuracy. Finally, the Kanban system was implemented in physical form, which, while effective in the short term, may present scalability constraints if the number of materials or the volume of requests increases significantly.

In conclusion, the integrated use of ABC classification, EOQ/ROP parameters, and a visual Kanban system within a Lean framework constitutes a practical and statistically supported alternative for stabilizing the supply of packaging materials. The evidence generated in this project indicates that such interventions can reduce stockouts, shorten response times, and support higher process reliability in packing operations for fragile goods.

Future work should include the periodic updating of inventory parameters, the evaluation of a digital Kanban or Andon system to enhance real-time visibility, and the extension of the same methodology to other material families whose shortage also affects production continuity. By institutionalizing these practices, organizations can move from reactive material management toward a more stable, demand-driven supply process that sustains both operational efficiency and product quality over time.

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