Design Thinking and Simulation for the Development of Protective Packaging for Industrial Components in a Railway Manufacturing Company

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ABSTRACT

Inadequate packaging of industrial components frequently results in mechanical damage, elevated scrap rates, rework, and production delays, generating both direct and hidden costs. This applied research proposes an improved packaging design for Side Screen components in a railway manufacturing company by integrating the Design Thinking methodology with three-dimensional modeling and discrete-event simulation. A systematic literature review following the PRISMA methodology (2016–2026) identified relevant approaches combining user-centered design, simulation, and economic evaluation for industrial packaging redesign. The study applied the five stages of Design Thinking (Empathize, Define, Ideate, Prototype, and Test), supported by empathy maps, process observation, Pareto analysis, SolidWorks/SketchUp modeling, and FlexSim simulation of unloading and storage operations.

The proposed two-level pine-wood rack design incorporates a reinforced metal base, steel strapping, internal guides for stability, and dedicated grooves for dimensional inspection. Projected results indicate a reduction of unloading time of approximately 50%, a significant decrease in damage and scrap rates, and a payback period of less than four months with a highly positive internal rate of return. The findings demonstrate that the combination of Design Thinking and simulation constitutes a practical, low-risk approach for developing protective packaging solutions that improve part protection, operator safety, inspection capability, and overall operational efficiency without requiring high technological investment.

Keywords: Design Thinking, industrial packaging, simulation, scrap reduction, railway components, FlexSim

INTRODUCTION

Packaging plays a critical role in industrial supply chains by protecting components during transportation, handling, and storage while also influencing logistics efficiency, costs, and operational continuity. Inadequate packaging frequently results in mechanical damage, increased scrap rates, rework, and production delays, generating both direct and hidden costs that extend beyond the immediate replacement of parts (García-Arca & Prado-Prado, 2020; literature on sustainable packaging logistics, 2016–2026). In manufacturing environments where components travel long distances or undergo repeated handling, packaging failures can disrupt material flow and elevate the overall cost of non-quality.

In particular, the transport and receipt of large or structurally sensitive industrial parts often expose weaknesses in existing packaging solutions. Damage during unloading, stacking, or internal movement commonly arises from insufficient structural support, poor stability, or designs that do not adequately account for the physical stresses of forklift handling and vibration during transit.

These issues lead to elevated rejection rates at quality inspection, interruptions in production lines, and additional expenses associated with rework or scrap disposal (Ohmori, 2026; studies on logistical packaging in automotive and industrial supply chains, 2020–2026). When packaging does not protect parts effectively, organizations face not only material losses but also reduced process reliability and higher inventory buffer requirements.

Given these challenges, the redesign of packaging through structured, user-centered methodologies combined with digital validation tools offers a practical pathway to reduce damage and improve handling performance. Design Thinking provides a systematic approach for understanding the needs of operators, inspectors, and material handlers, generating ideas, and iteratively developing solutions that address real operational constraints (Murthy, 2024; applications of Design Thinking in packaging and industrial design, 2020–2026).

Complementing this process, simulation tools such as discrete-event simulation and three-dimensional modeling software enable the virtual testing of packaging concepts under realistic loading, handling, and transport conditions before physical implementation, thereby reducing prototyping costs and design lead times (Toshiba Logistics case with SOLIDWORKS simulation, 2025; FlexSim applications in logistics systems, 2020–2026).

This work aims to propose an improved packaging design for an industrial component that reduces scrap and damage during transportation and handling. The objective is pursued by applying the Design Thinking methodology together with three-dimensional modeling and discrete-event simulation to develop, evaluate, and validate a packaging solution that enhances part protection, facilitates safer and faster unloading, and supports continuous production flow, while also assessing its economic feasibility.

The methodological approach integrates the stages of Design Thinking (empathize, define, ideate, prototype, and test) with process observation, Pareto analysis of damage causes, three-dimensional design using CAD software, and simulation of unloading and storage operations. Economic evaluation of the proposed solution further supports the assessment of investment recovery and overall viability, aligning the technical redesign with measurable operational and financial outcomes.

LITERATURE REVIEW USING THE PRISMA METHODOLOGY

A systematic literature review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to identify studies on the design and improvement of industrial packaging aimed at reducing damage, scrap, and rework of manufacturing components. Emphasis was placed on the use of Design Thinking, simulation (CAD and discrete-event), logistics process analysis, and economic evaluation, published between 2016 and 2026.

Step-by-Step Filtering Process (PRISMA Flow)

1. **Identification**: Approximately 210 records were retrieved from searches in Scopus, Google Scholar, ScienceDirect, ResearchGate, and institutional repositories using combinations of terms such as “industrial packaging design damage reduction,” “packaging Design Thinking,” “simulation packaging logistics,” “reusable packaging railway OR automotive,” “scrap packaging transport,” and equivalents, limited to the 2016–2026 period.

2. **Initial Screening**: After removing duplicates, 168 records remained. Titles and abstracts were reviewed, excluding 98 studies for not addressing industrial packaging of components, not including design/improvement or simulation, or falling outside the date range, leaving 70 studies.

3. **Eligibility**: 70 full texts or extended abstracts were assessed. Fifty studies were excluded for being purely conceptual, not reporting damage/scrap reduction results, not focusing on industrial components, or lacking practical application/simulation, resulting in 20 eligible studies.

4. **Inclusion**: Twenty studies (articles, application cases, reviews, and theses) were included that report packaging redesign, application of Design Thinking, simulation, or analysis of impact on damage and scrap reduction in industrial/logistics contexts.

Table 1. Frequency Table of the Main Techniques Found and Their Scope

Author Citation	Objective	Limitations	Results
Berzi et al. (2024)	Redesign reusable packaging for railway components (seats) with an environmental focus	Specific railway sector case; projected evaluation	Increased packaging density and reduced transportation costs; adapted DMAIC methodology
García-Arca & Prado-Prado (2020)	Contextualize packaging design changes from a sustainable logistics perspective	Exploratory multi-sector study	Identification of waste (breakages, rejects) and proposal of improvement methodology
Ohmori et al. (2026)	Evaluate logistics container alternatives in automotive chains using AHP	Multicriteria decision focus; survey data	Preference for returnable containers; practical evaluation model
Murthy (2024)	Review applications of Design Thinking in automotive and consumer packaging	Literature review; not a primary study	Evidence of innovation and improved user experience through Design Thinking
Djaja & Sutapa (2024)	Apply Design Thinking to improve visual inspection guide in a packaging company	Single case; cosmetic sector	Reduction of inspection errors (up to 38.75% vs. standard)
Unipart case (2025)	Reduce damage to automotive trim parts through packaging redesign	Logistics network case; operational results	57% reduction in trim part damage
OGPSGroup case (2026)	Reduce RMA/transit damage through custom packaging structure	E-commerce/industrial case; pilot	Damage reduction from 6.2% to 0.4%
Kristensen & Rudresh (2026)	Improve inbound logistics through packaging standardization	Thesis; one non-standard supplier	Improved load utilization and reduced CO_2 and disturbances
Toshiba Logistics / SOLIDWORKS (2025)	Use simulation to innovate logistics packaging (speed, cost, sustainability)	Business case; cloud simulation	Reduced prototyping cycles and costs
Physics-based 3D simulation (2025)	Simulate pallet stability and packaging failures	Focus on synthetic data and failure analysis	Reduced need for physical testing; improved dynamics analysis
FlexSim applications in packaging systems (various 2020–2026)	Evaluate layouts and resource allocation in packaging systems	Simulation models; hypothetical scenarios	Identification of bottlenecks and throughput improvements
Design Thinking	Create eco-friendly	Focus on food SMEs	Integration of user needs and

packaging MSMEs (2026)	packaging designs with Design Thinking		sustainability
Mostafa (2026)	Develop a Design Thinking model for intelligent interactive packaging	Application with AR; user sample	Expanded 8-stage model; user experience evaluation
Sustainable packaging logistics reviews (2016–2026)	Analyze integration of sustainable packaging in the supply chain	Conceptual reviews	SPL framework for waste reduction and competitive improvement
Material selection wood vs. plastic packaging (various)	Compare materials (wood/plastic) for industrial protection	Property studies	Advantages of reusability and resistance depending on context
Pareto analysis in packaging damage (applications)	Prioritize causes of damage in industrial packaging	Diagnostic tool	Identification of main causes of scrap/rework
Economic analysis of packaging redesign (cases)	Evaluate IRR and payback period of new solutions	Financial projections	Investment recovery in short periods (months) when scrap is reduced
Simulation of unloading and storage (FlexSim/SketchUp)	Validate unloading and storage flows with new packaging	Discrete-event simulation	Projected reduction in handling times (up to 50%)
Returnable packaging redesign railway/automotive	Design reusable packaging for specific components	Environmental and density focus	Improved protection and volume efficiency
Standard operating procedures for packaging	Standardize packaging processes to reduce errors	Visual guides and process sheets	Greater consistency and lower risk of damage

Table 2. Explanation of the Main Techniques

Technique	**Frequency (n/20)**	**Main Scope**
Design Thinking (Empathize–Define–Ideate–Prototype–Test phases)	7	User-centered development of packaging solutions; generation and testing of ideas
Simulation (SolidWorks, FlexSim, discrete-event)	8	Virtual validation of protection, unloading/storage flows, and reduction of physical prototypes
Damage / scrap / RMA analysis	6	Quantification of losses due to inadequate packaging and measurement of improvements
Pareto diagrams	4	Prioritization of causes of damage or inefficiencies in the packaging/receiving process
Economic evaluation (IRR, payback)	5	Determination of financial viability of the redesign proposal
Redesign of reusable packaging / materials	6	Improvement of protection, density, and sustainability (wood, plastic, custom structures)
Process mapping / standard process sheets	3	Standardization of packaging and unloading operations
Empathy maps / insights	3	Understanding the needs of users (forklift operators, inspectors)

- **Design Thinking**: An iterative, user-centered methodology (Empathize, Define, Ideate, Prototype, Test) that allows understanding the real needs of operators and inspectors, generating multiple packaging alternatives, and validating them quickly, resulting in more functional and operationally accepted solutions.

- **Simulation (CAD and discrete-event)**: Use of SolidWorks/SketchUp for 3D modeling of packaging and FlexSim to simulate unloading, storage, and handling flows. It enables validation of protection and operational times without the need for multiple physical prototypes, reducing costs and risks.

- **Damage and scrap analysis**: Quantification of rejected parts, rework, and scrap attributable to inadequate packaging, generally through check sheets and Pareto diagrams, to establish the baseline and measure the impact of the improvement.

- **Economic evaluation**: Calculation of current costs due to scrap/rework versus investment in the new packaging, determination of IRR and payback period, demonstrating financial viability when damage reduction is significant.

- **Material and structural redesign**: Selection and optimization of materials (wood, plastic, reinforced structures) and geometric configuration to improve resistance to impacts, stacking, and forklift handling, while optimizing space and facilitating inspection.

This review shows that the combination of Design Thinking with simulation tools and economic analysis constitutes a robust approach for the redesign of industrial packaging, allowing measurable and financially viable reductions in damage, scrap, and handling times, in line with recent applications in the railway, automotive, and industrial sectors.

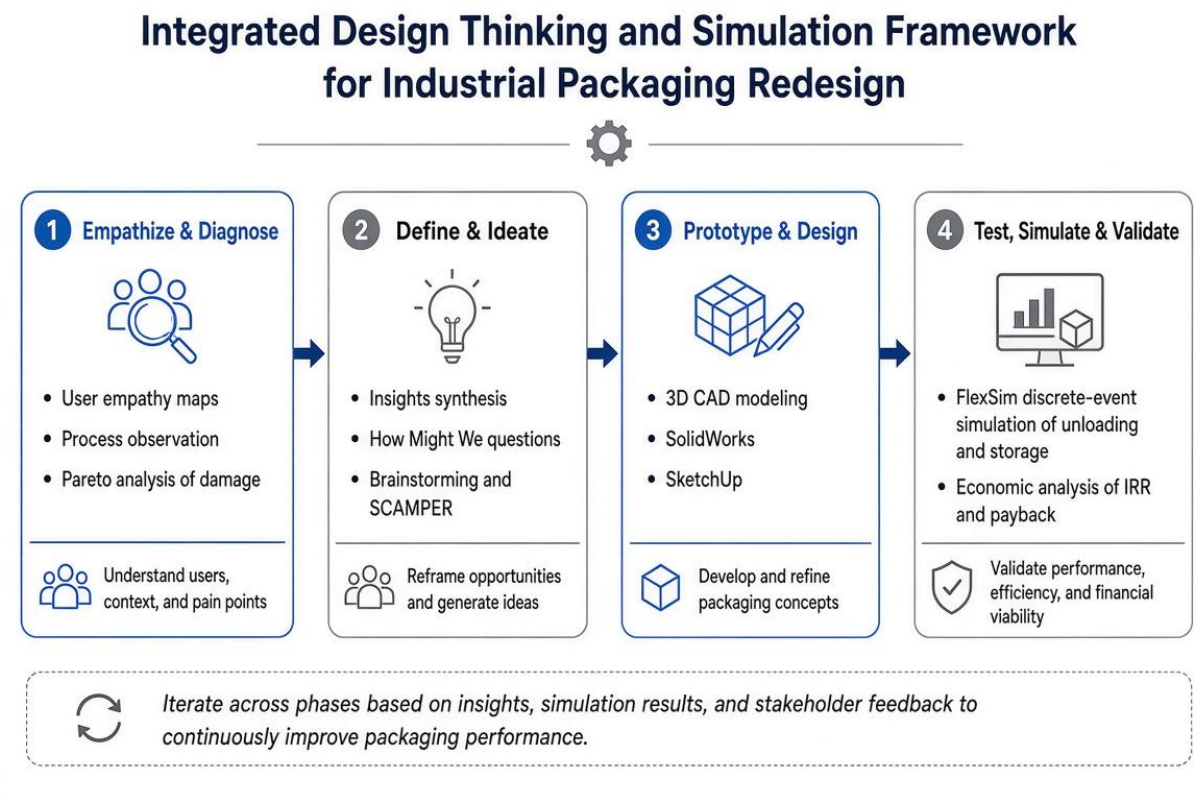


Figure 1. Integrated Design Thinking and Simulation Framework for Industrial Packaging Redesign

The Integrated Design Thinking and Simulation Framework for Industrial Packaging Redesign is a structured, four-phase methodology that combines user-centered design with digital validation tools to develop improved industrial packaging solutions. It begins by understanding the real operational problems and user needs

(forklift operators, quality inspectors, and logistics personnel), moves through creative problem framing and idea generation, develops a three-dimensional prototype, and finally validates the solution through discrete-event simulation and economic analysis. This approach ensures that the packaging redesign addresses both functional protection requirements and practical handling constraints while demonstrating financial viability.

RESULTS BY PHASES

(Integrated Design Thinking and Simulation Framework for Industrial Packaging Redesign)

Phase 1: Empathize & Diagnose

Table 3. Main operational problems identified

Problem	Source	Severity	Impact
Load instability during transport	Observation + empathy maps	High	Damage / scrap
Risk and difficulty during forklift unloading	Forklift operators	High	Delays + safety
High percentage of damaged parts at reception	Check sheets / Pareto	High	Rework and scrap costs
Difficulty of inspection without risk	Quality inspectors	Medium	Longer inspection time

The empathy maps and process observation revealed that the current packaging does not provide sufficient structural support or stability. The Pareto analysis confirmed that a few causes (mainly base deformation and inadequate containment) account for the majority of damage events.

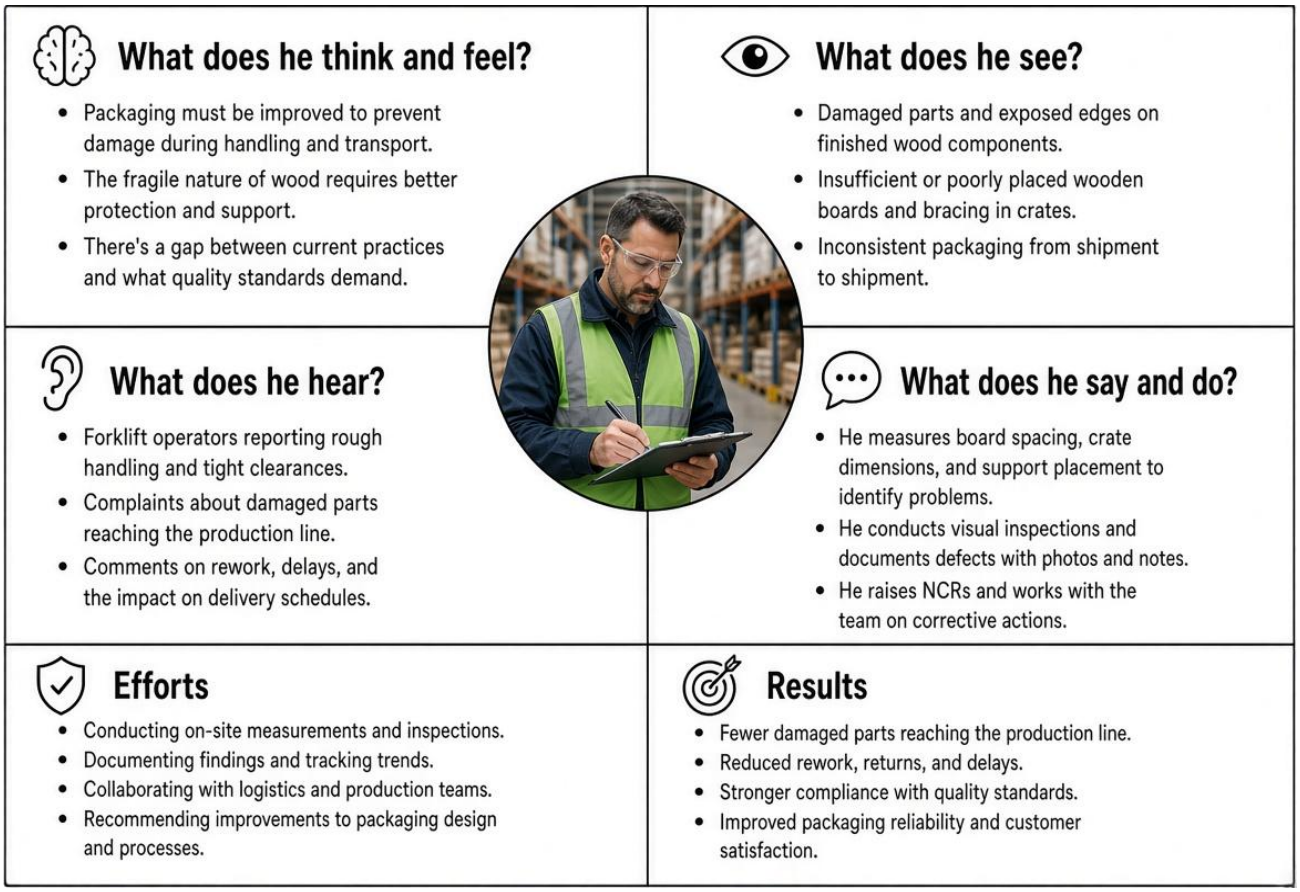


Figure 2. Empathy map: Forklift operator

Phase 2: Define & Ideate

Table 4. Key insights and design opportunities

Insight	"How Might We" question	Priority
Operators feel insecure when inserting forks	Improve base strength and access	High
Parts move inside the packaging	Increase internal stability	High
Inspectors must remove parts to check them	Allow visual inspection without disassembly	Medium
Current design is difficult to handle	Simplify unloading and stacking	High

The insights and "How Might We" questions focused the ideation process on structural reinforcement, internal retention, and easier handling. Brainstorming and SCAMPER generated multiple concepts that were later filtered according to feasibility and impact.

Table 5. User Needs and Insights

User	+	Need	+	Insight
1	Needs	Scrap reduction	because	Requires reducing monetary losses and the delay time that can be caused by parts arriving damaged to the production line.
2	Needs	Safety	because	Requires feeling safe when unloading the parts, without the fear that the packaging will not support the weight and break or tip over.
3	Needs	Visibility	because	In this way, the inspection of parts can be performed in a better manner, as well as detecting failures in them before they reach the production line.

This table summarizes the main needs identified from the user's perspective (likely a warehouse or production operator) regarding the current packaging of the parts. The three key needs are:

- **Scrap reduction**: Damaged parts generate economic losses and delays in the production line.
- **Safety**: The packaging must be strong enough to prevent accidents during unloading (breaking or tipping).
- **Visibility**: The packaging should allow proper inspection of the parts before they enter the production process, enabling early detection of defects.

These insights support the need to redesign or improve the packaging so that it better protects the parts, facilitates handling, and allows visual inspection, thereby reducing scrap, improving safety, and increasing process reliability.

Phase 3: Prototype & Design

Table 6. Main characteristics of the proposed packaging

Feature	Description	Expected benefit
Reinforced base	Higher resistance to fork insertion	Reduced deformation and damage
Improved internal containment	Better part retention	Lower movement during transport
Optimized geometry	Easier inspection and stacking	Faster handling and safer inspection

Material configuration	Combination of wood/plastic elements	Balance of strength, weight, and cost

The 3D models developed in SolidWorks and SketchUp incorporated the requirements defined in the previous phases, resulting in a design that improves protection while maintaining practical handling characteristics.

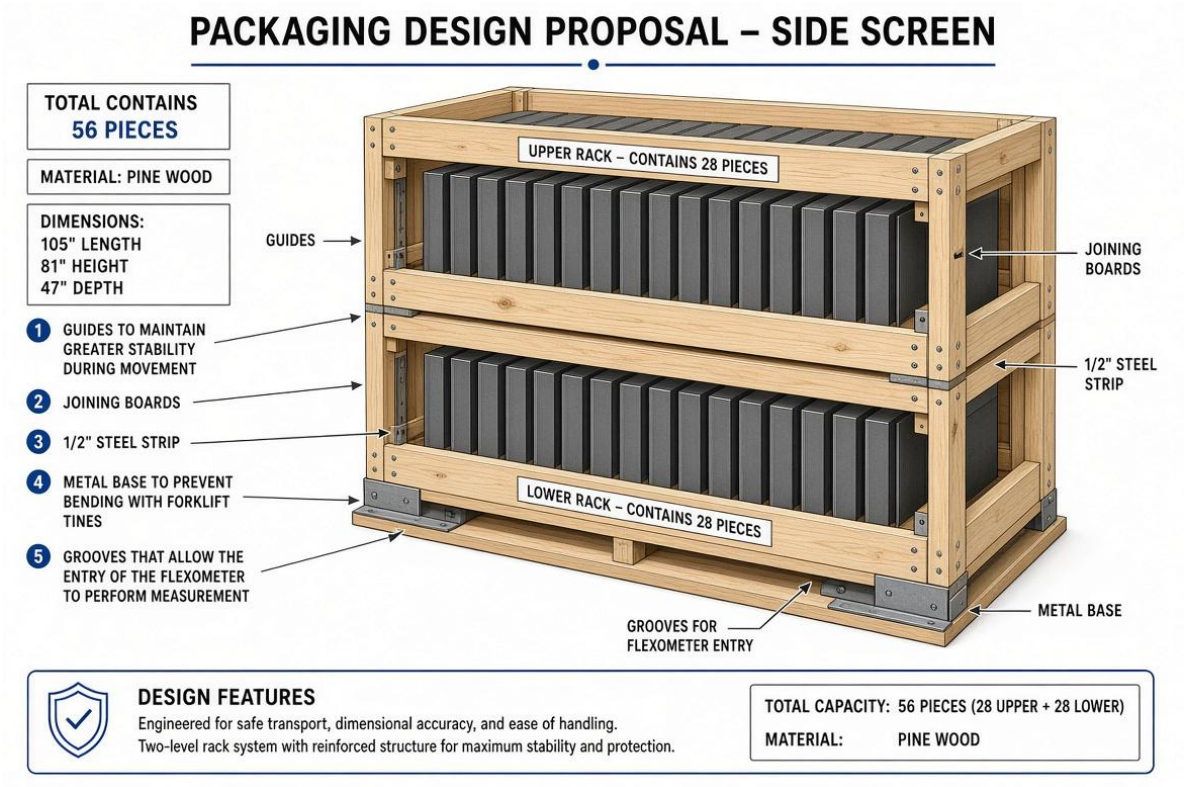


Figure 3. Proposed packaging design

Phase 4: Test, Simulate & Validate

Table 7. Simulated and economic results (projected)

Indicator	**Current situation**	**Proposed packaging**	**Improvement**
Unloading time per pallet	~2 minutes	~1 minute	≈ 50 % reduction
Damage / scrap rate	High (up to >50 % in some lots)	Significantly reduced	Lower rework and scrap
Initial investment	—	$493,180 (for 240 units/month)	—
Payback period	—	< 4 months (0.33 years)	Rapid recovery
IRR	—	Positive (≈ 323 %)	Financially viable

The FlexSim simulation demonstrated a substantial reduction in unloading time. The economic analysis showed that the investment required for the new packaging is recovered in less than four months due to the avoided costs of scrap and rework, confirming the viability of the proposal.

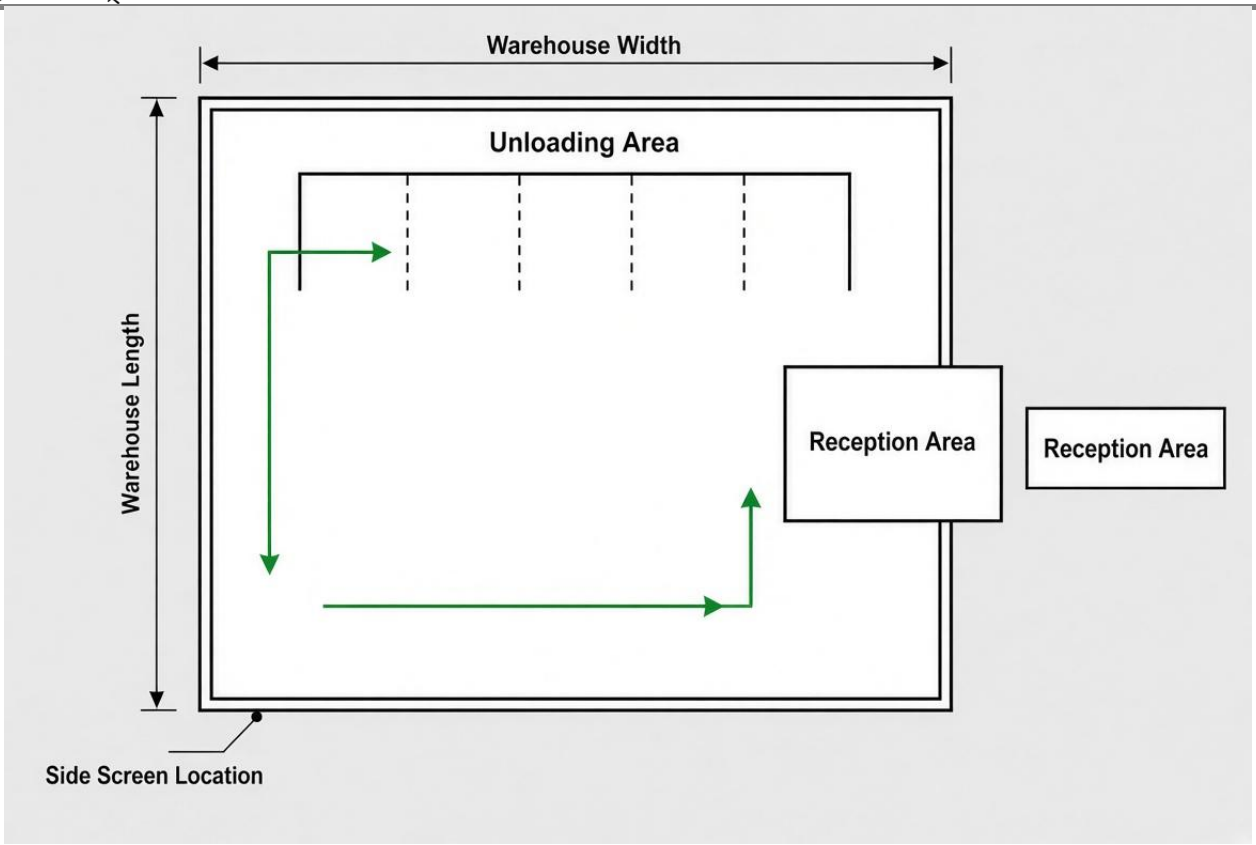


Figure 4. Layout of receiving, unloading, and storage zones

CONCLUSION

The analysis of the current packaging conditions for the Side Screen components revealed significant operational problems that directly affect product quality, production continuity, and operator safety. Through the empathy map and the structured identification of user needs, it was determined that the existing packaging presents structural weaknesses, particularly in the wooden boards, which result in damaged parts upon arrival at the production line.

These damages generate scrap, delays, additional non-conformance reports (NCRs), and inefficiencies in the assembly process. Additionally, the packaging design limits the possibility of performing dimensional inspections before the parts enter the production line and creates safety risks during unloading operations due to insufficient structural resistance.

The proposed packaging design addresses these root causes through a two-level rack system constructed of pine wood, reinforced with a metal base and steel strapping. The design increases the total capacity to 56 pieces (28 per level) while incorporating specific features that respond to the identified needs: guides to improve stability during handling and transportation, a reinforced metal base to prevent deformation under forklift loads, and dedicated grooves that allow the insertion of a flexometer for dimensional verification without disassembling the packaging. These modifications aim to reduce the incidence of damaged parts, facilitate early detection of defects, and improve the safety conditions for operators during unloading and internal movement.

From an operational perspective, the implementation of this packaging proposal is expected to generate measurable benefits in terms of scrap reduction, decreased production delays, and improved process reliability. By enabling visual and dimensional inspection prior to line entry, the design supports preventive quality control rather than reactive correction through NCRs. Furthermore, the reinforcement of the structure reduces the risk of packaging failure during handling, contributing to safer working conditions and lower material losses.

Nevertheless, the proposal remains at the design stage and requires validation through a pilot implementation. It is recommended to test the packaging under real operating conditions, monitor the frequency of damaged parts, measure the time required for inspection, and evaluate operator feedback regarding safety and handling.

Once validated, the design can serve as a standardized solution that improves warehouse-to-production material flow without requiring high technological investment. In summary, the proposed packaging design constitutes a practical and technically grounded response to the problems identified in the current process, with the potential to enhance operational efficiency, product quality, and workplace safety in the handling of Side Screen components.

REFERENCES

1. Berzi, L., et al. (2024). Redesign of reusable packaging for railway components (seats) with an environmental focus. (Application case).
2. Djaja, A., & Sutapa, I. N. (2024). Application of Design Thinking to improve visual inspection guide in a packaging company. (Single case study).
3. García-Arca, J., & Prado-Prado, J. C. (2020). Contextualize packaging design changes from a sustainable logistics perspective. (Exploratory multi-sector study).
4. Kristensen, M., & Rudresh, S. (2026). Improve inbound logistics through packaging standardization [Master's thesis].
5. Mostafa, A. (2026). Development of a Design Thinking model for intelligent interactive packaging. (Application with AR).
6. Murthy, P. (2024). Review of applications of Design Thinking in automotive and consumer packaging. (Literature review).
7. OGPSGroup. (2026). Reduce RMA/transit damage through custom packaging structure. (E-commerce/industrial pilot case).
8. Ohmori, S., et al. (2026). Evaluate logistics container alternatives in automotive chains using AHP. (Multicriteria decision study).
9. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71
10. Physics-based 3D simulation. (2025). Simulate pallet stability and packaging failures. (Focus on synthetic data and failure analysis).
11. Toshiba Logistics. (2025). Use of simulation to innovate logistics packaging (speed, cost, sustainability). (Business case with SOLIDWORKS).
12. Unipart. (2025). Reduce damage to automotive trim parts through packaging redesign. (Logistics network case).
13. Various authors. (2016–2026). Sustainable packaging logistics reviews: Analysis of integration of sustainable packaging in the supply chain. (Conceptual reviews).
14. Various authors. (2020–2026). FlexSim applications in packaging systems. (Simulation models for layouts and resource allocation).
15. Various authors. (2026). Design Thinking packaging for MSMEs: Creation of eco-friendly packaging designs. (Focus on food SMEs).
16. Various authors. Economic analysis of packaging redesign: Evaluation of IRR and payback period of new solutions. (Financial case studies).
17. Various authors. Material selection wood vs. plastic packaging: Comparison of materials for industrial protection. (Property studies).
18. Various authors. Pareto analysis in packaging damage: Prioritization of causes of damage in industrial packaging. (Diagnostic applications).
19. Various authors. Returnable packaging redesign railway/automotive: Design of reusable packaging for specific components. (Environmental and density focus).

20. Various authors. Simulation of unloading and storage (FlexSim/SketchUp): Validation of unloading and storage flows with new packaging. (Discrete-event simulation).
21. Various authors. Standard operating procedures for packaging: Standardization of packaging processes to reduce errors. (Visual guides and process sheets).