

Research Article

An Integrated Lean-Visual-Green (LVG) Model for Warehouse Layout Optimization and Carbon Footprint Reduction: A Case Study in the Food Products Industry

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ABSTRACT

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In modern industrial logistics, managing warehouses presents a key challenge-enhancing operational efficiency while minimizing environmental impact. However, existing studies on lean and green warehouse practices often address these dimensions separately, with limited integration into a unified framework applicable in real industrial contexts. This study proposes an integrated Lean-Visual-Green (LVG) model that combines waste reduction, visual control, and environmental impact assessment into a single analytical approach. Unlike conventional lean-green models, the LVG framework incorporates visual management to enhance operational clarity and support layout decision-making. A before-after comparative design was applied in a finished-goods warehouse in the food products industry with 81 stock-keeping units (SKUs). One year of historical data was analyzed to develop a Product Utilization Index (PUI), which was used for ABC classification and warehouse layout redesign. Following implementation, forklift travel distance decreased from 3,519,647.28 to 1,385,685.20 meters per year (-60.63%), with a corresponding reduction in CO₂ emissions from 35,372.49 to 13,926.11 kgCO₂ per year. The results demonstrated that the LVG model provides a practical and integrative approach for improving warehouse efficiency and reducing environmental impact through data-driven layout optimization.

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1. Introduction

In the context of escalating global environmental crises, sustainable warehouse and logistics management has become a strategic priority for organizations seeking to mitigate environmental impacts while maintaining operational efficiency. Warehouses, as a core component of logistics systems, consume significant amounts of energy and resources, often resulting in higher carbon footprints (CFO) compared to other logistics activities (Perotti and Colicchia, 2023; Luca *et al.*, 2025). Under the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 on industry and infrastructure, SDG 12 on responsible consumption and production, and SDG 13 on climate action, industries worldwide are being driven to adopt more sustainable practices in logistics and warehouse management. Numerous

studies have proposed technical innovations and modelling frameworks to assess warehouse sustainability. For instance, (Agyabeng-Mensah *et al.*, 2020) examined the relationship between green warehousing, social values, and economic performance, highlighting the role of ethics in logistics to support sustainability. Similarly, Nicoletti and Appolloni (2024) introduced the concept of green warehouse 5.0, which integrates smart technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and autonomous robotics into sustainable warehouse operations. Systematic literature reviews by Domagała (2022) and Kumar and Adil (2025) have also revealed research trends emphasizing renewable energy adoption, passive design strategies, and carbon emission reduction as key approaches to advancing sustainable warehousing.

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Advancements in warehouse technologies have continued to emerge, such as smart lighting systems that reduce electricity consumption in warehouses (Füchtenhans *et al.*, 2023), and PV–battery systems capable of efficiently controlling and storing renewable energy (Yasir *et al.*, 2024). Other developments include optimized routing and transportation system design aimed at lowering carbon dioxide (CO₂) emissions (Wang *et al.*, 2018; Shih-Che Lo, 2022). In addition, the logistics 4.0 paradigm, which emphasizes automation, has demonstrated environmental benefits for warehouses, particularly in reducing reliance on human resources and enhancing system control accuracy (Nantee and Sureeyatanapas, 2021). In this context, recent studies have increasingly emphasized the role of Industry 4.0 technologies in enhancing both operational performance and environmental outcomes, particularly through data-driven decision-making and real-time system integration (Sousa Jabbour *et al.*, 2018).

Nevertheless, despite these advances, several critical knowledge gaps remain. First, while existing models address energy efficiency and warehouse design, there is still a lack of integrated analytical frameworks capable of simultaneously improving environmental, economic, and operational performance under real-world constraints such as demand and supply uncertainty. This limitation has also been highlighted in prior studies on green logistics and operational research, which emphasize the need for integrated optimization approaches capable of addressing both cost efficiency and environmental impact simultaneously (Dekker *et al.*, 2012). For instance, Accorsi *et al.* (2017) proposed a multi-objective warehouse design model that minimizes costs and carbon footprint (CFO), yet it did not account for uncertainty factors. Similarly, Rajković *et al.* (2019) developed an Automated Storage and Retrieval System (AS/RS) model aimed at reducing CO₂ emissions, but the model did not sufficiently address investment considerations or demand variability. Kumar *et al.* (2022) examined the implications of carbon footprint (CFO) under fluctuating demand and supply conditions; however, their simulation failed to provide actionable policy guidelines or clear design strategies. Furthermore, while some studies have emphasized carbon reduction in specific sectors such as cold chains (Wang *et al.*, 2018), the food industry (Luca *et al.*, 2025), and transportation systems (Jerbi *et al.*, 2022), comprehensive evaluations of carbon reduction in warehouse operations remain limited, especially in terms of integrating smart technologies with ethical management practices. Although Jerbi *et al.* (2022) highlighted the positive influence of logistics 4.0 on warehouse sustainability, the broader organizational impacts derived from ethics and stakeholder engagement have yet to be thoroughly explored. Despite these findings, prior studies have demonstrated the benefits of lean-green integration, most approaches remain conceptually separated from practical warehouse layout design and lack explicit mechanisms for

improving operational visibility and decision-making in real industrial contexts. In particular, the role of visual management as a bridge between operational efficiency and environmental performance has not been sufficiently explored.

In parallel with technological developments, recent studies have emphasized the integration of lean and green approaches as complementary strategies for achieving operational efficiency alongside environmental sustainability. Lean principles primarily focus on eliminating operational waste and improving process flow efficiency, whereas green practices aim to reduce environmental impacts and resource consumption throughout logistics activities (Dües *et al.*, 2013). Prior research has demonstrated that lean practices can serve as an enabling mechanism for environmental improvement by reducing unnecessary movement, energy usage, and material waste within operational systems (Ferroq *et al.*, 2016). Furthermore, systematic reviews have highlighted that the integration of lean and green paradigms provides synergistic benefits by simultaneously enhancing productivity performance and environmental outcomes (Garza-Reyes, 2015). Additional studies have further strengthened this perspective by demonstrating that lean-green integration can be systematically implemented through structured frameworks that align process efficiency with environmental sustainability objectives (Zheng *et al.*, 2017). Despite these advances, applications integrating lean and green concepts within warehouse layout design and operational decision-making remain relatively limited, particularly in real industrial environments supported by empirical operational data. Moreover, existing studies tend to emphasize either process efficiency or environmental impact, with limited attention to how these dimensions can be operationally integrated through layout design and real-time warehouse control practices. This limitation highlights the need for a more comprehensive and practically applicable framework.

Another area that remains insufficiently explored is inventory management. Although ABC analysis techniques have been widely applied (Abdolazimi *et al.*, 2021a; Abdolazimi *et al.*, 2021b; Mashud *et al.*, 2022; Ray Silaen *et al.*, 2024), systematic investigations into their direct impact on the carbon footprint (CFO) are still lacking. Even the study by Mashud *et al.* (2022), which incorporated environmental considerations into inventory strategies, relied on deterministic models that may not accurately reflect real-world operational conditions. Emerging trends also point to the integration of blockchain technology into inventory management, aiming to enhance supply chain transparency and reduce carbon emissions (Priyan, 2024). At the same time, simulation frameworks for energy utilization and greenhouse gas (GHG) emission accounting are becoming increasingly common. For instance, Yaman (2024) proposed a structured approach to preparing GHG inventories and developing systematic measures for CFO mitigation. In addition, Life Cycle Assessment (LCA) has been widely recognized as a

standard methodological framework for evaluating environmental impacts across logistics systems, providing a more comprehensive basis for sustainability assessment (International Organization for Standardization, 2006). Other research focusing on organizational practices, such as sustainable logistics internships (De Assis *et al.*, 2024) and raw material inventory management in small and medium-sized enterprises (Vanessa and Helma, 2023), has also demonstrated the potential to lower carbon emissions through well-designed warehouse strategies. Furthermore, the application of Multi-Criteria Classification (MCC) models in conjunction with ABC analysis has gained attention as a more refined approach to inventory categorization (Kaabi, 2022).

The LVG Model will be applied to analyze, evaluate, and design warehouse systems capable of responding effectively to organizational constraints and real-world operating environments. Unlike traditional lean-green approaches, this study explicitly introduces “Visual” as a distinct and operationally grounded component that enhances transparency, supports decision-making, and reduces process ambiguity in warehouse layout and material handling systems. This integration provides a more holistic framework that connects process efficiency, operational control, and environmental performance within a single analytical structure. For instance, inventory classification using ABC analysis enables prioritization in storage and retrieval, while route analysis and forklift movement tracking within the warehouse identify bottlenecks and operational waste. The model also incorporates the calculation of environmental impacts by linking travel distance of material handling equipment to carbon dioxide (CO₂) emissions, alongside planning measures to reduce energy consumption and increase the share of renewable energy use. This approach not only supports efficiency and cost-reduction objectives but also aligns with environmental commitments and the United Nations Sustainable Development Goals, specifically SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). In addition, the proposed LVG model provides a structured integration mechanism that links operational decision-making with environmental performance through measurable indicators, such as travel distance and carbon emissions, thereby strengthening its conceptual contribution beyond a purely applied framework and reinforcing its potential for broader analytical application. Beyond addressing academic knowledge gaps, this research aspires to deliver both policy-level and practical industrial implications, ultimately contributing to the transition toward organizational or higher-level carbon neutrality (net zero).

To address these gaps, this study focuses on a real industrial case in the food products industry, where operational complexity, product variety, and demand variability present practical challenges for warehouse optimization. By employing

a data-driven and before–after comparative approach, the study aims to provide empirical evidence of how the LVG model can be applied to improve both operational efficiency and environmental performance under actual working conditions.

Therefore, to systematically examine the effectiveness of the proposed LVG model in addressing these operational and environmental challenges, this study establishes clear research objectives and testable hypotheses as presented below.

This study aims to develop and evaluate an integrated LVG model for improving warehouse operational efficiency while simultaneously reducing environmental impacts. The specific objectives of this research are as follows:

- (1) To develop an integrated warehouse management framework based on lean, visual, and green principles.
- (2) To evaluate the impact of warehouse layout redesign on operational efficiency, particularly in terms of material handling distance.
- (3) To assess the reduction of carbon dioxide (CO₂) emissions resulting from improved warehouse operations.

Based on the theoretical integration of lean and green operational principles, the following research hypotheses are proposed:

- H1: Implementation of the LVG model significantly reduces forklift travel distance in warehouse operations.
- H2: Reduction in travel distance leads to a proportional decrease in CO₂ emissions generated from material handling activities.
- H3: ABC-based warehouse layout redesign improves operational efficiency through optimized storage allocation and workflow clarity.

The remainder of this paper is organized as follows. Section 2 describes the materials and methods employed in the development and implementation of the LVG model. Section 3 presents the results and discussion, focusing on operational efficiency improvement and environmental impact reduction. Finally, section 4 concludes the study and outlines implications and future research directions.

2. Materials and Methods

This study employed an applied research approach with the objective of developing a warehouse management framework that simultaneously enhances operational efficiency and reduces carbon dioxide (CO₂) emissions. The research began with an in-depth investigation of the internal management processes within the finished goods warehouse of Doi Kham Food Products Co., Ltd., focusing on product flow structures, order-picking behaviors, forklift movements, and systematic patterns of storage utilization.

The research process was designed under the LVG Model, an integrated framework that emphasizes efficient resource utilization (lean), clear communication and operational visibility (visual), and comprehensive consideration of environmental

impacts (green). This framework was employed as the basis for analyzing quantitative data such as product picking frequency, material handling distances, and carbon footprint calculations. The analysis was further linked with strategies including ABC classification for inventory prioritization, optimal storage allocation, and redesigned material flow routes to minimize waste and improve energy efficiency. Collectively, these measures were structured into a system-level improvement simulation, guided by the principles of operational feasibility and environmental sustainability. The methodology was executed through the following steps.

To ensure methodological rigor and reproducibility, the analysis was conducted using structured data processing and validation procedures. All datasets were verified for completeness and consistency prior to analysis, and calculations were performed using spreadsheet-based analytical tools (e.g., Microsoft excel) to support transparency and traceability. Reliability was ensured through cross-validation of calculated indicators such as travel distance and CO₂ emissions against operational records.

2.1 Data collection process

The finished goods warehouse of Doi Kham Food Products Co., Ltd. covers an area of approximately 1,000 square meters and is equipped with a racking system comprising six rows of four-tier shelves, providing a total capacity of 880 pallets. The warehouse operations begin with the receipt of products from the semi-finished goods warehouse, transported by diesel-powered forklifts, followed by inspection and storage on the racks. When orders are received from the central warehouse in

Bangkok, items are picked and recorded using the SAP business system.

For this study, one year of historical data (January 1, 2023 to December 31, 2023) was collected, covering 81 active stock-keeping units (SKUs). The selection of this one-year data collection period was intentionally designed to capture seasonal variations in product demand, order frequency, and warehouse activity patterns, thereby providing a more representative assessment of operational behavior under real-world conditions and reducing bias associated with short-term fluctuations. As summarized in Table 1, the total annual picking frequency (PF) was 32,948 transactions, with a total annual quantity (TAQ) of 7,785,843 units. The calculated Product Utilization Index (PUI) reached 3,227,570,505 units per year, while the total annual travel distance (TDY) for material handling amounted to 3,519,647.28 meters, resulting in carbon dioxide (CO₂) emissions of 35,372.49 kg CO₂ per year. High-movement items, such as 100% tomato juice (200 ml), were picked 736 times per year with a total volume of 197,398 units, generating a cumulative travel distance of 158,432.40 meters and annual emissions of 1,592.25 kgCO₂. In contrast, low-movement items, such as concentrated red guava juice (750 ml), were picked only 15 times per year with a total volume of 159,053 units, corresponding to a travel distance of 2,601.72 meters and annual emissions of 26.15 kgCO₂. These data formed the basis for ABC classification using Pareto principles, which was subsequently employed to redesign the warehouse layout for optimal efficiency.

Table 1 Annual summary of product dispatch frequency and volume in 2023.

No.	Product name	PF (times/year)	TAQ (units)	PUI (times × quantity)	TDY (meters)	CO ₂ /Y (kgCO ₂)
1	100% Tomato Juice 200 ml	736	197,398	145,284,928	158,432.40	1,592.25
2	100% Tomato Juice 750 ml	517	66,408	34,332,936	37,439.88	376.27
3	100% Tomato Juice 750 ml × 12 bottles	396	189,117	74,890,332	81,667.44	820.76
4	100% Honey Tangerine Juice 750 ml	587	150,922	88,591,214	96,608.28	970.91
5	100% Honey Tangerine Juice 250 ml	568	119,594	67,929,392	74,076.60	744.47
...	...	...	...	...	...	...
77	Concentrated Red Guava Juice 750 ml	15	159,053	2,385,795	2,601.72	26.15
78	Concentrated Watermelon Juice 250 ml	26	177,870	4,624,620	5,043.12	50.68
79	Concentrated Pink Guava Juice 750 ml	43	85,189	3,663,127	3,994.56	40.15
80	Plum and Mulberry Juice Blend 750 ml	739	30,272	22,371,008	24,395.52	245.17
81	Carrot and Guava Juice Blend 750 ml	747	156,802	117,131,094	127,730.76	1,283.69
Totals		32,948	7,785,843	3,227,570,505	3,519,647.28	35,372.49

Note: PF = Picking Frequency (times/year), TAQ = Total Annual Quantity (units), PUI = Product Utilization Index (times × quantity), TDY = Total Distance per Year (meters), CO₂/Y = Total CO₂ per Year

2.2 Analysis process and improvement approach using the LVG model

To address inefficiencies in space utilization and product movement within the finished goods warehouse, particularly concerning product placement, travel distance, and operational clarity, this research began with an analysis of actual warehouse processes. ABC analysis was applied in conjunction with real operational data to calculate the Product Utilization Index (PUI), derived from the product of picking frequency (PF) and total accumulated quantity (TAQ). This metric provided a more accurate prioritization of items compared to using either frequency or volume alone, as it reflected the actual utilization level of each product. The analysis results classified products into three groups: Group A, representing high-frequency, high-volume items that should be placed near receiving and dispatch areas to minimize travel distance and handling time; Group B, representing medium-importance items stored in accessible zones; and Group C, representing low-movement items that can be placed deeper within the warehouse.

Following classification, a new warehouse layout was developed based on prioritization derived from the PUI. Visual Management concepts were incorporated through a visual control system that assigned color codes to each product category: green for Group A (frequent access), yellow for Group B (moderate importance), and blue for Group C (infrequent use). These codes were implemented in both the warehouse layout and actual storage locations, enabling workers to identify and retrieve products quickly and accurately, reducing human error, minimizing training time for new staff, and eliminating unstructured storage congestion. Furthermore, the redesigned storage system reduced forklift travel distances and associated carbon dioxide (CO₂) emissions from material handling, thereby establishing a foundation for long-term sustainability.

Synthesizing these initiatives, the improvement framework was formalized under the LVG model, with the objective of providing a systematic and sustainable solution. The lean dimension emphasizes waste reduction and resource efficiency, the visual dimension supports operational clarity and traceability while reducing human error, and the green dimension focuses on mitigating environmental impacts, particularly CO₂ emissions. Importantly, the LVG Model highlights a data-driven design approach, replacing reliance on operator experience with empirically grounded decision-making. This ensures an efficient storage system that supports sustainable operations while fulfilling both logistics requirements and the organization's environmental commitments in the long term.

2.3 Environmental impact assessment of warehouse improvement

To evaluate the environmental impacts associated with warehouse operations, this study established the indicator of carbon dioxide (CO₂) emissions generated from forklift operations, as forklifts represent the primary equipment used for internal material handling. The measurement framework was

based on the total annual travel distance of forklifts, with emissions calculated using the Emission Factor (EF_m) standardized and certified by the Thailand Greenhouse Gas Management Organization (TGO) (Thaicarbonlabel, 2025), where the emission calculation is based on the assumption of a constant fuel consumption rate for diesel-powered forklifts under normal operating conditions. Factors such as equipment age, maintenance condition, operator behavior, idle time, and load variation were not explicitly considered in this study. While this simplification follows standard carbon footprint accounting practices, it may introduce minor deviations from actual operational emissions; however, the use of a consistent emission factor ensures comparability between pre- and post-improvement scenarios.

The purpose of this analysis was to compare CO₂ emissions before and after the warehouse improvement, while controlling for external variables such as workforce size, warehouse system configuration, information system, and floor space. This ensured that any observed differences accurately reflected the impact of implementing the LVG Model. The calculation of CO₂ emissions was derived from actual annual forklift travel distances, which were then linked to diesel fuel consumption through Equation (1) (Thaicarbonlabel, 2025), following the standard methodology for carbon footprint (CFO) assessment:

$$CO_2 \text{ Emissions (kg)} = D \times EF_m \quad (1)$$

Where: D = travel distance of material handling (meters), EF_m = emission factor per meter (kgCO₂/meter)

The value of EF_m was derived from the estimated diesel consumption of forklifts, which averages 3.75 liters per kilometer, or 0.00375 liters per meter. Multiplying this consumption rate by the diesel emission factor of 2.68 kgCO₂ per liter yields the emission factor per meter, as expressed in Equation (2) (Thaicarbonlabel, 2025).

$$EF_m = 0.00375 \times 2.68 = 0.01005 \text{ kgCO}_2/\text{meter} \quad (2)$$

The calculated values were subsequently compared between the pre- and post-warehouse layout improvement periods to quantitatively assess the reduction in CO₂ emissions. This reduction represents a key objective of green logistics embedded within the LVG Model framework.

2.4 Comparative analysis of research results

Following the implementation of warehouse improvements based on the LVG Model, empirical data were collected to compare pre- and post-improvement outcomes. The data collection was conducted continuously over a one-year period to enable a concrete and academically significant assessment of changes in operational performance. Throughout this process, external variables that could potentially influence the evaluation results, such as workforce size, warehouse management system,

information system, and available storage space, were controlled to remain constant. This ensured the reliability of the comparison and accurately reflected the impacts of applying the LVG model in warehouse improvement. The comparative evaluation was designed to cover a 12-month period, from February 1, 2024 to January 31, 2025, thereby allowing for a meaningful measurement of operational performance after the warehouse redesign under the LVG framework. As with the pre-improvement phase, external variables, including workforce size, warehouse system, available space, and information system, were strictly controlled to enhance the credibility of the results and provide a valid reflection of the LVG model's effectiveness in improving warehouse operations. In addition to descriptive comparison, the study acknowledges the importance of statistical validation in assessing the significance of observed improvements. Although the primary objective is to demonstrate practical industrial applicability, future extensions of this work may incorporate statistical hypothesis testing (e.g., paired *t*-test or non-parametric methods) and sensitivity analysis to further validate the robustness of the results. Furthermore, sensitivity analysis on emission factors could be conducted to evaluate the impact of variability in fuel consumption assumptions on CO₂ estimation.

3. Results and Discussion

This study collected and analyzed data before and after the warehouse improvement through the application of the LVG model, in order to systematically compare outcomes in terms of both operational efficiency and environmental impacts. The evaluation emphasized three main aspects: warehouse space utilization, reduction in product travel distance, and reduction of carbon dioxide (CO₂) emissions generated from forklift operations, which constitute the primary material handling activity in the organization's internal logistics system. The findings can be summarized into two main areas: (1) results of product classification and warehouse layout redesign under the LVG model, and (2) operational performance improvements related to environmental impact reduction, particularly the measurable and verifiable decrease in CO₂ emissions.

3.1 Product classification and layout redesign under the LVG model

By applying the LVG model, which integrates lean warehousing, visual management, and green logistics, the finished goods warehouse of Doi Kham Food Products Co., Ltd. implemented ABC classification based on the Product Utilization Index (PUI). The results were subsequently plotted in a Pareto chart (Figure 1) to analyze product priority levels and further categorized into Groups A, B, and C according to cumulative percentage (Cum. %) thresholds, as summarized in Table 2, which presents the outcomes of ABC classification.

Based on the historical data analysis using ABC classification and Pareto charting, with the Product Utilization

Index (PUI) serving as the grouping criterion, all 81 stock-keeping units (SKUs) were classified into three categories: Group A comprised 5 items (6.17%), Group B comprised 19 items (23.46%), and Group C comprised 57 items (70.37%). This classification accurately reflected the operational priorities and logistical impacts of each product, forming a critical basis for redesigning storage allocation in line with the LVG model, which effectively integrates lean warehousing, visual management, and green logistics.

Following this classification, a new warehouse layout was designed by considering product usage frequency, handling volume, and movement-related impacts, while utilizing a racking system with a total capacity of 880 pallets. The revised allocation assigned 288 pallets to Group A items, which represent high-movement and large-volume products, strategically placed near the entrance and receiving/dispatch points to minimize travel distance and handling time. Group B was allocated 424 pallets, positioned in zones that remain accessible but do not require proximity to entry points. Group C, consisting of low-movement and low-volume items, was assigned 156 pallets located in the innermost section of the warehouse. In total, 868 pallets, or 98.64% of available capacity, were allocated, leaving 12 pallets (1.36%) as reserve space to accommodate contingencies or future product introductions.

In addition, the principle of visual control was applied to enhance efficiency in product picking and verification. Color codes were assigned to designate storage zones for each product category: green for Group A, yellow for Group B, blue for Group C, and purple for reserve or unallocated spaces, as illustrated in Figure 2. This color-coding system, developed under the visual management approach, improved clarity and traceability in warehouse operations, reduced human error, shortened the training time required for new employees, and strengthened systematic product control. This improvement can be explained by the reduction of search time and decision uncertainty during picking operations, as visual cues enable workers to immediately identify storage zones without relying on memory or complex instructions. Consequently, operational flow becomes more streamlined, reducing unnecessary movement and handling inefficiencies, which directly contributes to shorter travel distances and improved overall warehouse efficiency. These findings not only demonstrate practical improvements in warehouse operations but also highlight the potential of the LVG model as a foundation for further analytical modelling and optimization in sustainable logistics systems.

The redesigned warehouse layout was subsequently implemented in the facility, with performance data collected over a one-year period (February 1, 2024 to January 31, 2025). The operational outcomes were analyzed and summarized in Table 3 to evaluate both warehouse operational efficiency and the measurable reduction of carbon dioxide (CO₂) emissions from internal logistics processes within the organization.

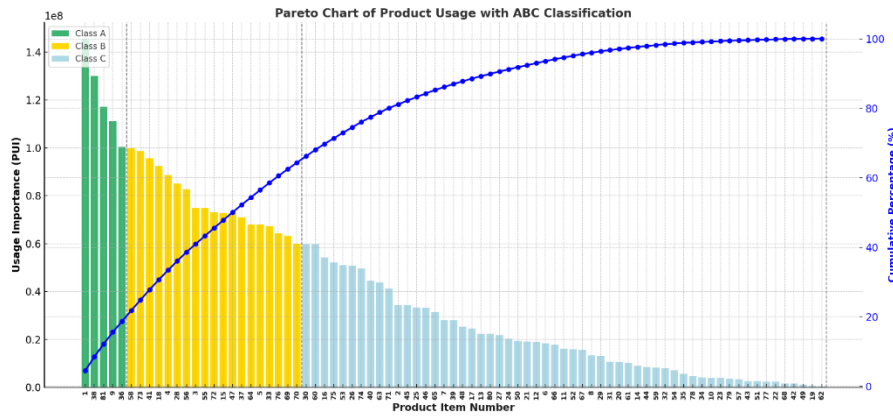


Figure 1 Pareto chart of product usage based on ABC classification.

Table 2 Product classification based on ABC analysis.

Item No	Product name	PF (times/year)	TAQ (units)	PUI (times × quantity)	%(f)	Cum. %	Class
1	Tomato Juice 100% 200 ml	736	197,398	145,284,928	4.50%	4.50%	A
38	Butterfly Pea Drink 700 ml	679	191,472	130,009,488	4.03%	8.53%	A
81	Carrot and Guava Juice 750 ml	747	156,802	117,131,094	3.63%	12.16%	A
9	Passion Fruit Juice 750 ml	556	199,724	111,046,544	3.44%	15.60%	A
36	Watermelon Juice 750 ml	768	130,618	100,314,624	3.11%	18.71%	A
58	Butterfly Pea with Honey Drink 250 ml	696	143,465	99,851,640	3.09%	21.80%	B
73	Mulberry Concentrate 750 ml	734	134,530	98,745,020	3.06%	24.86%	B
41	Carrot and Apple Juice 750 ml	653	146,571	95,710,863	2.97%	27.83%	B
18	Aromatic Coconut Water 750 ml	538	171,811	92,434,318	2.86%	30.69%	B
4	Mandarin Orange Juice 100% 750 ml	587	150,922	88,591,214	2.74%	33.43%	B
...	...	...	...	...	...	...	...
68	Coconut Concentrate 750 ml	30	56,255	1,687,650	0.05%	99.89%	C
42	Plum Concentrate 750 ml	376	4,290	1,613,040	0.05%	99.94%	C
49	Coconut Water with Nata de Coco 750 ml	40	27,777	1,111,080	0.03%	99.98%	C
19	Soy Milk 400 g x 12 bottles	64	8,125	520,000	0.02%	99.99%	C
62	White Guava Concentrate 750 ml	14	16,965	237,510	0.01%	100.00%	C
Totals		32,948	7,785,843	3,227,570,505	100%	-	-

Note: PF = Picking Frequency (times/year), TAQ = Total Annual Quantity (units), PUI = Product Utilization Index (times × quantity), %(f) = Percentage (%), Cum. % = Cumulative Percentage (%)

3.2 Operational efficiency improvement and carbon reduction through the LVG model

In this study, data from the year 2023 were compared with data collected after the warehouse improvement in 2024, while maintaining a constant number of 81 stock-keeping units (SKUs). Although the number of SKUs remained unchanged between the two periods, the total product volume differed significantly. To control for variability caused by external factors such as fluctuations in order volumes or other related influences, the researchers employed the average Product Utilization Index (PUI) to normalize the data prior to statistical analysis. This method reduced variability from external factors and ensured that the results accurately reflected the effectiveness of the warehouse layout redesign.

Furthermore, to enhance the robustness of the analysis and clearly demonstrate the impact of the improved storage system, the study reported both annual data and annualized averages in parallel. This approach increased the reliability of the findings and provided a comprehensive view of the operational and environmental improvements achieved. The detailed results are presented in Table 4.

From the data presented in Table 4, it was found that in 2024 the total annual product quantity (TAQ) reached 7,938,831 units, representing a 1.96% increase compared to 2023, which recorded 7,785,843 units. However, the number of picking transactions (PF) in 2024 decreased to 32,153, down from 32,948 transactions in 2023, reflecting a 2.41% reduction. This change resulted from an increase in the number of units per

picking transaction (per pallet), which, while still constrained by pallet storage capacity, allowed each picking operation to

transport larger volumes and consequently reduced the overall number of transactions.

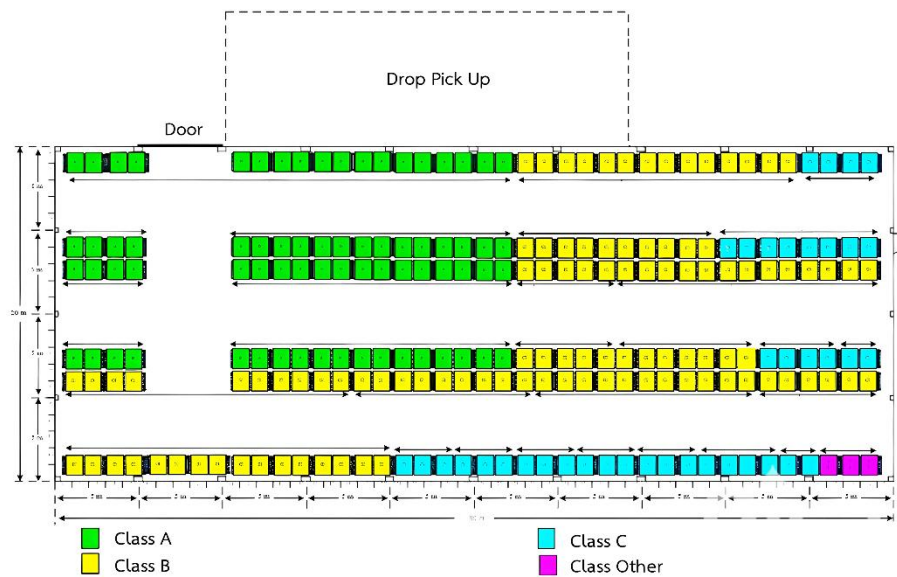


Figure 2 Warehouse layout based on ABC classification and visual control.

Table 3 Operational performance and CO₂ impact of warehouse activities by product group.

PIN	PF (times/year)	TAQ (units)	PUI (times × quantity)	Class	NPR	TDY (meters)	CO ₂ /Y (kgCO ₂)
1	715	213,602	152,725,430	A	65	62,374.84	626.87
38	649	186,460	121,012,540	A	63	55,816.66	560.96
81	741	152,015	112,643,115	A	51	50,287.60	505.39
9	541	210,688	113,982,208	A	66	47,675.34	479.14
36	743	129,143	95,953,249	A	43	43,067.87	432.83
58	690	157,101	108,399,690	B	22	42,869.06	430.83
73	746	130,469	97,329,874	B	21	42,393.98	426.06
41	625	151,956	94,972,500	B	22	41,091.32	412.97
18	534	184,623	98,588,682	B	27	39,684.63	398.83
4	571	136,468	77,923,228	B	24	38,034.68	382.25
...	...	...	...	...	...	...	...
68	30	58,085	1,742,550	C	2	724.53	7.28
42	367	4,640	1,702,880	C	1	692.50	6.96
49	39	25,927	1,011,153	C	1	477.02	4.79
19	62	8,619	534,378	C	1	223.23	2.24
62	13	17,151	222,963	C	1	101.95	1.02
Totals	32,153	7,938,831	3,205,504,281	-	712	1,385,685.20	13,926.11

Note: PIN = Product Item Number, PF = Picking Frequency (times/year), TAQ = Total Annual Quantity (units), PUI = Product Utilization Index (times × quantity), NPR = Number of Pallet Rotations per Year, TDY = Total Distance per Year (meters), CO₂/Y = Total CO₂ per Year

The Product Utilization Index (PUI) in 2024 was 3,205,504,281 units per year, a slight decrease of 0.68% from 3,227,570,505 units in 2023. This indicates that overall product utilization patterns remained relatively stable, though differences existed at the individual product group level.

The study revealed a significant reduction in total annual travel distance (TDY), which declined from 3,519,647.28 meters in 2023

to 1,385,685.20 meters in 2024, a 60.63% decrease. Similarly, the average distance per picking transaction (ADP) decreased from 8,490.38 meters to 3,526.90 meters, representing a 58.46% reduction. These reductions clearly demonstrate the effectiveness of the warehouse layout redesign under the LVG Model.

Correspondingly, carbon dioxide (CO₂) emissions followed the same trend. The total annual CO₂ emissions (CO₂/Y) declined

from 35,372.49 kgCO₂ in 2023 to 13,926.11 kgCO₂ in 2024, reflecting a 60.63% reduction directly linked to the decrease in travel distance. Likewise, CO₂ emissions per picking transaction

(CO₂/P) dropped from 85.33 kg CO₂ to 35.45 kg CO₂, a 58.46% reduction.

Table 4 Comparison of internal distance and CO₂ emissions before and after warehouse improvement.

Year	PF (times/year)	TAQ (units)	PUI (times × quantity)	TDY (meters)	ADP (meters)	CO ₂ /Y (kgCO ₂)	CO ₂ /P (kgCO ₂)
2023	32,948.00	7,785,843.00	3,227,570,505.00	3,519,647.28	8,490.38	35,372.49	85.33
2024	32,153.00	7,938,831.00	3,205,504,281.00	1,385,685.20	3,526.90	13,926.11	35.45
Difference	795.00	-152,988.00	22,066,224.00	2,133,962.08	4,963.48	21,446.38	49.88
% Change	-2.41%	1.96%	-0.68%	-60.63%	-58.46%	-60.63%	-58.46%

The results confirm a direct linear relationship between the reduction in travel distance (TDY) and CO₂ emissions. When comparing pre- and post-improvement conditions, the 60.63% reduction in travel distance corresponded exactly with the 60.63% reduction in CO₂ emissions. This outcome is attributable to the mathematical formulation of CO₂ emission calculations, which are directly proportional to travel distance and the emission factor (EF_m), a constant value defined by the Thailand Greenhouse Gas Management Organization (TGO) for diesel fuel consumption. Thus, when travel distance decreases, CO₂ emissions decrease proportionally. These findings demonstrate that the redesigned warehouse layout under the LVG model is highly effective in reducing material handling distances and significantly mitigating environmental impacts in a quantifiable manner. In addition to environmental benefits, the substantial reduction in travel distance also contributes to measurable improvements in labor productivity and equipment utilization efficiency. Shorter travel routes reduce idle time, improve cycle time per operation, and increase the effective use of forklift resources, thereby enhancing overall operational throughput. These operational improvements highlight the broader impact of the LVG model beyond environmental performance.

From an economic perspective, the significant reduction in travel distance (60.63%) directly contributes to lower fuel consumption and operational costs associated with material handling activities. Although this study does not explicitly quantify cost savings or return on investment (ROI), the proportional relationship between travel distance and fuel usage suggests a strong potential for cost reduction in long-term warehouse operations. This indicates that the LVG model can provide not only environmental benefits but also tangible economic advantages for warehouse management.

3.3 Discussion

The implementation of the LVG model demonstrated the potential of an integrated warehouse system design that can simultaneously enhance storage efficiency and reduce environmental impacts. The outcomes are presented in two major dimensions: (1) improving warehouse operational efficiency and (2) achieving measurable reductions in carbon

dioxide (CO₂) emissions. From a managerial perspective, the LVG model provides a structured approach that can be implemented incrementally. Warehouse managers can begin by analyzing product movement data, followed by ABC classification and visual zoning, before proceeding to layout redesign. This stepwise approach reduces implementation complexity and allows gradual adaptation within existing operational constraints.

In practice, this phased implementation approach is particularly beneficial in industrial environments where operational disruptions must be minimized. Managers can initiate pilot zones before full-scale deployment, allowing performance monitoring and gradual workforce adaptation.

Regarding operational efficiency, this study applied ABC classification using the Product Utilization Index (PUI) to prioritize items, thereby aligning product placement with utilization behavior and significantly reducing picking time. This approach is consistent with the findings of Abdolazimi *et al.* (2021a), Abdolazimi *et al.* (2021b), and Ray Silaen *et al.* (2024), who emphasized that ABC analysis remains a flexible tool and, when combined with real utilization data, enhances the accuracy of inventory management. Furthermore, the integration of visual management with lean principles improved clarity and traceability in warehouse operations, reduced human error, and shortened the training period for new employees. This supports the proposition of Nantee and Sureeyatanapas (2021), who noted that automation and visual control tools play a vital role in reducing labor dependence and increasing control accuracy, particularly under the logistics 4.0 paradigm. Similarly, Kumar and Adil (2025) highlighted that intelligent warehouse technologies should adopt adaptive structures capable of responding flexibly to fluctuating order volumes, a requirement addressed by the LVG model in this study through the systematic classification of products into A, B, and C categories.

More importantly, the observed efficiency gains can be explained through a reduction in operational complexity and cognitive load during picking activities. The use of visual control mechanisms, such as color-coded zoning, enables faster recognition, minimizes search time, and reduces decision

uncertainty among operators. This causal mechanism highlights that the contribution of the “Visual” component extends beyond communication, acting as an operational enabler that directly influences process efficiency.

With respect to CO₂ reduction, the results showed that the redesigned warehouse layout reduced forklift travel distance by over 60%, leading to a corresponding decrease in annual CO₂ emissions from 35,372.49 kgCO₂ to 13,926.11 kgCO₂, or 60.63%. This trend indicates that more efficient product placement inherently minimizes unnecessary movement and energy consumption within logistics operations. Similar findings were reported by Accorsi *et al.* (2017), Rajković *et al.* (2019), and Luca *et al.* (2025), who established a strong relationship between spatial efficiency and carbon footprint reduction in warehouse systems, especially in automated and complex environments. In addition, Shih-Che Lo (2022) and Wang *et al.* (2018) confirmed that optimized routing and data-driven analyses of equipment movement significantly reduce CO₂ emissions. Complementary perspectives from Domagała (2022) and Fächtenhans *et al.* (2023) further demonstrated that even moderate changes, such as upgrading lighting systems or reconfiguring storage structures, can cut CO₂ emissions by several thousand kilograms annually, underscoring the systemic power of targeted interventions without requiring large-scale investments.

In addition to environmental benefits, the reduction in travel distance also implies improvements in labor productivity and equipment utilization efficiency. Shorter travel routes reduce idle time, increase cycle efficiency, and enhance the overall throughput of material handling operations.

From an economic standpoint, the reduction in travel distance is directly associated with lower fuel consumption and operational costs. Although this study does not explicitly quantify cost savings or ROI, the proportional relationship between distance reduction and fuel usage indicates strong potential for long-term economic benefits in warehouse operations.

Compared to prior literature, this study is distinctive in its use of real operational data to redesign warehouse systems, differing from earlier works that relied primarily on deterministic models without accounting for seasonal fluctuations or environmental variables (Kumar *et al.*, 2022; Priyan, 2024). Moreover, the LVG model presents opportunities for extension into other systems such as cross-docking, blockchain-enabled inventory management, and cold chain logistics, all of which demand both operational efficiency and environmental sustainability.

Furthermore, unlike previous studies that primarily focus on either operational optimization or environmental performance independently, this study demonstrates how both dimensions can be simultaneously achieved through an integrated and data-driven framework, thereby strengthening the practical and analytical contribution of the LVG model.

From a broader operational perspective, the findings suggest that the LVG model possesses a degree of generalizability to

warehouse environments that share similar operational characteristics, particularly medium-scale facilities relying on manual or semi-automated material handling systems. The integration of ABC-based storage prioritization, visual control mechanisms, and distance-based environmental assessment can be adapted to warehouses where product movement patterns and storage allocation decisions significantly influence operational performance. In such contexts, the model provides a practical framework for aligning efficiency improvement with environmental objectives without requiring substantial infrastructure investment.

However, the applicability of the LVG model may be influenced by several operational conditions. Warehouses operating fully automated Auto-mated Storage and Retrieval Systems (AS/RS), highly dynamic real-time allocation systems, or facilities with extremely high SKU variability may require further modification of the model parameters and decision rules. In addition, differences in energy sources, equipment types, and organizational policies may affect the magnitude of environmental benefits achieved, suggesting that performance outcomes should be interpreted in relation to local operational contexts.

In practical implementation, several challenges may arise, including resistance to layout changes from operational staff, the need for retraining to adapt to visual control systems, and temporary performance fluctuations during the transition phase. These challenges can be mitigated through phased implementation, staff involvement, and continuous monitoring of operational performance.

These considerations indicate that while the LVG model offers a transferable conceptual and analytical framework, its implementation should be supported by context-specific data analysis and operational assessment. Future research may therefore extend the model by incorporating digital monitoring technologies, adaptive optimization algorithms, or multi-site comparative studies to further validate its scalability and robustness across diverse industrial sectors.

In addition, future studies may incorporate statistical hypothesis testing and sensitivity analysis to further strengthen the robustness and generalizability of the findings. Taken together, the findings of this study provide empirical support for the proposed research objectives and hypotheses. The significant reduction in forklift travel distance confirms hypothesis H1, while the proportional decrease in CO₂ emissions supports hypothesis H2. Furthermore, improvements in operational efficiency resulting from ABC-based layout redesign validate hypothesis H3. These results collectively demonstrate that the LVG model effectively integrates operational efficiency enhancement with environmental impact reduction under real warehouse conditions.

4. Conclusion

This research introduced the integrated LVG model as a sustainable approach to finished goods warehouse management. The model combines lean principles to enhance

space utilization, minimize waste, and reduce unnecessary product movement; visual principles to establish clarity, transparency, and traceability while reducing operational errors; and green principles to mitigate environmental impacts from logistics activities through systematic evaluation of CO₂ emissions. By applying this model through ABC classification and visual management in the case study of Doi Kham Food Products Co., Ltd., the results demonstrated clear effectiveness. The total travel distance for material handling was reduced by 60.63%, from 3,519,647.28 meters per year to 1,385,685.20 meters per year. This directly translated into an equivalent reduction in CO₂ emissions, from 35,372.49 kgCO₂ per year to 13,926.11 kg CO₂ per year. These findings highlight that the LVG model can simultaneously enhance warehouse operational efficiency and support environmentally sustainable practices.

Beyond operational and environmental benefits, the LVG model aligns closely with the United Nations Sustainable Development Goals (SDGs). Specifically, it supports SDG 9 (industry, innovation, and infrastructure) by applying data-driven and innovative warehouse management techniques; SDG 12 (responsible consumption and production) through tangible reductions in storage and handling waste; and SDG 13 (climate action) by reducing CO₂ emissions from warehouse and logistics operations. Thus, the LVG model provides an important pathway for industrial organizations to adopt environmentally responsible practices and contribute to carbon reduction goals at organizational, societal, and national levels. Despite these contributions, several limitations of this study should be acknowledged. First, the research is based on a single case study within the food products industry, which may limit the generalizability of the findings to other industrial contexts. Second, the analysis relies on a one-year dataset, which, although sufficient to capture seasonal variations, may not fully represent long-term operational dynamics. Third, the environmental impact assessment is based on a deterministic emission model assuming constant fuel consumption, which does not account for operational variability such as equipment condition, operator behavior, or load differences.

Furthermore, the applicability of the LVG Model may depend on specific operational conditions, such as warehouse size, level of automation, and product variety. Highly automated systems or warehouses with dynamic real-time allocation may require adaptation of the model structure and decision parameters.

Looking forward, the LVG model can be further developed and adapted to warehouses in other industries with similar constraints, thereby expanding its role in enhancing efficiency and environmental sustainability on a broader scale. Future studies should also explore the integration of digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and blockchain with the LVG model to improve accuracy and effectiveness in product and data management.

Moreover, extending the assessment to include economic and social dimensions will elevate the value of this research by generating broader policy and industry-level impacts in pursuit of sustainable development. Furthermore, this study contributes to the development of an operationally grounded framework that can be extended toward statistical validation, simulation-based optimization, and broader theoretical generalization in future research. In addition, future research may incorporate statistical validation methods and sensitivity analysis to enhance the robustness and theoretical rigor of the LVG framework, as well as multi-case or cross-industry studies to further validate its scalability and applicability.

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