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IMPLEMENTATION AND PERFORMANCE ANALYSIS OF LINEAR INTEGER MODELS IN WAREHOUSE OPTIMIZATION

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Abstract

Warehouses serve as essential facilities for storing raw materials, finished products, defective items, equipment, & other organizational assets until they are needed. Additionally, they function as staging areas for the packaging and distribution of products to customers, particularly in consumer-driven industries. Effective warehouse management aims to minimize storage time, reduce space requirements, and shorten delivery lead times through improved asset management practices. The research employs a hybrid strategy using linear programming (LP) and dynamic decision-making methods to increase efficiency in the warehouse. The linear programming (LP) model identifies the maximum quantity of goods that could be stored in the warehouse under the scenarios considered in the study. In addition, the research presents critical determinants affecting the use of warehouse space in full capacity. Through the execution of this methodological approach, businesses will be able to make more intelligent and strategic choices in regards to storage and logistics. The process enables enhanced resource allocation, increases operational effectiveness, and ultimately leads to higher productivity within supply chains. The model is especially valuable for businesses whose core operations involve high levels of warehousing and distribution, providing actionable insights into the optimization of space utilization and delivery performance.

Keywords: Linear Programming Model; Storage optimization; Warehouse management. Excel solver; Decision-Making Model.

1. INTRODUCTION

In today's global marketplace, businesses are keener on maximizing warehouse effectiveness to enhance production levels and ease distribution. With increasingly complex supply chains and rising customer expectations, businesses are turning to data-driven approaches like Linear Programming (LP) to optimize warehouse operations. **1)** Warehouse utilization deals with optimally utilizing storage space to ease goods storage, picking, and dispatch, enhance throughput, and save costs. **2)** Rule-based or legacy heuristic procedures are generally lacking in addressing massive inventories, fluctuating demand, limited space, and the need for prompt order fulfillment. LP, an algorithmic optimization method, solves the above problems by establishing the optimal distribution of resources such as storage room, within given constraints such as warehouse layout, product sizes, patterns of demand, and handling requirements. **3)** The advent of

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globalization, increased operating expenses, and compressed delivery timelines have made warehouses an integral part of active supply chains. Strategic location of products, effective retrieval systems, and reduced travel distances in warehouses increase order fulfillment and customer satisfaction. **4)** LP models allow companies to optimize storage space, decrease handling times, and enhance control over inventory, enabling flexibility to seasonality changes and varying demands.

5) By combining LP with warehouse management systems and enterprise resource planning software, firms have real-time decision-making capabilities, track inventory levels, and act quickly to disruptions without causing excessive stockouts and overstocking. This research investigates an LP-based solution for warehouse optimization considering constraints such as storage capacity, product dimensions, shelf capacities, and delivery timetables. **6)** By using case studies, it illustrates LP applicability to different types of warehouses, such as distribution centers and in-plant storage areas. The study seeks to determine the influential factors on warehouse space utilization, design a customized LP model, and examine its overall performance in the actual case studies. It offers practical implications for decision-makers to apply LP in various industrial environments. **7)** The main objectives are to cut down lead and delivery times, and maintain proper inventory levels to service changing or seasonal consumer needs. With the increase competition at a record high, organizations in different industries have to work towards achieving top- notch operational efficiency and embracing perpetual improvement approaches to maintain and improve their performance indices.

8) To remain competitive, profitable companies are using sophisticated technologies to track, store, and move products globally. These technologies reduce wastage, minimize operational expenditure, and greatly improve customer service. Consequently, supply chain management practices have been refined to include an array of methods with the sole purpose of streamlining warehouse operations and inventory management more effectively. These processes are critical for guaranteeing optimal storage capacity utilization and product availability when required. Warehouse management is now an integral part of business success. This has a direct influence on an organization's capability to meet customer demands quickly and precisely. **9)** Industries all over the world are adopting cutting-edge solutions to enhance warehouse processes and logistical performance as a whole. This encompasses the incorporation of contemporary tools and methodologies that enable businesses to keep pace with ever-changing market requirements while ensuring high standards of service.

The present research focuses on enhancing the use of supplier warehouses and maximizing in-plant warehouse operating efficiency. The aim is to optimize space for storage to meet the prevailing level of product demand. **10)** A number of essential aspects are taken into account in the optimization process. These are the efficient use of the space that is available for storage, the storage rack layout and design, the unit density per shelf, and the overall size and frame of the warehouse. **11)** All of these are significant in determining how efficiently a warehouse can be utilized to store goods and provide room for the flow of products. **33)** In addition, this study aims to ascertain the ideal quantities of

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products that should be kept in a given warehouse space. The positioning optimization is critical in ascertaining effective storage, fast retrieval, and prompt distribution of products to end-users.

12) Last but not least, with increased storage and handling of products within a warehouse, businesses are in a position to increase operational flexibility, reduce bottlenecks, and answer customer needs effectively.

The primary goals of this study are outlined as follows:

1. To use a linear Programming model (LPM) to determine the optimal number of boxes/containers to be effectively stored/placed on each assigned rack in the warehouse.
2. To identify the main factors or criteria responsible for achieving maximum utilization of total warehouse space.

13) This section outlines the specific aims of the study, which are focused on improving how warehouse space is used through the application of mathematical and decision-making tools:

1.1. LP Model for Storage Optimization

14) The first aim is to utilize Linear Programming—a mathematical optimization technique—to determine the maximum no. of boxes/containers that can be loaded on each rack.

This will involve taking into account constraints such as rack size, box size, and potentially weight capacity. **15)** The LP model will assist in ensuring each available space bit is utilized efficiently without any constraint being violated.

1.2. Identifying Utilization Criteria

The second objective is to determine what most affects the efficient use of the storage space in the warehouse. **17)** These may be aspects such as how the racking is laid out, rate of product access, stacking capacity, or the nature of products to be stored. Having such requirements enables more specific strategies in warehouse management.

1.3. Decision-Making Model for Placement

The third aim is to build a practical tool or model that helps managers decide the best locations for storing boxes. **18)** By using the criteria identified in the second objective, this model will suggest optimal box placements to ensure efficient storage and retrieval, ultimately making warehouse operations faster and more organized.

To accomplish these goals, this study involves analyzing the dimensional data of both the warehouse & the products' boxes to develop the Linear Programming (LP) model. The optimal solution generated by this model aims to maximize/optimize the no. of boxes that can be efficiently stacked on the available shelves within the warehouse. Additionally, the model identifies the suitable types and quantities of products that can be accommodated on each shelf.

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2. LITERATURE REVIEW

Inventory and warehouse management are major components of efficient supply chain processes. Some researchers have developed methods to optimize storage space usage, cost-saving, and planning activities in warehouses over the years.

The studies conducted in this area are aimed at addressing specific issues like space optimization, labor allocation, and the computation of cost through mathematical models and simulation software.

19) A significant study in this context was conducted solved by Shetty et al., who developed a linear programming (LP) model for the Indian garment industry. They sought to optimize the use of storage racks in terms of different significant

factors such as dimensions of storage boxes, product quantities, and production rates. This way, they optimized the usage of space by minimizing the number of racks used. **20)** One of one of the specific techniques used in their approach was the ABC analysis, a classification technique based on the value or importance of the inventory.

21) By using this technique, they were able to arrange materials in a rational and sequential order, thereby ensuring improved organization and simpler retrieval process in the warehouse.

Another significant contribution was by **22)**, who developed a simulation-based decision-support tool (DM-T) for warehouse evaluation. **23)** Applied this through mathematical modeling, choosing simulation as the means of informing logistics planning. Their system was intended to assist warehouse managers in deciding on appropriate levels of labor and space usage for maximum utilization. **24)** The model was based on inputs such as dimensions of the warehouse, placements of the racks, and rack measurements and was applied through Arena simulation software. **25)** Their strategy adopted a volume-based storage policy and was concerned with optimizing the volume use of the storages available in the given warehouse configuration.

In the same line, **26)** also employed an LP model, but their interest leaned toward inventory and cost control. Their effort sought to present a systematic approach to managing inventory levels and evaluating related costs efficiently.

27)12) Conducted research on warehouse optimization in the context of an assembly and distribution company. **28)**Their study was comprehensive, factoring in multiple cost-related aspects such as implementation costs, labeling costs per item, and handling costs due to product damage. **29)** To prioritize these factors, they employed the Weighted Sum Approach (WSA)—a traditional method used to assign relative importance to different criteria in decision-making processes.

30) Together, these studies highlight different yet complementary strategies for enhancing warehouse efficiency. While some researchers employed mathematical models like linear programming, others used simulation tools to visualize and test warehouse scenarios.

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31) The inclusion of cost analysis and operational data in these models ensures that the solutions are not only technically sound but also economically viable. **32)** These efforts collectively contribute to the development of smarter, more adaptive warehouse systems across industries.

3. DESIGN AND METHODOLOGY

In this research, different factors were taken into account to optimize the storage space in the warehouse. Initially, essential data and values necessary for warehouse expansion were gathered through literature reviews and expert feedback. A Linear Programming model (LPM) was then developed to evaluate the maximum/optimum no. of boxes/containers that could be stored in the supplier's warehouse.

The study's findings provided key insights for enhancing the decision-making tool, which incorporates both linguistic scale values and value-based input from decision-makers.

3.1. Linear Programming (LP)

Linear Programming (LP) is an optimization method/technique is used to find the best possible outcome for a specific objective function, given a set of constraints & decision variables. The goal of LP is to either maximize or minimize the objective function. It is a simple yet powerful technique that is widely applicable across various fields.

The fundamental terms commonly used in linear programming (LP) are as follows:

- **Objective function –** It defines the desired result of a linear equation (LE), which can involve either maximizing or minimizing a specific value. For instance, profit is typically considered a maximization of the objective based on the provided data.
- **Constraint –** They are predefined conditions applied to the objective function to ensure the linear equation (LE), stays within specified limits. For example, they may restrict the no. of products that can be placed/reserved on the shelves.
- **Decision variable -** The decision variables, which represent the final outcome, must be clearly defined. These variables are typically represented by symbols such as *x* and *y* in the formulation of the (LE) linear equation.
- **Non – negativity –** This condition requires that decision variables must have values equal to or greater than zero.

The LP model is formulated by following these steps.

Step1: Identify the crucial variables involved.

Step2: Evaluate the decision variables that require optimization.

Step3: Develop the objective function.

Step4: Derive the constraints based on the provided data.

Step5: Solve the linear programming model and interpret the outcomes.

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Table 1: factors that influence how much warehouse space is used.

Criteria		Description
C1	Access to every location	Easy or Simple access to the shelves for product storage is an important consideration. Without it, bottlenecks may arise during the loading & unloading of the pallets or boxes. Ideally, the path to the needed items should be as short and efficient as possible.
C2	Order characteristic	The ordering patterns of the commodities & their placement within the warehouse should be analyzed. Based on this analysis, dedicated storage areas can be assigned to ensure efficient material reordering during replenishment.
C3	Frequency of products	The frequency of product movement is tracked in the warehouse because sales are inconsistent and fluctuate based on changing customer's orders.
C4	Area for storage	The pallets are organized and placed on shelves, so it's important to assess the storage layout and its impact on pallet movement from shelves to receiving area.
C5	Product's placement	Product placement is crucial in warehouse management. Frequently requested items are stored near the distribution center, while less popular products are kept on the farthest racks, which are accessed less often.
C6	Material handling	Efficient material handling is essential for optimal use of warehouse space. If a product gets damaged during handling or storage, it causes delays for the receiving team in moving the item to the next department.

3.2. Implementation

To determine the optimal placement within the warehouse and reduce pallet movement, data was gathered from LOPAN's logistics department. The Table 2 outlines the size/dimensions of key components, including the warehouse, racks, shelves, boxes, and pallets. The Table 3 details the no. of boxes based on the percentage distribution and extra data regarding the no. of products each box can hold. Table 4 displays the weekly demand of products from January 2025 to March 2025.

Table 2: Pallets, Shelves, Warehouse, Boxes, and Racks dimensions.

	Details	Dimensions
Warehouse	Total area for storage Capacity for total storage Warehouse's height Warehouse's length	557.420 m^2 (6 thousand sq. ft.) 10000 to 12000 cartons 4 meters 110 meters
Pallets	Max weight (L * W * H) Volume	700 Kilogram (1.2 meter × 0.8 meter × 0.15 meter) 0.144 m^3
Shelves	length of shelves width of shelves height of shelves	22.0 meter 1.30 meter 2.20 meter

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Boxes	Max weight (L * W * H) of Box A Volume of the Box A (L * W * H) of Box B Volume of the Box B (L * W * H) of Box C Volume of the Box C	20 kilograms (0.60 × 0.40 × 0.40) meter 0.096 m^3 (0.60 × 0.20 × 0.20) meter 0.024 m^3 (0.60 × 0.30 × 0.20) meter 0.036 m^3
Racks	The boxes' maximum racking height No. of Racks No. of Shelves in a Rack (L * W * H) of Rack 1 (L * W * H) of Rack 2 Total Volume of the 15 Rack (13R1+2R2)	2.150 meter 15 3 (22 × 1.30 × 6.60) m (19.80 × 1.30 × 6.60) m 2793.650 m3

Table 3: Information as well as box quantities according to the number & percentage of commodities.

Boxes	Maximum/Optimum amount in a single pallet	The percentage taken into account for storage of warehouse	Maximum Cartons Determined by Percentage	Average Product Quantities
Box A	20	55-60	7200	35-40
Box B	80	20-30	3600	20-25
Box C	40	25-10	1200	15-20

Table 4: Weekly product requirements from January through March

Weeks	Units of average requirement	Weeks	Units of average requirements
Week 2	265127	Week 10	349649
Week 3	403777	Week 11	462614
Week 4	421158	Week 12	562452
Week 5	449974	Week 13	277279
Week 6	368098	Week 14	209425
Week 7	292351	Week 15	271177
Week 8	313496	Week 16	177547
Week 9	316759	Week 17	134029
		Total	**5274912**

The procedure outlined in the previous section 3.1 was used to construct the linear programming model (LPM).

Step A1: Emphasize the crucial variables required for building the model.

Step A2: Determine the decision variables that should be optimized (Maximized / Minimized), along with the provided data. In the warehouse analysis, the decision variables involve the quantity of boxes that can be stored per pallet and arranged on the shelves.

The number of Box A units that can be placed on the rack = x_1.

The number of Box B units that can be placed on the rack = x_2.

The number of Box C units that can be placed on the rack = x_3.

Step A3: Define or construct the objective function.

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By arranging the greatest possible no. of boxes, cartons on the pallets at warehouse's each rack, this optimization technique seeks to optimize space use.

The given equation for the desired function uses the identical volume of the pallets because LOPAN's supplier uses the precise pallet's dimensions/size listed in Table 2:

$$\text{Max Z} = x_1 + x_2 + x_3$$

Step A4: Determine the constraints based on the data or information provided by the industry and integrate these restrictions into the objective function and decision variables.

The primary constraints for the warehouse include the total rack space volume of 2793.648 m^3 and the specified percentage of each box type initially stored on the shelves according to their dimensions.

Hence, the objective function must comply with the following limitations:

$$0.0480x_1 + 0.0240x_2 + 0.0400x_3 \leq 2793.648$$

Where,

$$x_1 \leq 7200 + x_2 \leq 3600 + x_3 \leq 1200.$$

All the variables must have non-negative values, meaning none of them can be less than zero.

$$x_1, x_2, x_3 \geq 0$$

Hence, the linear programming (LP) formulation for Case 1- based on the box percentage constraints—is as follows:

Max $Z_1 = x_1 + x_2 + x_3$

Subject to constraints (STC),

$$0.0480x_1 + 0.0240x_2 + 0.0360x_3 \leq 2793.648$$

Where,

$[x_1 \leq 7200, x_2 \leq 3600, x_3 \leq 1200]$ Boxes

All the variables must have non-negative values, meaning none of them can be less than zero.

$$x_1, x_2, x_3 \geq 0$$

The Linear programming (LP) formulation for the Case 2 – optimize the space of the warehouse upto 100% and evaluate the max no. of the boxes that can be stored – as follows:

Max $Z_2 = x_1 + x_2 + x_3$

Subject to constraints (STC),

$$0.0480x_1 + 0.0240x_2 + 0.0360x_3 \leq 2793.648$$

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Where,

$[x_1 \leq 43200, x_2 \leq 21600, x_3 \leq 7200]$ Boxes

All variables must have non-negative values, meaning none of them can be less than zero.

$$x_1, x_2, x_3 \geq 0$$

The Linear programming (LP) formulation for Case 3 – optimize the quantity of the boxes that can be stocked, depends upon demand on a monthly basis of the products– as follows.

The constraints should be considered the total no. of boxes that can be stocked, and one other limitation includes the no. of products preserved in boxes, depending on the above information/data taken out from Tables 2 & 3.

Max $Z_3 = x_1 + x_2 + x_3$

Subject to constraints (STC),

$$0.0480x_1 + 0.0240x_2 + 0.0360x_3 \leq 192000$$

Where,

$[x_1 \leq 4032000, x_2 \leq 1152000, x_3 \leq 288000]$ Commodities

All variables must have non-negative values, meaning none of them can be less than zero.

$$x_1, x_2, x_3 \geq 0$$

The Linear programming (LP) formulation for the Case 4 – optimize the quantity of the boxes that should be stocked, depends upon demand on a monthly basis of the products– as follows.

The constraints should be considered the total no. of boxes that can be stocked, and one other limitation includes the no. of products stocked in the boxes, depending on the information taken out from Table 2 & 3.

Max $Z_4 = x_1 + x_2 + x_3$

Subject to constraints (STC),

$$0.0480x_1 + 0.0240x_2 + 0.0360x_3 \leq 12000$$

Where,

$[x_1 \leq 288000, x_2 \leq 90000, x_3 \leq 24000]$ Commodities

All variables must have non-negative values, meaning none of them can be less than zero.

$$x_1, x_2, x_3 \geq 0$$

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4. RESULT

In case 1, Warehouse utilization is determined by the percentage allocation of demand boxes and the company's specified maximum limits. The constraints are set as follows: x_1 ranges from 55% to 60% (or 7200 boxes), x_2 from 20% to 30% (or 3600 boxes), and x_3 from 10% - 25% (or 1200 boxes). An analysis using the linear programming (LP) Excel Solver revealed that only 475.188 m^3 of the available 2793.648 m^3 warehouse space is being used. The current box limits and variable constraints have been fully utilized. However, since just 17.01% of the warehouse's capacity is in use, there is clear potential for improvement, which prompts the exploration of Case 2.

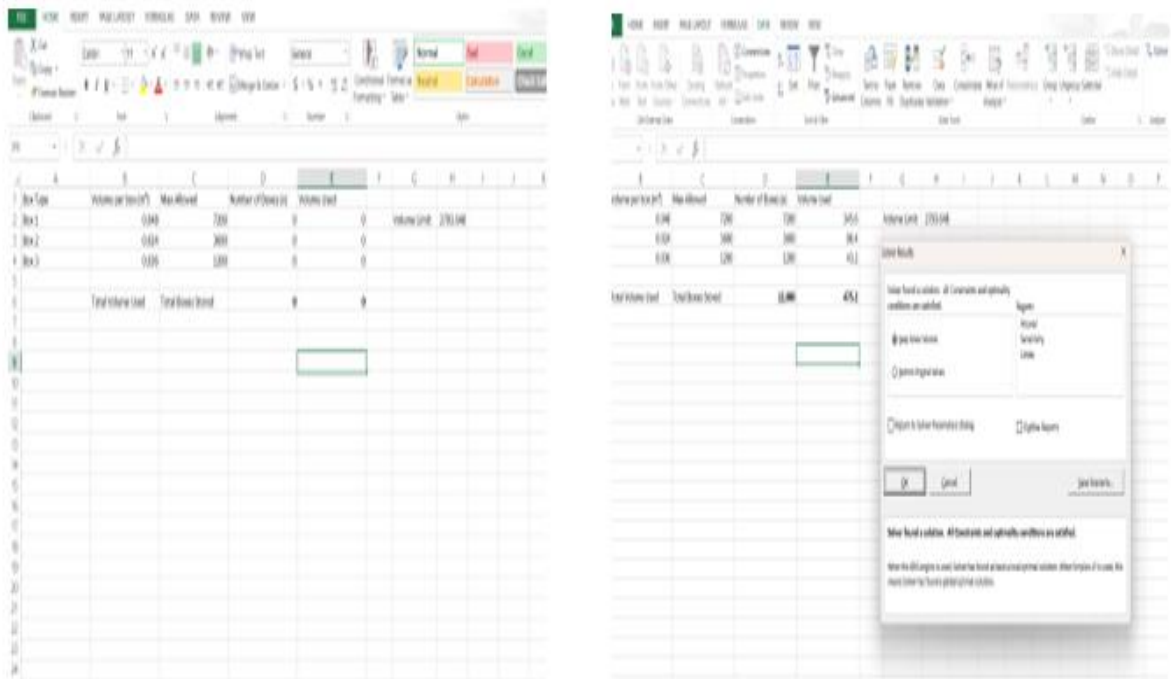

Fig 1: Represents the case 1 scenario.

Case 2 aims to maximize/optimize warehouse space utilization by calculating the optimal no. of boxes to store based on demand percentages, prioritizing efficient rack usage. The variable limits are significantly expanded compared to Case 1, with constraints set at $x_1 \leq 43{,}200$ (Box A), $x_2 \leq 21{,}600$ (Box B), & $x_3 \leq 7{,}200$ (Box C).

The results show full warehouse capacity utilization, accommodating 42,001 units of Box A, 21,600 units of Box B, and 7,200 units of Box C, totaling 70,802 boxes on shelves.

This represents a remarkable 483% to 500% increase in storage capacity compared to Case 1, showcasing a six-fold expansion in variable limits.

These findings enable the logistics team to strategically allocate products across shelves, ensuring optimal use of available space while meeting demand requirements.

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The enhanced storage capacity highlights the effectiveness of the optimization approach, allowing for significantly higher inventory levels and improved operational efficiency.

By leveraging these insights, the team can make informed decisions about product placement, streamline warehouse operations, and maximize resource utilization to support business objectives.

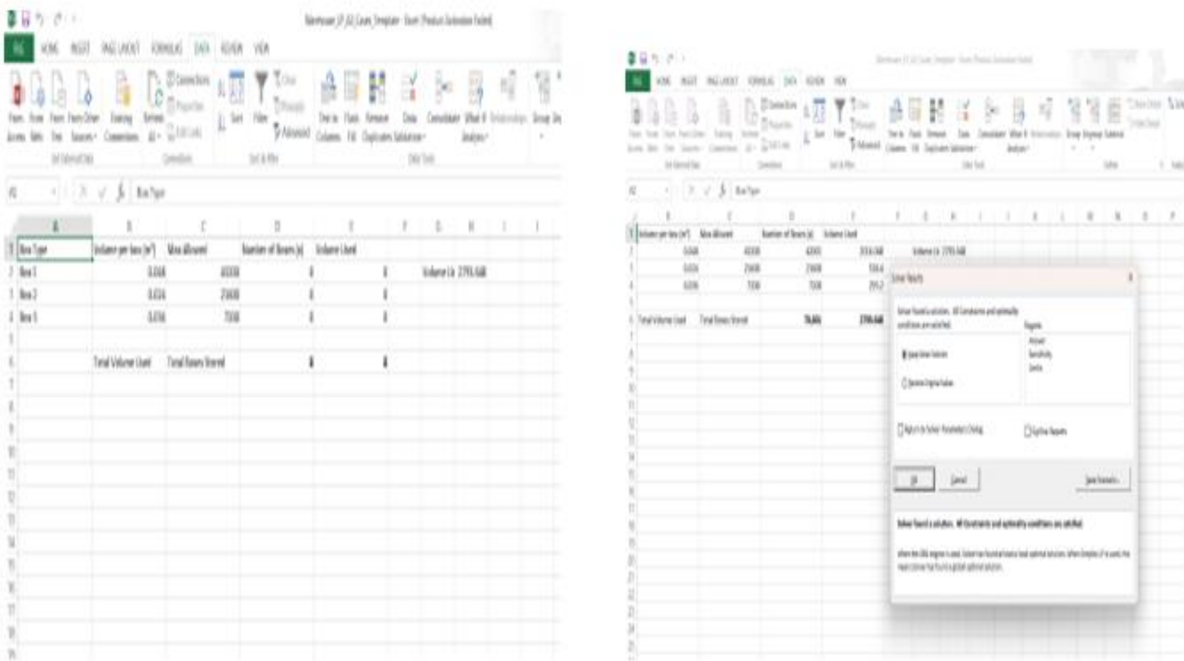

Fig 2: Represents the case 2 scenario.

In Case 3, the constraints are defined by the monthly demand for products from July to October and the total number of items packed in each box. The distribution of boxes is based on warehouse standards set by the supplier's department.

The product distribution percentages are as follows: Box A accounts for 55–60% of the total demand (equivalent to 4,032,000 items), Box B covers 20–30% (1,152,000 items), and Box C represents 10–25% (288,000 items). Based on these percentages, the ideal number of boxes required to fulfill customer’s demand over the 4-month peak season is calculated.

The results indicate that 91,660 units of the Box A, 57,600 of Box B, and 19,200 of Box C should be stored in the warehouse. To address weekly supply needs, the recommended quantities are 5,729 of Box A, 3,600 of Box B, & 1,200 of Box C.

This totals 10,529 boxes/week, ensuring consistent inventory availability to meet customer orders efficiently during high-demand periods. This case helps plan warehouse space and stock levels in alignment with seasonal demand variations.

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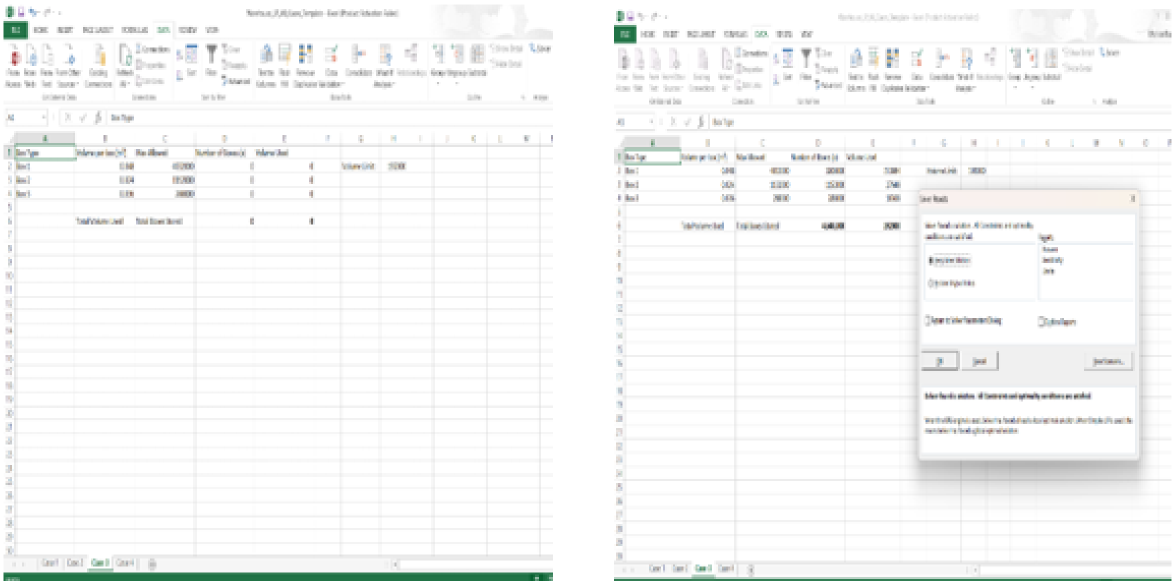

Fig 3: Represents the case 3 scenario.

Case 4 aims to identify the most efficient no. of boxes that should be preserved in the warehouse based upon demand on a monthly basis and the capacity of each box. Similar to Case 3, this case highlights how weekly customer demand affects warehouse storage decisions. Box allocations are distributed according to product proportions: Box 1 should accommodate 55–60% of the total products, or 288,000 units; Box 2 should store 20–30%, or 90,000 units; and Box 3 should hold 10–25%, or 24,000 units. Under these guidelines, the optimal weekly storage figures are 5,343 boxes of type 1, 4,500 of type 2, and 1,600 of type 3, totaling 11,443 boxes to fulfill customer needs each week.

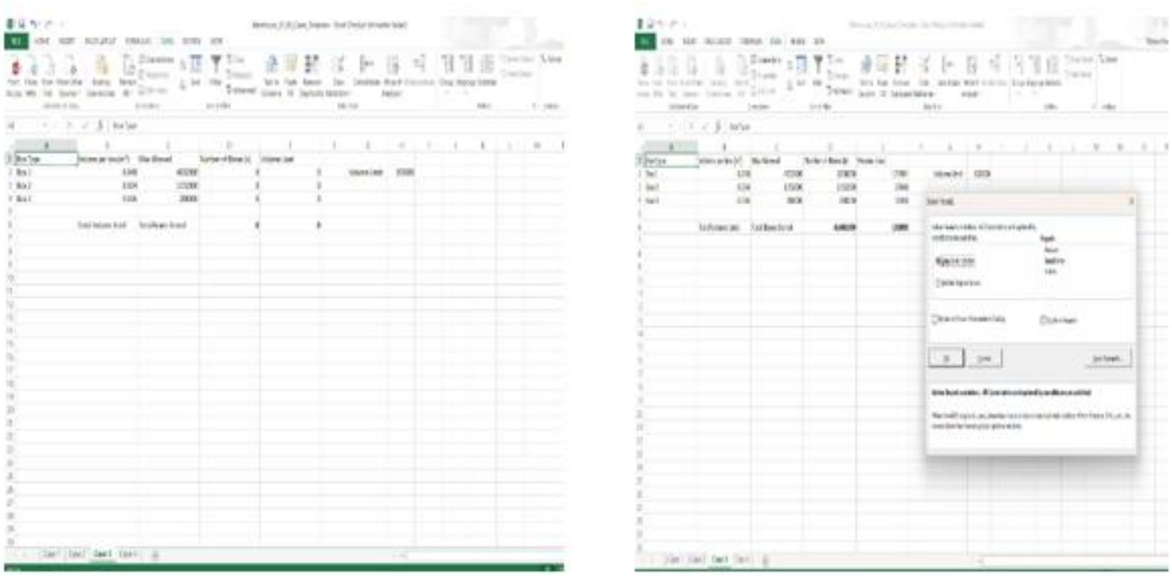

Fig 4: Represents the case 4 scenario

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When analyzing all four linear programming cases, Case 1 and Case 2 prioritize maximizing warehouse space by determining the no. of boxes that can be fully utilize the storage area. Conversely, the case 3 and case 4 are centered on meeting product demand by storing only the quantity required to satisfy customer orders. This comparison shows how storage planning can be customized: either for capacity optimization or for demand-based inventory control. Linear programming offers a versatile solution for warehouse management, enabling businesses to enhance productivity and adapt quickly to changing operational requirements.

5. CONCLUSION

This research was conduct to enhance the efficiency of the supplier's warehouse. A methodology/framework was developed and applied to improve LOPAN's warehouse operations, specifically by optimizing the no. of boxes that can be preserved & maximizing space for storage through strategic box placement on racks. Using the dimensions/size & dimensions/size & number of boxes, the no. of products per box, and the total rack volume, a linear equation (LE) was developed, with a constraint of 2793.648 m^3 for the rack capacity. The results from the Case 2 revealed that the warehouse could be used to its full capacity (100%) by increasing the number of boxes stored. This led to a total storage capacity of 70,802 boxes, marking a 483% increase from the initial number. Thus, the optimal storage range falls between 10,196 and 70,802 boxes.

Cases 3 and 4 focused on aligning inventory levels with customer demand. For Case 3, meeting demand from January to February requires 168,460 boxes, or approximately 42,115 boxes/month. In Case 4, fulfilling the weekly customer requirement needs 11,443 boxes. However, these quantities are subject to change due to seasonal variations and shifting customer needs. The study also identified the key cost factors as access to storage areas, order's pattern, product characteristics, frequency/repetition, & material handling. Meanwhile, storage space and product placement are seen as benefit factors. This framework can be applied to enhance storage efficiency in any organization or distribution center that manages a warehouse.

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