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A Decision-Support Model for Warehouse Space Allocation Using Linear Programming

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ABSTRACT

Modern supply chains depend heavily on efficient warehouse management since it directly affects operating expenses, space usage, and customer satisfaction. Ineffective or underutilized storage space is frequently the result of poor storage allocation, which drives up costs and delays order processing. The best use of resources cannot be ensured by traditional allocation techniques, which are either manual, or rule based. The paper suggests a Linear Programming (LP) model as a solution to this problem. LP is a popular optimization method that makes it feasible to allocate limited resources effectively while following certain guidelines, leading to the best potential outcome. The methodology created here aims to minimize handling and storage expenses overall while maintaining service-level criteria. Additionally, it guarantees that all of the warehouse's capacity is employed without any unused space. To show how the model works in practice, an example dataset is used. The findings indicate that the Linear Programming-based strategy gives managers a trustworthy decision-support tool for the efficient allocation of goods in a warehouse setting with a constrained capacity.

1. INTRODUCTION

[5.[6]] Warehousing plays a vital role in the supply chain (SC), serving as an intermediary between producers & end customers because production schedules rarely align seamlessly with fluctuating market demands, warehouses act as essential or important storage hubs that guarantees the availability of the products. [5.[8]] With the effective management, warehouses help maintain a consistent & reliable flow of goods. However, with the rise or variation in the variety of products, uncertain demand patterns, & growing expectations for faster or rapid delivery at lower costs, optimization of warehouse space has become increasingly important. Inefficient storage allocation often results in two main issues: underutilized capacity and higher operating expenses. [5.[11]] Underutilization occurs when the certain storage areas remain empty or null or misallocated despite increasing demand for specific products. Conversely, inappropriate allocation may overload in some zones, leading to higher handling effort, higher labor requirements, & increased costs. These inefficiencies slow order & negatively affects the customer's satisfaction, underscoring the importance of systematic optimization methods. To handle these challenges, this study employs LP, an optimization technique designed to solve the allocation problems under the multiple constraints. [5.[22]] Linear Programming is particularly well-suited for warehouse applications, as it accounts for restrictions such as storage limits, demand requirements, & handling costs while evaluating the most economical solution. Unlike the manual or rule-based approaches, Linear Programming ensures structured & optimal allocation results.

[5.[15]] Discussed that the Linear Programming model allocates the warehouse space among the various categories of product, each & every category defined by the constraints like **"minimum demand of products, maximum storage capacity for products, & associated handling costs"**. The objective function of the model is to optimize the total expenses while including a penalty term for the unused capacity. This penalty discourages the idle warehouse storage space, encouraging overall utilization of the warehouse. [5.[25]] By setting the penalty greater than handling costs, the model ensures that the availability of space is used as efficiently as possible. Overall, the outcomes or results highlight Linear Programming as a reliable decision-making framework. [5.[20]] Using data inspired by real-world scenarios, the model generates optimized allocation strategies that help warehouse managers optimize costs, meet demand effectively, & improve service performance.

2. LITERATURE REVIEW

Numerous studies have applied optimization methods to warehouse management:

[5.[1]] Defined that the Linear Programming can effectively enhance warehouse space utilization while minimizing storage waste, with their research emphasizing its practical application in the issues of real-world allocation scenarios. **[5.[2]]** Explained a foundational review of warehouse operations research, stressing how the mathematical programming supports storage assignment, order picking, & efficient resource use. **[5.[3]]** Concentrated on optimizing warehouse layouts & order picking, demonstrating that optimization techniques lead to notable gains in efficiency & less handling expenses. **[5.[4]]** Analyzed mixed-integer programming approaches for multi-commodity warehouse optimization, achieving better space allocation and improved handling of diverse product types. **[5.[5]]** Investigated principles of warehouse design & highlighted how optimization tools contribute to better performance and reduced logistics expenditures. **[5.[8]]** Examined different storage strategies & concluded that mathematical models, especially LP-based ones, help reduce travel distances & operational delays. **[5.[11]]** Surveyed warehouse management research and underscored mathematical programming as an essential tool for addressing storage assignment, space utilization, and capacity limits. **[5.[13]]** Addressed warehouse management and facilities planning, emphasizing the role of analytical and optimization approaches in maximizing storage efficiency and cutting material-handling costs. **[5.[15]]** Proposed a structured framework for warehouse design and operation, recognizing space allocation as a critical domain where optimization methods yield significant benefits. **[5.[17]]** Analyzed product allocation policies using mathematical models, showing that systematic optimization surpasses heuristic-based methods in improving space use. **[5.[20]]** Investigated supply chain logistics, noting that linear and integer programming models play a crucial role in optimizing storage and lowering operational expenses. **[5.[25]]** Proposed an optimization-based model for dynamic storage allocation and found that linear programming methods improved both storage capacity usage and retrieval efficiency in multi-product environments. **[5.[26]]** Emphasized in his work on warehouse management that systematic optimization approaches, including LP, are essential for dealing with growing complexity in modern warehouses. **[5.[31]]** Developed models for warehouse order batching and space allocation, concluding that mathematical optimization can enhance throughput while ensuring efficient use of limited capacity.

3. METHODOLOGY

Problem Definition

A warehouse must allocate space to multiple product groups. Each product has:

- A minimum required allocation (to ensure service levels),
- A maximum allowable allocation (due to demand or slotting restrictions),
- A handling/storage cost per pallet.

The total warehouse capacity is finite. The objective is to minimize total handling and storage costs while utilizing all available space.

Assumptions

1. Products are stored in pallets of fixed dimensions.
2. Each product has both minimum and maximum allowable allocations.
3. Pallets cannot exceed storage limits.
4. The warehouse has a fixed capacity.
5. A penalty cost is introduced for unused capacity to ensure maximum utilization.

Mathematical Model's Notation

n : Number of products

x_i : Pallets allocated to product i

c_i: Handling/storage cost per pallet for product i

d_i : Minimum allocation for product i

u_i : Maximum allocation for product i

W : total warehouse capacity

s: unused warehouse space (decision variable)

p_o : Penalty cost per pallet of unused space

Decision Variables

x_i: Pallets allocated to product i ∈ {A, B, C, D}

S = Unused space (Pallets)

Objective Function

$$Minimize\ Z = \sum_{i=1}^{4}(c_i * x_i) + p_o * s$$

Constraints

Capacity utilization: $\sum_{1=1}^{4} x_i + s = W$

Minimum requirements: $x_i \geq d_i, \forall$ i

Maximum allocation: $x_i \leq u_i, \forall$ i

Non-negativity: $x_i, s \geq 0$

Numerical Illustration

A warehouse stores four product groups with the following parameters:

Products	**Handling/storage cost per pallet for product i (c_i)**	**Minimum allocation for product i (d_i)**	**Maximum allocation for product i (u_i)**
A	12	150	400
B	9	120	350
C	7	80	300
D	5	50	500

Table 1 Handling Costs, Minimum Allocation & Maximum allocation of the Products

Total warehouse capacity: W = 1000 pallets

Penalty cost: p_o = 15

Implementation

Step 1: Allocate minimum requirements.

$\sum d_i$ = 150+120+80+50 = 400

Remaining capacity = 1000-400 = 600.

Step 2: Allocate remaining space to cheapest products first.

- Fill D to its max (add 450 pallets). Remaining = 150.
- Allocate 150 pallets to C (within its limit). Remaining = 0.

Step 3: Final allocation:

x_A= 150, x_B = 120, x_C = 230, x_D= 500, s = 0

Step 4: Compute cost:

4. RESULTS

Optimal Allocation

After solving the model with help of Excel solver, the optimal allocation is:

Product	Min Req	Max Limit	Optimal Allocation (x_i)
A	150	400	150
B	120	350	120
C	80	300	230
D	50	500	500
Total	400	1550	1000

Table 2 Optimal Allocations

Unused space s =0.

Optimal Cost

Z = 12*150 + 9*120 + 7*230 + 5*500

Z = 1800 + 1080 + 1610 + 2500 = 6990

Thus, the **minimum handling/storage cost = 6990 units**.

Sensitivity Insights

- **If capacity increases** beyond 1000:
  - ✓ First 70 pallets go to Product C (up to 300 max) at incremental cost of 7 per pallet.
  - ✓ Next 230 pallets go to Product B (at 9).
  - ✓ Remaining 250 pallets go to Product A (at 12).
- If capacity decreases below 1000, Product A (highest cost) would be reduced first, followed by B, while D and C remain prioritized as low-cost options.
- **If penalty for unused space** $p_o$drops below 5, the model would leave capacity unutilized rather than allocate to costly items.

5. CONCLUSION

This study demonstrates the effectiveness of linear programming in warehouse optimization. Using a dataset of four product groups, the LP model minimized storage costs while ensuring full warehouse utilization and adherence to service-level requirements. The approach provides a structured decision-support tool for warehouse managers, enabling them to allocate resources optimally.

Future research may incorporate demand uncertainty, dynamic reallocation, and integration with distribution networks to further enhance applicability.

Discussion

The numerical illustration highlights how LP systematically balances service-level constraints with cost efficiency. By meeting minimum allocations first, then filling with low-cost products, the model ensures full utilization at minimum cost. This contrasts with heuristic or manual allocation methods, which often result in suboptimal storage use.

The model is flexible and can be adapted to:

- Multi-warehouse systems,
- Integration with transportation costs,
- Stochastic demand settings,

Multi-period planning horizons.

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