Optimizing the arrangement of products within the best location of a warehouse, to maximize space utilization

R25-062

Project Proposal Report

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B.Sc. (Hons) Degree in Information Technology

Department of Computer Science and Software Engineering Sri Lanka Institute of Information Technology

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DECLARATION

I declare that this is my work. This proposal does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any other university or institute of higher learning. To the best of my knowledge and belief, it does not contain any previously published material written by another person except where the acknowledgment is made in the text.

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Signature of the supervisor: ________________________ Date ______________

Signature of the co-supervisor: _____________________ Date ______________

ABSTRACT

This project presents a warehouse optimization system designed to maximize space utilization through intelligent product arrangement. By applying the Best-Fit algorithm, the system dynamically allocates products to the most suitable storage locations, reducing wasted space and improving overall efficiency. The optimization process considers product dimensions, demand frequency, and warehouse constraints to ensure that items are placed in positions that balance both accessibility and storage density

The solution integrates 3D visualization tools to provide a graphical representation of space utilization within the warehouse. This allows managers to monitor how products are distributed across shelves and to identify underutilized or congested areas in real time. Visualization not only enhances decision-making but also improves operational planning by clearly illustrating the impact of optimized arrangement strategies.

Developed using Python with optimization libraries and 3D rendering frameworks, the system is scalable, cost-effective, and adaptable to various warehouse types. By employing algorithmic optimization instead of manual arrangement, the system minimizes human error, increases operational throughput, and ensures effective use of limited warehouse space.

Keywords: Warehouse optimization, Best-Fit algorithm, Space utilization, 3D visualization, Product arrangement, Inventory management, Python, Decision support systems, Supply chain efficiency, Storage density, Logistics optimization, Demand-based storage, Computational optimization, Warehouse simulation, Python-based modeling

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
CBM	Cubic Meter Measurement: A unit of volume used in logistics to measure product space utilization.
WMS	Warehouse Management System: Software that manages warehouse operations including storage, retrieval, and tracking.
BFA	Best-Fit Algorithm: A heuristic algorithm used to allocate products into the most suitable available space.
3D	Three-Dimensional: Graphical representation of warehouse space and product arrangements.
Flask	A lightweight Python web framework used to develop web applications and APIs.
API	Application Programming Interface: A set of protocols that enable communication between different software applications.
py3dbp	Python 3D Bin Packing: A Python library for simulating and visualizing 3D space utilization and product arrangement.
DBMS	Database Management System: Software for storing, retrieving, and managing structured data.

1. INTRODUCTION

Warehouses are the backbone of modern supply chains, acting as storage points for raw materials, finished goods, and essential inventory. As businesses continue to expand, one of the biggest challenges faced by warehouse operators is how to make the most of the limited storage space available. A poorly arranged warehouse does not only waste valuable cubic capacity but also slows down product retrieval, increases labor costs, and reduces overall operational efficiency.

In practice, many warehouses still rely on traditional storage methods such as fixed slotting or random placement of items. While these approaches are simple, they rarely achieve the best use of space and often leave unused gaps on shelves or racks. As demand grows and order fulfillment speed becomes a priority, there is a pressing need for smarter strategies that can adapt product placement to both size and demand, while maximizing cubic meter (CBM) utilization.

This project focuses on solving this issue by using the Best-Fit algorithm to optimize product arrangement within a warehouse. The algorithm dynamically allocates items to the most suitable storage positions, reducing wasted space while ensuring that goods remain accessible. To complement this, a 3D visualization component is introduced, allowing warehouse managers to clearly see how space is being used and to analyze different arrangement strategies in real time.

The system is implemented using Python along with optimization and visualization libraries, including py3dbp for 3D bin packing. By combining algorithmic precision with interactive visualization, this research aims to deliver a solution that is not only accurate in terms of storage optimization but also practical for real-world warehouse operations. Ultimately, the project highlights how computational methods can be applied to one of the most common logistical problems—making better use of warehouse space—while keeping usability and efficiency at the center of the solution.

1.1 Background

Warehousing has become one of the most critical components in today's logistics and supply chain operations. As businesses scale, the demand for storage space increases, and warehouses are often pushed to operate with limited capacity. One of the recurring challenges in this environment is the underutilization of available space due to poor product arrangement. Even when sufficient cubic capacity exists, inefficient placement of goods often leads to wasted space, higher costs, and slower operations [1].

Traditionally, warehouses have relied on simple storage strategies such as dedicated storage, where each product has a fixed slot, or random storage, where goods are placed wherever free space is available. Another widely used method is ABC classification, which organizes items based on demand frequency. While these approaches provide a level of organization, they fall short in maximizing cubic meter (CBM) utilization and rarely adapt to changing product dimensions, order patterns, or fluctuating demand [2].

To address this issue, researchers and practitioners have increasingly explored optimization techniques. The Best-Fit algorithm and its variations are commonly applied to the Bin Packing Problem (BPP), where the objective is to fit items into containers in a way that minimizes wasted space [3][4]. By applying similar logic to warehouses, products can be placed in the most suitable location to ensure higher storage density while keeping retrieval practical [5].

In recent years, the use of 3D visualization technologies has further strengthened warehouse management. Unlike traditional 2D layouts, 3D representations provide a clear picture of how racks, shelves, and products occupy space. Tools like py3dbp, a Python-based 3D bin packing library, allow warehouse managers to not only calculate utilization but also see it in real time, making it easier to identify inefficiencies and improve arrangements dynamically [6][7].

This combination of algorithmic optimization and visual feedback has the potential to transform warehouse operations. Instead of relying solely on manual planning, managers can use data-driven insights to arrange products more efficiently, cut down on wasted space, and enhance the speed of retrieval. As businesses face rising warehousing costs, limited urban storage facilities, and growing customer expectations for fast delivery, such optimization approaches are becoming increasingly vital [8].

The proposed system builds on these ideas by integrating Best-Fit placement strategies with CBM-based analysis and 3D visualization, aiming to provide a practical, scalable solution for warehouse space optimization.

1.2 Literature Survey

This chapter reviews the major research contributions related to warehouse optimization, focusing on four components: product arrangement strategies, CBM-based utilization, optimization algorithms, and 3D visualization of product placement. These areas provide the foundation for developing an integrated system that maximizes warehouse space utilization through algorithmic optimization and real-time visualization.

1.2.1 Product Arrangement Strategies

Warehouse operations have long relied on storage strategies such as dedicated storage, random storage, and class-based allocation (ABC analysis). Bartholdi and Hackman [1] explained that while these methods help in maintaining order and accessibility, they often result in underutilized capacity when product dimensions and demand fluctuate. Recent studies (e.g., Angulo & Fajardo [2]) highlight the importance of dynamic slotting and layout reconfiguration to improve retrieval speed and reduce wasted capacity[11].

1.2.2 CBM Utilization

Cubic Meter Measurement (CBM) has become a standard metric in logistics and warehousing to evaluate how effectively available space is being used. In high-density storage environments, especially in metropolitan areas where space is costly, optimizing CBM is directly linked to operational efficiency and profitability. By calculating the actual cubic volume occupied by products relative to the total storage capacity, managers can identify unused gaps and restructure product placement to increase density. Studies have shown that warehouses that actively measure and optimize CBM not only reduce storage costs but also improve order consolidation and container loading efficiency [1][3].

Despite its importance, much of the existing research has focused on picking efficiency and retrieval times, often neglecting the aspect of maximizing volumetric utilization. Traditional slotting strategies like ABC classification improve accessibility but do not guarantee optimal space usage when product shapes and sizes vary[12]. This highlights a research gap where algorithms that directly integrate CBM optimization into storage decision-making could provide a significant advantage [4]. Incorporating CBM into warehouse layout planning ensures that both space utilization and operational flow are addressed simultaneously, making it a vital dimension of modern warehouse optimization [5].

1.2.3 Optimization Algorithms

The Bin Packing Problem (BPP) is one of the most studied challenges in operations research, and it provides a direct analogy to warehouse storage allocation. The objective of BPP is to place a set of items of varying sizes into the minimum number of bins or containers without exceeding capacity. Among the different heuristic approaches to solving this NP-hard problem, the Best-Fit algorithm is widely recognized for its effectiveness. Best-Fit works by placing each item in the fullest bin or slot where it still fits, thereby reducing wasted space within each container [3][4]. Researchers such as Martello and Toth [5] have emphasized its applicability in logistics, noting that it provides a balance between solution quality and computational efficiency.

Recent advances have extended these algorithms beyond theoretical models to practical warehouse applications. Singh and Sharma [6] demonstrated that integrating bin packing algorithms with visualization tools can lead to better space utilization while maintaining accessibility for product retrieval. Such approaches not only minimize the number of racks or slots required but also allow for dynamic reallocation of products as demand and inventory levels change. This demonstrates that heuristic algorithms like Best-Fit, when combined with modern visualization and data-driven systems, are capable of bridging the gap between mathematical optimization and real-world warehouse management [1][5].

1.2.4 3D Visualization in Warehouse Management

Traditional 2D layouts provide limited insight into how space is being used. 3D visualization has emerged as a powerful tool to bridge this gap. By simulating racks, shelves, and product placement in three dimensions, managers can better understand utilization and make real-time decisions. Bortolini et al. [7] showed that virtual simulation can significantly reduce time and cost in layout design. Libraries like py3dbp [6] extend this concept to warehouses by combining optimization with 3D visualization, offering both analytical and practical benefits [14].

1.3 Research Gap

Although warehouse optimization has been widely studied, most research still focuses on retrieval efficiency and order picking, with less attention on maximizing CBM utilization [1]. Existing algorithms such as Best-Fit and other bin packing heuristics are well known in theory but are rarely applied in practical warehouse settings. Moreover, there is a lack of real-time 3D visualization tools to help managers clearly see and adjust product arrangements [6][7]. Current systems also overlook usability and accessibility, often producing solutions too complex for daily operations. This project aims to close these gaps by integrating CBM optimization, algorithmic placement, and interactive 3D visualization into a single, practical framework [5].

1.3.1 Utilization of Warehouse CBM

Most existing research in warehouse management has focused on improving retrieval speed or order picking, while overlooking the issue of cubic meter measurement (CBM) utilization. As a result, warehouses often fail to maximize their full storage capacity, leading to wasted space and higher operational costs. Few studies have directly addressed methods to optimize product arrangement for maximum CBM usage [4].

1.3.2 Limited Application of Optimization Algorithms in Practice

While optimization techniques such as the Bin Packing Problem (BPP) have been studied extensively in operations research [3][4], their practical use in warehouses remains restricted. The Best-Fit Algorithm, one of the most common heuristics for BPP, works by placing each item into the most filled location where it still fits, thereby minimizing leftover space in storage slots or containers. This approach is efficient in theory and has been shown to reduce wasted space compared to simpler strategies such as First-Fit or Random-Fit.

However, in real warehouse environments, direct application of Best-Fit is often constrained by practical considerations. Many studies that use Best-Fit and similar algorithms focus purely on mathematical optimization, aiming to maximize utilization without accounting for operational accessibility [4]. For example, while the algorithm may pack products tightly to minimize empty space, it might also create layouts that make retrieval more time-consuming for staff. This lack of balance between space efficiency and usability has limited its adoption in industry practice [5].

Furthermore, current research often applies Best-Fit to controlled or simulated datasets rather than dynamic warehouse conditions, where product sizes, demand patterns, and inventory levels frequently change. As a result, although Best-Fit demonstrates strong potential for CBM optimization, its integration into flexible, real-time warehouse management systems remains underexplored [5]. This gap highlights the need for solutions that not only optimize space through algorithms like Best-Fit but also maintain practicality and adaptability for day-to-day warehouse operations.

1.3.3 Lack of Real-Time Visualization Tools

Although layout optimization techniques exist, most of them remain theoretical or limited to 2D representations [7]. There is a clear lack of real-time 3D visualization tools that allow managers to see how products occupy warehouse space dynamically. Without visualization, inefficiencies go unnoticed, and decision-making becomes less effective.

1.3.4 Usability and Accessibility Issues in Warehouse Systems

Most optimization systems are developed for academic or computational purposes and often lack a user-friendly interface for warehouse managers. While they achieve strong results in simulations, these models are usually too technical for daily use and may require specialized knowledge to operate [1]. This gap between research and practice has limited adoption, as managers struggle to interpret complex outputs. Studies show that even advanced slotting and bin packing systems are rarely applied in real warehouses because they do not provide intuitive visualization or decision-support tools [2]. To make such solutions practical, optimization must be combined with accessible features such as 3D visualization and simplified dashboards, ensuring that results are both effective and easy to apply [3].

1.4 Research Problem

Warehouses are critical components of global logistics and supply chains, responsible for storing vast quantities of goods in increasingly limited spaces. Despite their importance, many warehouses still suffer from inefficient space utilization, where large portions of cubic meter (CBM) capacity remain unused due to poor product placement strategies [1]. Traditional approaches such as dedicated storage, random storage, and ABC classification improve organization and accessibility but rarely achieve maximum space utilization, particularly when products vary in size, shape, and demand frequency [12]. As a result, warehouse operations face higher costs, slower retrieval times, and logistical bottlenecks.

In operations research, problems such as the Bin Packing Problem (BPP) have been studied extensively, and algorithms like Best-Fit are well-known for minimizing wasted space [3][4]. However, these solutions are often applied only in controlled simulations and do not fully account for the practical constraints of real warehouses, such as accessibility, dynamic product inflows, and changing demand patterns [5]. This disconnect between mathematical optimization and operational usability has limited the adoption of such algorithms in real-world practice.

Another major gap lies in the lack of real-time visualization tools. Current optimization systems often generate abstract or complex outputs that are difficult for warehouse managers to interpret and implement. Research shows that 3D visualization and virtual simulation can significantly enhance decision-making by providing clear insights into space utilization and product arrangements [6][7]. Yet, such visualization is rarely integrated with optimization algorithms, leaving managers without practical tools to bridge the gap between analysis and implementation [14].

Therefore, while research on warehouse management has advanced in areas such as order picking, automation, and slotting, there remains no unified solution that integrates CBM optimization, algorithmic placement (Best-Fit), and interactive 3D visualization into a single framework. This project seeks to fill that gap by developing a practical, scalable, and user-friendly system that not only improves space utilization but also enhances accessibility and decision-making for warehouse managers.

As global supply chains continue to grow in complexity, the need for efficient and adaptable warehouse systems has become more urgent. Rising storage costs, rapid fluctuations in demand, and increasing customer expectations for faster delivery place additional pressure on warehouse operations [8]. Without optimized product arrangement, companies face higher logistics expenses and reduced competitiveness. By integrating Best-Fit algorithms, CBM-driven analysis, and 3D visualization, this research aims to deliver a practical solution that addresses both theoretical gaps and real-world challenges, contributing to the development of smarter, more sustainable warehouses.

2. OBJECTIVES

2.1 Main Objective

To develop and implement a comprehensive, real-time warehouse space optimization system that integrates Best-Fit algorithms, CBM-based analysis, and 3D visualization. The goal is to create a practical, scalable solution for maximizing space utilization and improving warehouse layout efficiency through data-driven insights and dynamic visual feedback.

2.2 Specific Objectives

1. **To develop a warehouse space optimization algorithm utilizing the Best-Fit**

   The objective is to leverage Best-Fit algorithms to dynamically allocate products into the most suitable storage locations based on product size, demand frequency, and available space. The algorithm will minimize wasted cubic meter (CBM) space while ensuring accessibility for retrieval operations. The system will be tested against traditional storage strategies to highlight improvements in space efficiency [1].

2. **To implement 3D visualization of warehouse layout and space utilization**

   This objective focuses on creating a 3D visualization system to provide a dynamic, interactive view of product placement within the warehouse. The tool will integrate with the Best-Fit algorithm to offer warehouse managers real-time insights into how products are distributed across available space. The 3D output will allow for the identification of underutilized areas and enable immediate adjustments to the layout [2][3].

3. **To integrate CBM-based analysis for optimized product arrangement**

   The third objective is to incorporate Cubic Meter Measurement (CBM) into the layout optimization process, ensuring that the product arrangement not only maximizes space but also follows a data-driven methodology. By evaluating the volume of products and the available storage space, the system will reduce unused CBM and improve storage density while ensuring practical retrieval [4][5].

4. **To assess the impact of real-time product reallocation on warehouse efficiency**

   This objective will analyze the effects of real-time product reallocation based on changing inventory levels, demand, and product movement patterns. The system will incorporate machine learning models to predict optimal product placement at any given time, ensuring that the layout remains flexible and adaptable to dynamic warehouse conditions [6].

5. **To combine all modules into a deployable, real-time warehouse space optimization system**

   The final objective is to integrate all components (Best-Fit algorithm, 3D visualization, CBM analysis) into a unified, real-time warehouse optimization system. This solution will run on standard computing hardware, using existing warehouse management systems (WMS) and CCTV infrastructure. The system will provide interactive dashboards and predictive overlays, giving warehouse managers visual alerts for potential inefficiencies and suggesting dynamic adjustments [13].

3. METHODOLOGY

This research adopts a design and implementation-based methodology to develop a real-time warehouse space optimization system integrating Best-Fit algorithms, CBM-based analysis, and 3D visualization. The design phase begins with an analysis of warehouse storage inefficiencies, particularly underutilized cubic meter (CBM) space caused by poor product arrangement [1][2]. Based on this analysis, the system architecture is designed to include a Best-Fit module for dynamic product allocation, a CBM analysis module to compute occupied and unused storage volumes, and a 3D visualization module for interactive, real-time display of product placement [3][4]. Publicly available warehouse datasets and simulated layouts will be used to test and validate the algorithm, ensuring that the proposed approach can accommodate different product sizes, demand patterns, and warehouse configurations [5].

The implementation phase involves programming the Best-Fit heuristic to assign products to the most appropriate storage locations, minimizing wasted space while maintaining practical accessibility [5]. The 3D visualization module, developed using Python libraries such as py3dbp and Matplotlib, will provide interactive dashboards to monitor space utilization, identify inefficiencies, and adjust layouts dynamically [6][7]. All modules will be integrated into a single deployable system that can operate in real-time with existing warehouse management systems (WMS) and data inputs from inventory monitoring. The system's performance will be evaluated based on space utilization efficiency, retrieval time improvements, and adaptability to dynamic inventory changes, ensuring that it provides a practical and scalable solution for modern warehouse operations [8][14].

3.1. System overview

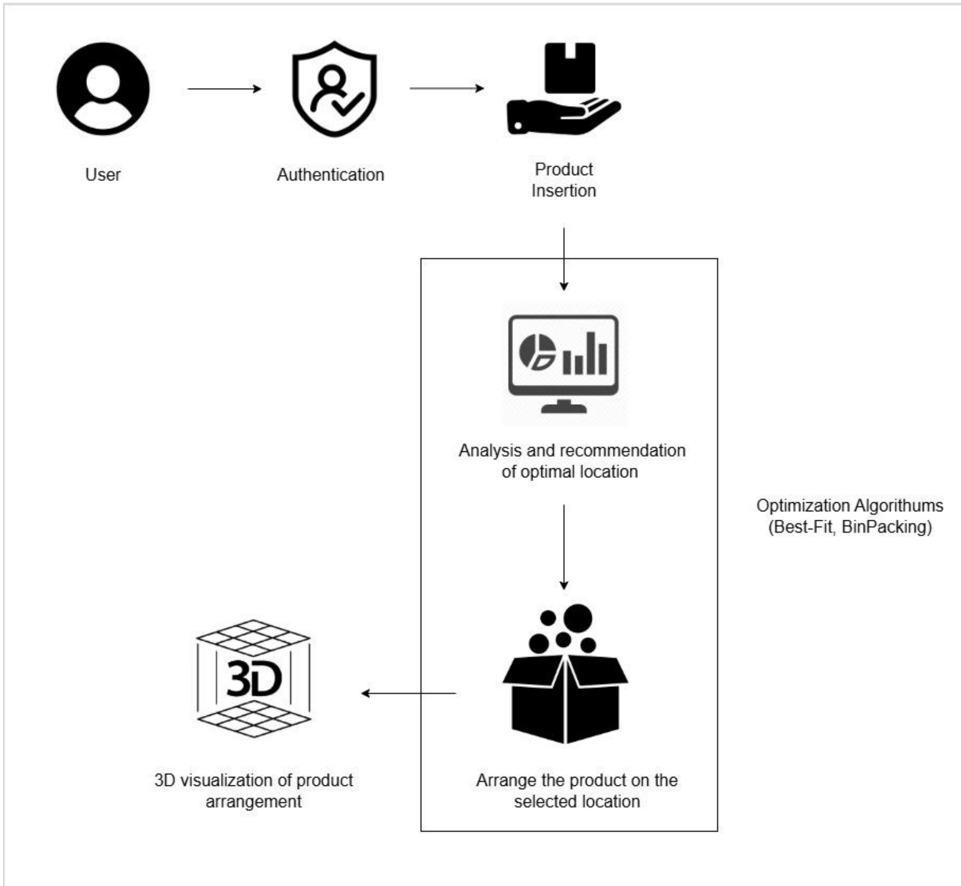

Figure 1 System Overview Diagram

The system architecture diagram illustrates the complete workflow of the proposed warehouse space optimization system. The process begins with the user logging into the system through a secure authentication interface. Upon successful login, the user accesses the dashboard, which acts as the central control panel for interacting with warehouse space optimization functionalities. From the dashboard, the user can select a product for storage or retrieval, triggering the system to analyze the product's characteristics, including dimensions, weight, and demand frequency [9].

Once a product is selected, the system consults the warehouse database to evaluate current storage conditions and recommends the best storage location based on available slots, accessibility, and current CBM utilization [1][2]. The system then retrieves the CBM of both the suggested shelf and the product, allowing the Best-Fit algorithm to calculate the most efficient placement while minimizing wasted space. Following this, the 3D visualization module generates an interactive representation of the warehouse, displaying the product in its recommended location alongside other stored items. Managers can view the layout from multiple perspectives, assess space utilization, and simulate alternative arrangements dynamically.

The outputs of these modules are integrated into a central decision engine, which synthesizes CBM efficiency, Best-Fit placement, and 3D visualization data to provide actionable insights on the dashboard. The system continuously updates in real-time as new products are added or inventory levels change, ensuring optimal space utilization while maintaining accessibility for warehouse operations [3][4]. This approach allows managers to make informed decisions quickly, enhances operational efficiency, and bridges the gap between algorithmic optimization and practical warehouse management [5][6].

4. REQUIREMENT

4.1 Functional Requirements

- **User Authentication:** The system shall allow warehouse managers to securely log in and access the optimization dashboard.
- **Product Selection and Data Input :** Users shall be able to select products and enter dimensions, weight, and demand frequency, or upload this data in bulk.
- **Best-Fit Optimization Module :** The system shall allocate products to storage locations using the Best-Fit algorithm, ensuring maximum CBM utilization and accessibility.
- **CBM Calculation :** The system shall calculate the volume occupied by products and shelves, highlighting unused space and suggesting better allocation.
- **3D Visualization Module :** The system shall generate interactive 3D visualizations of warehouse layouts, showing product placement and storage efficiency in real time.
- **Dynamic Reallocation :** The system shall suggest alternative product placements if inventory changes or demand patterns shift, maintaining optimal space utilization.
- **Dashboard Interaction :** The system shall provide a real-time dashboard displaying optimized layouts, CBM usage, and 3D visualizations for decision-making.
- **Reporting and Analytics :** The system shall generate reports summarizing space utilization, high-density areas, and suggestions for layout improvement.

4.2 User Requirements

- Users should be able to securely log in and access the warehouse optimization system.
- Users should be able to view 3D layouts and suggested storage locations for selected products.
- Users should receive real-time recommendations on product placement and CBM utilization.
- The system should provide actionable insights in a simple, intuitive manner so that warehouse managers can make informed decisions.
- The dashboard should be easy to use in standard web browsers on desktops or laptops without additional software installation.

4.3 System Requirements

4.3.1 Hardware Requirements

- Standard PC or server capable of running Python-based optimization scripts.
- Optional GPU support if large-scale warehouse datasets require faster computation.
- Display device or monitor capable of rendering 3D visualization clearly.

4.3.2 Software Requirements

- **Operating System:** Windows or Linux.
- **Programming Language:** Python (for Best-Fit algorithm, CBM calculations, and 3D visualization).
- **Libraries/Frameworks:** py3dbp, Matplotlib/Plotly, Pandas, NumPy.
- **Web Framework:** Flask or Streamlit for dashboard development.
- **Database:** SQLite or any relational database for storing warehouse inventory and layout data.
- **Web browser:** Standard browser for accessing the dashboard.

4.4 Non-Functional Requirements

- Performance
- Scalability
- Security
- Usability
- Reliability
- Maintainability

4.5 Gantt chart

Figure 2 Gantt Chart

4.6 Work Breakdown structure

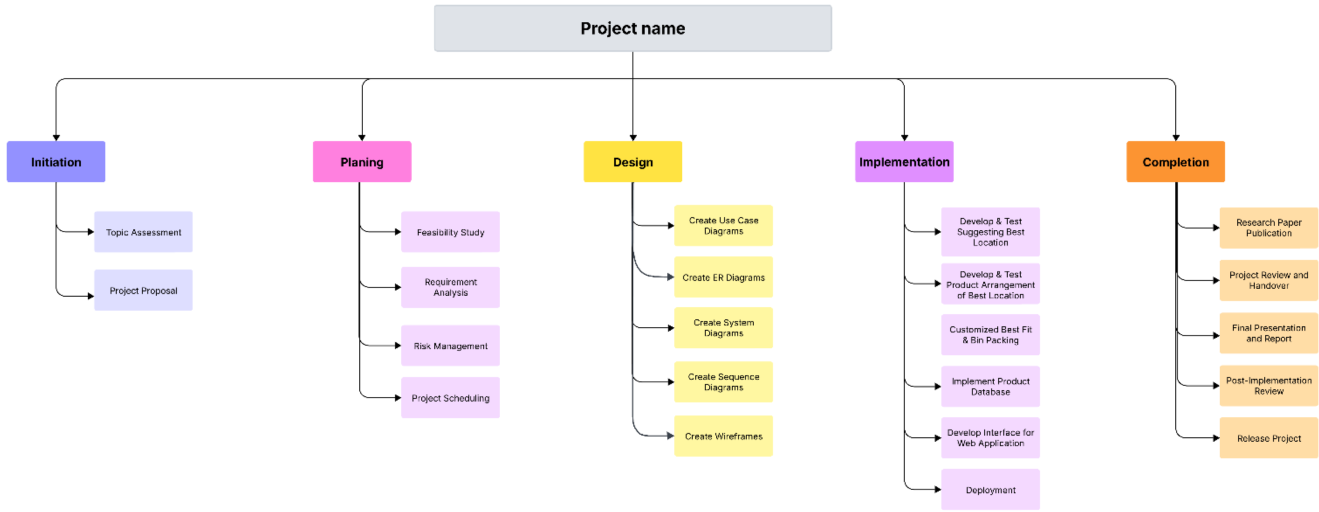

Figure 3 Work Breakdown Structure

5. BUDGET AND BUDGET JUSTIFICATIONS

5.1 Budget

Budget Topic	Description	Estimated Cost (LKR)	Notes
1. Basic Software Development	Backend and frontend development for Best-Fit algorithm, CBM calculations, and dashboard integration.	25,000	Focus on core features for optimization and visualization.
2. Hardware Infrastructure	Use of existing PCs or servers, optional GPU for large-scale optimization and 3D rendering.	120,000	Leverage existing warehouse hardware where possible, upgrades only if needed.
3. Open-Source Tools	Use open-source software to avoid licensing costs.	15,000	Covers small costs for premium libraries or cloud compute credits.
4. Data Management & Security	Database setup, inventory data storage, secure login and access control.	20,000	Ensure protection of warehouse data and secure access.
5. Testing & Evaluation	Simulated warehouse testing, small-scale real data trials, user feedback, and dashboard refinements.	35,000	Iterative testing for accuracy of placement, CBM utilization, and 3D visualization.

Table 1 Budget Table

5.2 Budget Justification

The proposed budget is designed to support a real-time warehouse space optimization system using Best-Fit algorithms, CBM analysis, and 3D visualization. Each item ensures the system can perform core optimization tasks and provide actionable 3D layout insights while keeping costs efficient.

1. **Basic Software Development (LKR 25,000)**

   This budget supports development of the Best-Fit optimization module, CBM calculations, and 3D visualization dashboard using open-source Python tools. The focus will be on implementing essential functionality to ensure the system can suggest optimal product placements and generate interactive 3D outputs.

2. **Hardware Infrastructure (LKR 120,000)**

   The budget assumes using existing PCs/servers; however, optional GPU support is included for high-performance computation when handling large warehouse datasets or real-time 3D rendering. Upgrades will be minimal and only applied if necessary.

3. **Open-Source Tools (LKR 15,000)**

   Python libraries such as py3dbp, Matplotlib/Plotly, NumPy, and Pandas will be used. This allocation also covers any minor costs for additional visualization or cloud compute credits required for testing large datasets.

4. **Data Management & Security (LKR 20,000)**

   This budget item ensures that all warehouse and inventory data used by the system is securely stored and protected. The cost covers the implementation of open-source security tools to authenticate users, control access levels, and handle sensitive data such as product dimensions, CBM calculations, and layout configurations. Secure login protocols, access logs, and optional authentication services such as Firebase OAuth will be incorporated to prevent unauthorized access. The allocation prioritizes essential security measures to maintain data integrity while keeping the system operational and user-friendly.

5. **Testing & Evaluation (LKR 35,000)**

   This part of the Targeted testing will be performed on simulated and real warehouse layouts to evaluate Best-Fit placement accuracy, CBM utilization, and 3D visualization performance. Feedback will be used to refine the system for practical deployment.

5.3 Commercialization

This project has strong commercialization potential within the warehouse and logistics technology market. It targets businesses seeking **efficient space utilization**, dynamic product arrangement, and real-time 3D visualization to optimize warehouse operations.

1. **Target Market:**

The initial target customers include:

- Warehouses and distribution centers (retail, logistics, manufacturing).
- Large-scale storage facilities require efficient CBM usage.
- E-commerce fulfillment centers seeking faster order processing and optimized layouts.
- Companies with constrained urban warehouse space seeking higher storage density.
- Enterprises with existing WMS or inventory management systems that can integrate with the proposed system.

2. **Unique Selling Points (USPs):**

- **Algorithm-Driven Optimization:** Uses Best-Fit algorithm for optimal space utilization.
- **Real-Time 3D Visualization:** Interactive layout visualization for practical decision-making.
- **CBM-Based Placement:** Ensures maximum cubic meter utilization for every storage location.
- **Cost-Effective & Open-Source:** Minimal reliance on proprietary software; uses widely available libraries.
- **Practical Deployment:** Can integrate with existing warehouse management systems without downtime.

3. **Market Entry Strategy:**

    - **Pilot Programs**: Offer discounted or trial access to selected warehouses for testing and testimonials.
    - **Partnerships**: Collaborate with WMS providers, warehouse automation firms, and logistics consultants.
    - **Online Marketing**: Showcase 3D visualization features, case studies, and ROI benefits on a professional website.
    - **Industry Events**: Demonstrate at logistics, supply chain, and warehouse technology conferences.

4. **Scalability and Expansion:**

    - **Cross-Domain Applications:** Can be adapted for cold storage, container loading, or manufacturing storage systems.
    - **Customizable Dashboards:** Support multiple languages and layout types.
    - **Cloud and Edge Deployment:** Offer cloud-based or on-premises solutions depending on client needs.
    - **Mobile Integration:** Real-time visualization and layout recommendations accessible via tablets or smartphones for warehouse staff.

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