Industry 4.0 Warehouse Management System

R25-062

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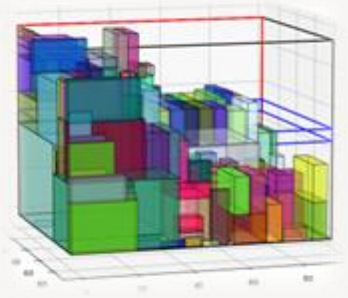
Abstract

The goal of this research is to develop an Industry 4.0-driven Warehouse Management System (WMS) designed to optimize operations, enhance safety, and reduce costs. The system integrates container space optimization, order picking route optimization, real-time fire detection using computer vision, and alerts for abnormal stock movement, all working together to improve warehouse efficiency and safety. The project utilizes AI, computer vision, and real-time data processing to address common warehouse challenges, improving decision-making and operational performance.

Introduction

- **Overview:**
    - Warehouses are vital components of modern supply chains. Optimizing warehouse operations leads to significant cost savings, improved efficiency, and better service delivery.
    - This research focuses on applying Industry 4.0 technologies to improve warehouse management, ensuring the efficient use of space, optimized order picking, better safety measures, and real-time monitoring of stock movements.
- **Challenges Addressed:**
    - Space utilization inefficiencies
    - Time-consuming order picking processes
    - Insufficient fire detection systems
    - Lack of real-time stock movement monitoring



literature survey

- Solutions such as SAP Ex WMS, Oracle WMS exist for warehouse needs, but they lack Industry 4.0 focused features such as Stock Movement Instabilities, Fire Detection with Computer Vision, Order Picking Route Optimization & Container Space Optimization.

Research Gap

The research gap includes,

the lack of dynamic space optimization systems, inefficient order picking, the absence of AI-driven real-time fire risk assessments, and limited predictive analytics for real-time stock movement alerts, all of which hinder warehouse efficiency and safety.

Research Questions

- **Limited Fire Detection:** How can we provide real-time fire alerts near critical areas like racks, hindering rapid response ?
- **Inefficient Space Utilization:** Lack of intelligent systems for dynamically optimizing warehouse space leads to inefficiencies. How can we address that ?
- **Route Inefficiency:** How can we save time and energy by minimizing warehouse route problems ?
- **Stock Instabilities:** How to predict incidents which address sudden movements in stock, leading to undetected inventory issues ?

Main Objective

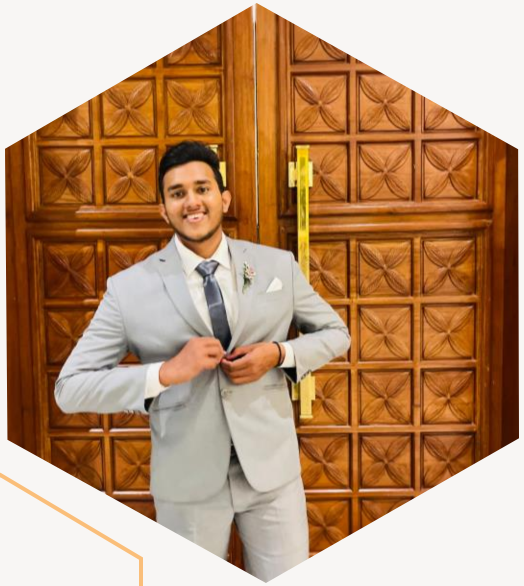
To develop an optimized warehouse management system that enhances space utilization, improves inventory turnover adaptability, streamlines year-end evaluations and mitigates risks associated with sensitive goods

Sub Objectives

- Maximize warehouse space utilization by leveraging algorithms to dynamically allocate inventory.
- Develop a real-time, optimized order picking and forklift path system that reduces time, enhances safety, and minimizes congestion.
- Implementing systems to detect fire hazards based on proximity to critical zones and trigger real-time alerts.
- Analyse and predict for abnormal stock movements, improving safety and operational efficiency.

Aspect 01

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



Introduction

Why is product arrangement optimization important?

- Efficient use of warehouse space ensures cost savings.
- Proper arrangement reduces retrieval time and operational inefficiencies.
- Aligns with the overall objective of maximizing warehouse CBM utilization.

Problems

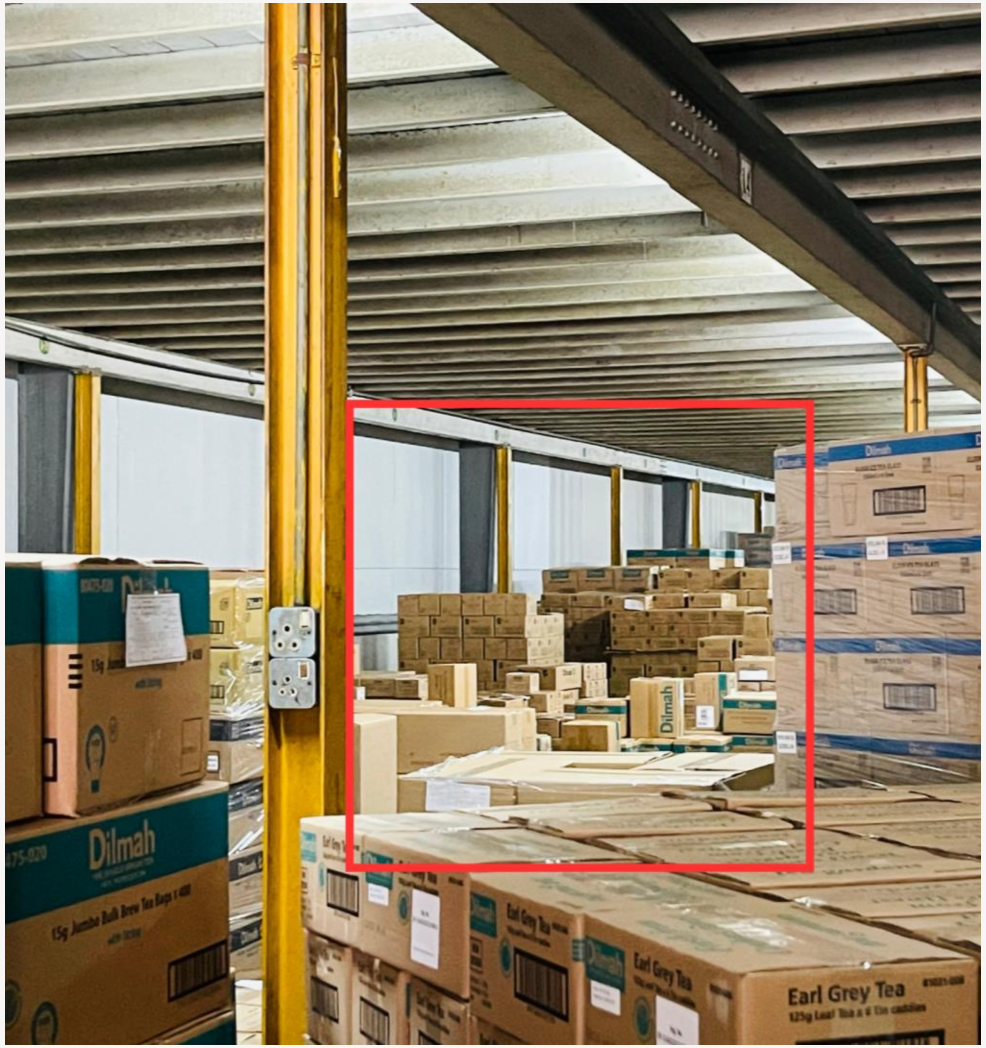
Disorganized layout, leaving gaps and unused areas leads to space wastage

Need for a systematic method to arrange products within predefined locations.

Problems

Difficulty in accommodating products while maintaining accessibility

Designed for horizontal storage, leaving significant vertical space underutilized.



Literature Review

[1] Bartholdi, J.J.; Hackman, S.T. "Warehouse and Distribution Science". 2019. Available online: https://www.warehouse-science.com/book/index.html (accessed on 30 May 2020)

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[3] Bartholdi JJ, Hackman S (2008) "Allocating space in a forward pick area of a distribution center for small parts". IIE Trans 40(11):1046–1053. https://doi.org/10.1080/07408170802167662

[4] Ammouri B. 2023. "Digital twin technologies enable facility efficiency. Plant Engineering" 77(l) DOI 10.1016/j.jmsy.2019.10.001.

Research Gap

	Research A [1]	Research B [2]	Research C [3]	Research D [4]	Proposed Solution
Product Arrangement in Location to Maximize CBM Utilization	✗	✗	✗	✗	✓
Real-Time Visualization of Product Arrangement (2D/3D)	✗	✗	✗	✓	✓
Machine Learning and Algorithms for Product Arrangement	✓	✓	✗	✗	✓
Usability and Accessibility in Storing Products	✓	✗	✓	✗	✓

Novelty

Optimizing product arrangements within the best warehouse location, this research leverages CBM-specific strategies, real-time 2D visualization.

Container space optimization: - Leveraging maximum space available within a rack without wasting any space. Drawing the optimized space with allocated objects.

Objectives

Main Objective

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

Sub Objectives

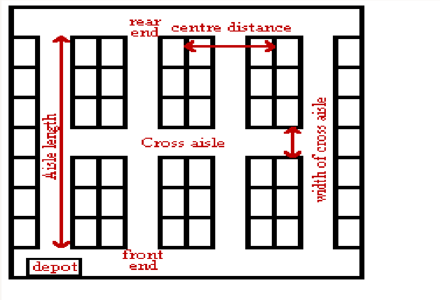
- Create predictive models based on CBM-specific data to optimize product storage arrangements dynamically
- Provide real-time 2D visual representations of optimized product arrangements
- Enhance Usability and Accessibility

Methodology

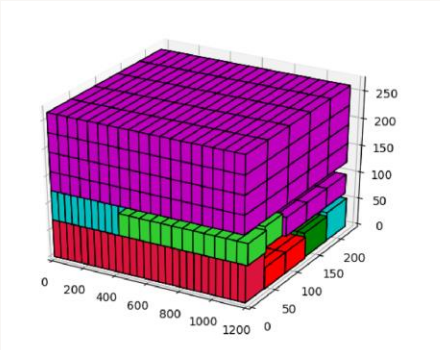
Product information
with CBM

Data Analyzation

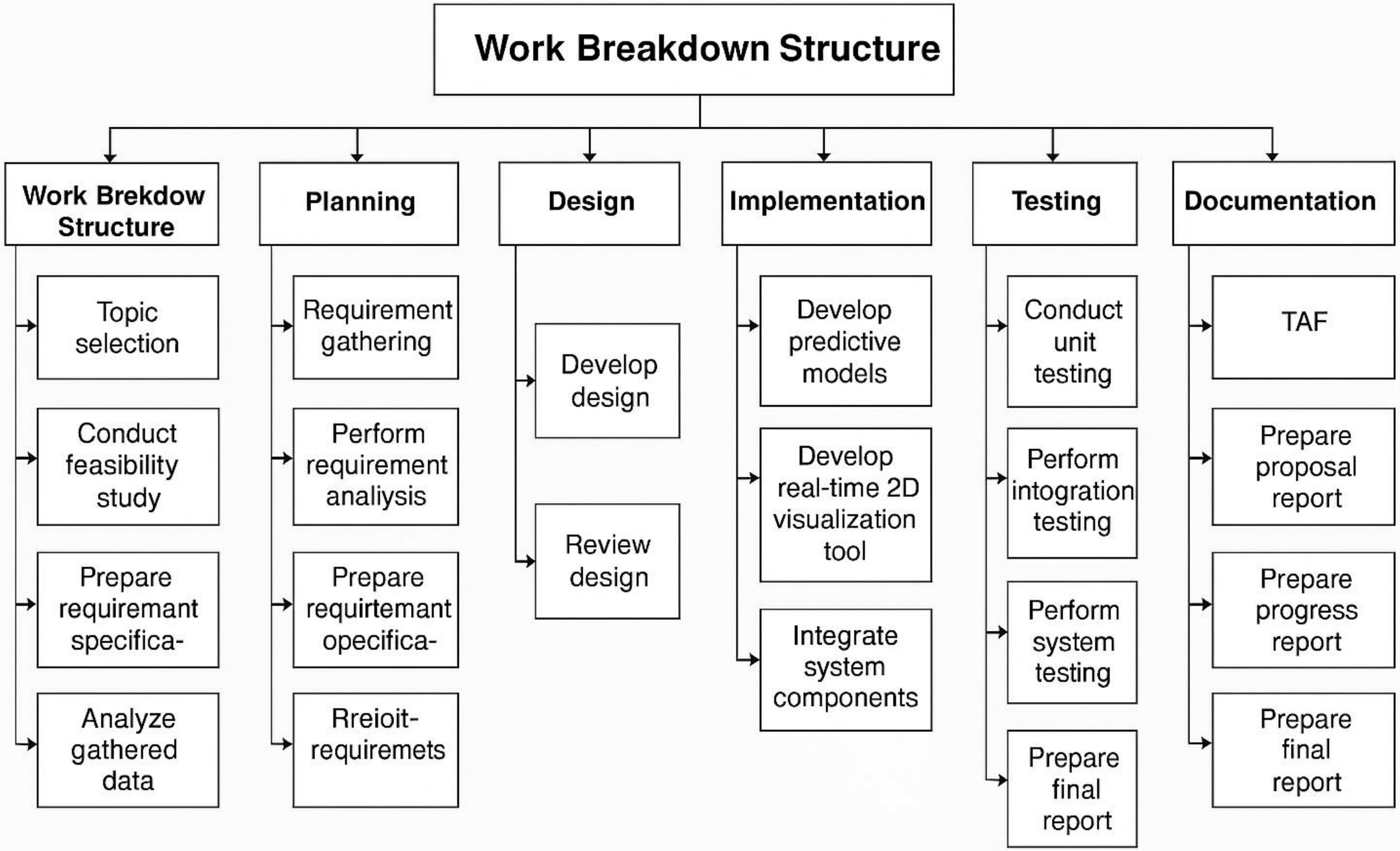
Selecting the best location of the
warehouse to store the product



Creating the Arrangement
in selected location



Output with Selected location
and Arrangement visualization


Work Breakdown Structure
Work Brekdow Structure
Topic selection
Conduct feasibility study
Prepare requiremant specifica-
Analyze gathered data
Planning
Requirement gathering
Perform requirement analiysis
Prepare requirtemant opecifica-
Rreioit- requiremets
Design
Develop design
Review design
Implementation
Develop predictive models
Develop real-time 2D visualization tool
Integrate system components
Testing
Conduct unit testing
Perform intogration testing
Perform system testing
Prepare final report
Documentation
TAF
Prepare proposal report
Prepare progress report
Prepare final report

Technologies

Aspect 02

Order picking route optimization

Introduction

- When a Warehouse user has multiple items to get when fulfilling an order, it can be a time-consuming process, with efficient routes, we can reduce time and energy wasted by the worker.
- This main goal is to implement a pathfinding algorithm used to find the most efficient route for picking orders in a warehouse, considering time, effectiveness, flagged obstacles and other workers and vehicles operating on-site.

Research Problem

- How can we optimize worker productivity and efficiency by mapping the path the user needs to take on the Warehouse

Objectives

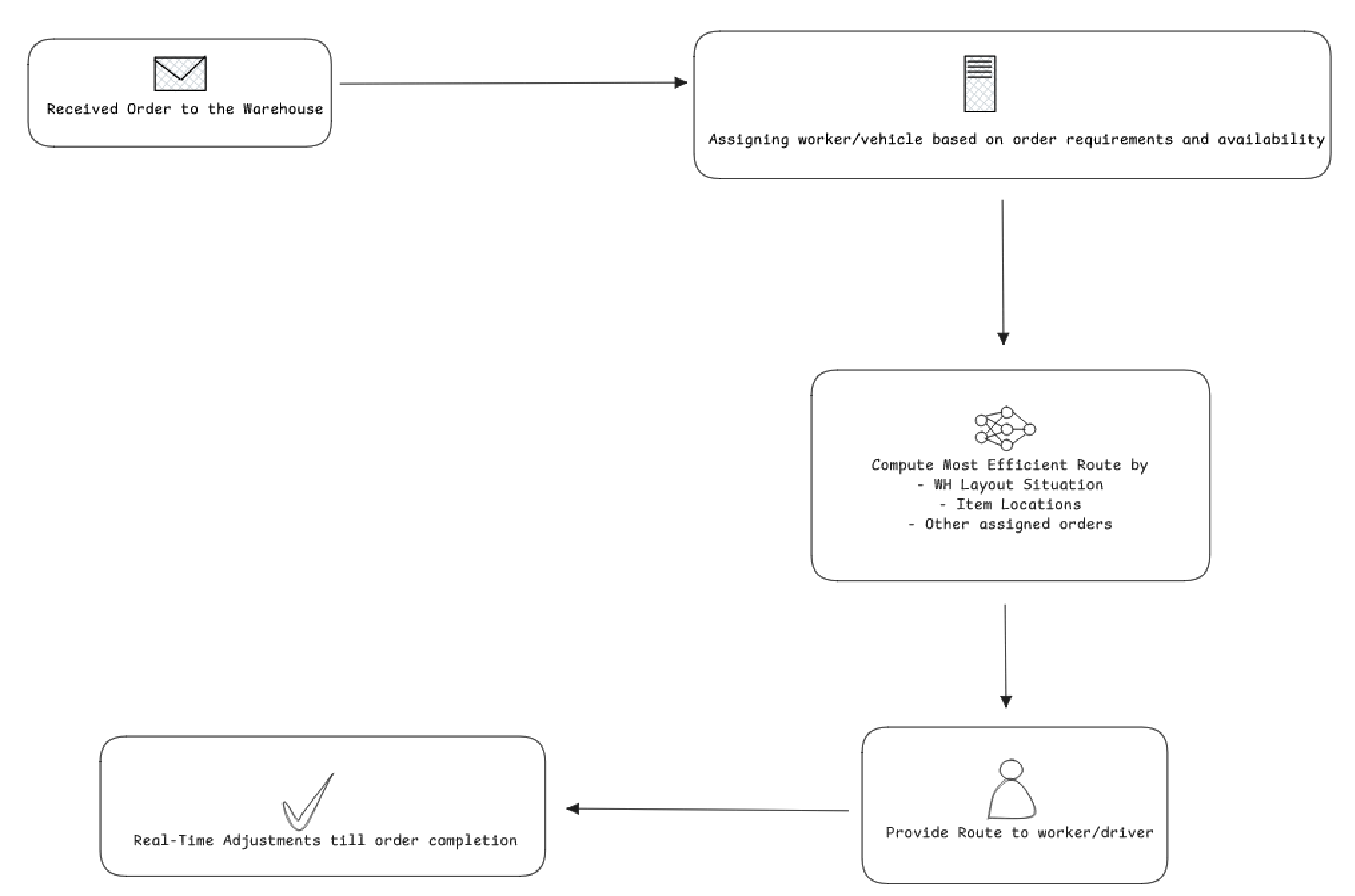
Main Objective

- Develop an efficient and real-time route optimization system for warehouse order pickers and forklifts, using an Algorithm and GPS tracking, to reduce time, avoid collisions, and improve operational efficiency.

Sub Objectives

- Implement the Algorithm which will compute the shortest most efficient path for the user.
- Using tracking tech to record the positions of workers and forklifts in real time, adjusting paths dynamically as needed.
- Map the routes of the warehouse, to the warehouse layout.

Methodology



Technologies

Next.Js

AWS Lambda

Flask

Google OR

Python

PostgreSQL

Research Gap

- **Path Mapping**
  - Mapping the path to fulfill the order, is a function that is not available in the existing system
- **Dynamic Path Adjustment:**
  - Current systems do not dynamically adjust to real-time changes in the warehouse environment, such as congestion or maintenance zones.
- **Collision Avoidance:**
  - There is limited research on real-time collision avoidance between order pickers and forklifts in large warehouse environments.
- **Integration of GPS and Pathfinding:**
  - Few systems integrate **real-time GPS tracking** with **optimized pathfinding algorithms** like Dijkstra's to provide a seamless, real-time solution.

Novelty

Novelty of this system lies in its dynamic, real-time optimization of warehouse navigation. Key novel aspects include:

- Custom Path Finding Algorithm
- Real-Time Path Adjustments
- Collision Avoidance
- Maintenance Zone Integration

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- Li, X., et al. (2023). "Optimized Pathfinding in Smart Warehouses." *International Journal of Logistics Management*.
- Y. Zhang, L. Zhang, and W. Li, "Real-time Dynamic Path Planning in Automated Warehouses," *Journal of Warehouse Technology*, 2021.
- "GPS Tracking in Warehouse Management: Real-time Positioning and Path Optimization," *Journal of Supply Chain Management*, 2022.

Aspect 03

Vision-Based Fire Detection and Prevention System for Warehouse Safety Using Real-Time Camera Surveillance

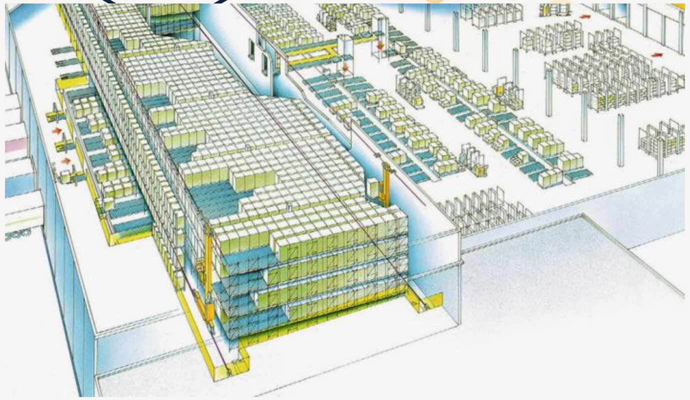
Tharana P A S - IT21822094

Introduction

This project focuses on improving warehouse safety by detecting fires using surveillance cameras and AI. It helps identify fires early, analyze risk areas, and guide quick responses to reduce damage and save lives.

Research Problem

- Most fire detection systems are **slow and reactive**—they only respond after the fire has started growing.
- They **don't show where the fire is** or how close it is to important assets like shelves.
- They **don't estimate fire size**, which is critical for response planning.
- They **cannot predict fire spread**, leaving staff unaware of how fast or where it may move.
- **No current system** provides a **complete, camera-only solution** for fire detection, risk analysis, and prediction in warehouse environments.



Objectives

Main Objective

- To develop a smart, real-time fire monitoring system using AI and existing warehouse CCTV cameras, providing early alerts and fire risk analysis.

Sub Objectives

- Detect fire (flames or smoke) from video feeds
- Identify shelves or objects near the fire
- Measure the size of the fire (small, medium, large)
- Predict the direction the fire might spread
- Display all information clearly on a user dashboard.

Research Gap

Gap	Description
1. No full camera-based system	No existing solution combines fire detection, size, spread, and nearby object risk using only cameras.
2. Ignores fire surroundings	Current systems don’t analyze shelves or items near the fire.
3. No fire spread prediction	Most systems can’t predict how or where fire will move.
4. High cost of extra hardware	Many need sensors or IoT devices, which increase setup and maintenance cost.
5. Fire size not used in alerts	Fire size is rarely linked to emergency actions or warning levels.
6. Not designed for indoor use	Spread models are built for outdoor fires, not complex indoor warehouse layouts.
7. No all-in-one system	Most solutions are separate tools, not a unified platform.

Novelty

The proposed system uses only existing surveillance camera ,no extra sensors or hardware are needed. It not only detects fire but also measures fire size and identifies nearby shelf risks. By predicting fire spread, it supports safer evacuation and faster response. The system is cost-effective, easy to install, and scalable for different warehouse setups. **This makes it more effective in complex environments, warehouses. This technology is especially important in Sri Lanka, where it is not used.**

Methodology

- Use AI models like YOLO and CNN to detect fire and shelves
- Estimate fire size with image processing
- Predict spread using video sequences
- Combine all features into one real-time dashboard for monitoring

Functional and Non-Functional Requirements

Functional Requirements:

- Real-time fire and shelf detection
- Fire size classification
- Spread prediction
- Alerts and notifications
- Live dashboard with visual updates

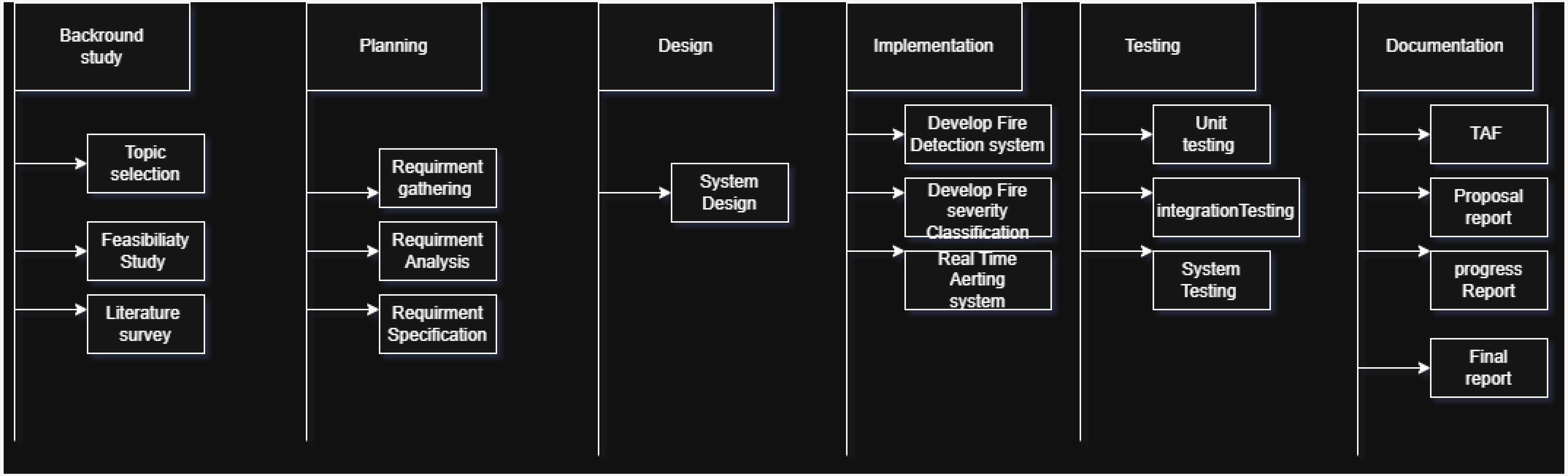
- Non-Functional Requirements:

- Fast and accurate performance
- Easy to use and understand
- Safe and secure data handling
- Works with existing warehouse setups
- Reliable and scalable system

Tools and technology

OpenCV

Work Break-Down Structure



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Aspect 04

stock movement instabilities by analyzing historical inventory data.

Introduction

- This system provides real-time alerts for sudden stock movement instabilities by analyzing historical inventory data. When a movement exceeds the normal range (based on average past behavior), the system triggers an real-time alert and visually highlights the affected rack location on a warehouse map. This allows warehouse staff to immediately investigate and resolve potential issues, enhancing both efficiency and accuracy in inventory management.

Research Problems

Threshold Determination:

•There is limited research on effectively setting statistical thresholds based on historical data to distinguish normal from abnormal stock movement.

Integration with Historical Data:

•Current inventory systems often focus on current data, leaving a gap in predictive analysis using past data to drive proactive decision-making.

Alert Accuracy:

•Without careful analysis, systems may trigger too many false alarms, How can statistical or machine learning techniques be applied to minimize false positives and negatives when triggering alerts for inventory movements

Main Objective

●To develop a predictive inventory management system that leverages historical inventory movement data to detect anomalous stock movements and give real-time alerts.

Sub Objectives

Data Aggregation and Preprocessing:

- Collect and integrate historical inventory movement records from existing WMS systems.
- Develop data cleaning and normalization processes to ensure high-quality inputs for analysis.

Baseline Modeling and Anomaly Detection:

- Establish dynamic statistical baselines (e.g., using time-series forecasting) for normal stock movements.
- Implement and optimize anomaly detection algorithms to flag movements that exceed the baseline thresholds.

Visualization and Alerting Mechanism:

- Design a user-friendly dashboard that visually maps anomalies onto warehouse rack layouts.
- Integrate automated notification systems (e.g., email, SMS) to alert managers when anomalies are detected.

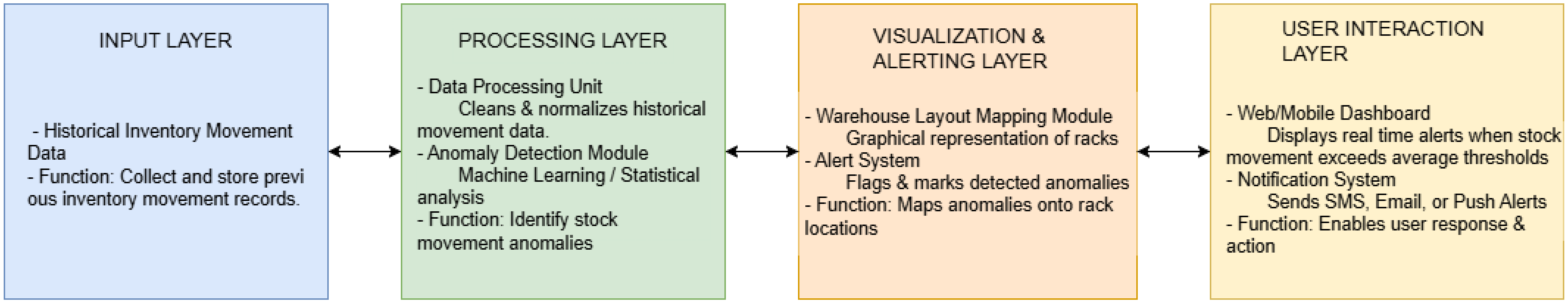
System Evaluation and Performance Optimization:

- Evaluate the system's prediction accuracy and responsiveness using defined metrics (e.g., false positive/negative rates, cost savings, and response times).

Research Gaps

- **Leverage Historical Data:** Few studies have investigated the use of historical inventory movement data for predictive anomaly detection.
- **Threshold Determination:** Limited research exists on establishing statistically sound thresholds to trigger alerts based on past data.
- **Cost-Effective Solutions:** There is an opportunity to develop systems that provide actionable insights without the cost and complexity of installing and maintaining real-time IoT sensor networks.

Methodology



Functional Requirements

- **Historical Data Collection:**
- Ability to gather historical inventory movement data from ERP/WMS systems.
- **Data Preprocessing:**
- Data cleaning, normalization, and integration processes.
- **Forecasting and Baseline Modeling:**
- Load pre-trained forecasting models for both inbound and outbound quantities and generate future forecasts based on historical trends and apply rolling averages to smooth predictions.
- **Deviation/Anomaly Detection:**
- Compare real observed data against forecasted values and flag deviations where actual dispatch or inbound quantities differ from forecasted values by more than a configurable percentage threshold.
- **Visualization and Mapping:**
- Display a digital warehouse layout with rack-level mapping of anomalies.
- Graphical representations (charts, heat maps) of historical and predicted inventory trends.
- **Alerting and Notification:**
- Automated alert system that triggers notifications (email, SMS, in-app) when anomalies are detected.
- Options for users to customize alert thresholds and frequency.

Non-Functional Requirements

- **Performance:** The system should process data and generate alerts within a predefined response time (e.g., under 5 seconds for each anomaly detection cycle).
- **Scalability:** Must handle large volumes of historical data and scale with growing data size and number of inventory nodes.
- **Reliability and Availability:** Ensure continuous system operation with high uptime (e.g., 99.9% availability).
- **Security:** Ensure data confidentiality and integrity with encryption and access controls.
- **Usability:** User-friendly dashboard with intuitive navigation and clear visualizations. And minimal training required for warehouse staff to effectively use the system.

Tools & Technologies

References

1. Fang, X., & Chen, H. C. (2022). *Using vendor management inventory system for goods inventory management in IoT manufacturing*. Enterprise Information Systems, 16(7).

2. Teerasoponpong, S., & Sopadang, A. (2022). *Decision support system for adaptive sourcing and inventory management in SMEs*. Robotics and Computer-Integrated Manufacturing.

3. Maheshwari, P., et al. (2021). *Internet of Things for Perishable Inventory Management Systems: Application and Managerial Insights for SMEs*. Annals of Operations Research, 1-29.

4. PackageX Blog. (2024). *Real-Time Inventory Management – Benefits and Challenges*.

5. Inoxoft. (2025). *7 Reasons to Invest in Real-Time Inventory System for Your Warehouse Operations*.

Budget

Hardware Costs:

- Cameras, – LKR 30,000

Hosting Costs:

- AWS s3 instance – LKR 30,000 * 12
- AWS Lambda instances – LKR 20,000 * 12

Other Expenses

- Misc – LKR 10,000

Total Estimated Budget: LKR 90,000/=

Project Requirements

Functional Requirements

1. Real-Time Monitoring: The system must enable users to monitor warehouse operations, including product arrangements and space utilization, in real time.
2. Dynamic Product Storage Optimization: Use Machine Learning models to dynamically suggest optimal product arrangements based on CBM, product turnover rates, and constraints.
3. Interactive User Interface: Develop an intuitive web-based application using React and Python Django (or Node.js with Express.js) for seamless user interaction.
4. Inventory Security Features: Provide safeguards for sensitive and high-value goods by implementing risk management measures such as access controls and alert systems.
5. Customizable Storage Strategies: Allow users to input constraints (e.g., product fragility, weight, or stacking rules) to tailor the storage optimization process.

Project Requirements

Non-Functional Requirements

1. Performance: The system should provide real-time responses for 3D visualization and storage optimization, with minimal latency.
2. Usability: The user interface must be intuitive, enabling users with varying levels of technical expertise to interact with the system effectively.
3. Scalability: The system should support increasing warehouse sizes, product volumes, and additional features without compromising performance.
4. Compatibility: Ensure compatibility across major web browsers and devices, including desktops, laptops, and tablets.
5. Reliability: The system must operate reliably under various conditions, ensuring data accuracy and uninterrupted service.

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[6] **Yang, Y., & Zhang, X. (2020).** "AI-based fire detection systems in warehouse management: A review." *Computers, Materials & Continua, 64*(2), 1071-1089

Thank you...