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AI Powered Smart Forecasting for Zero Food Waste

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Abstract

Food waste has become a serious challenge in modern retail systems due to inaccurate demand estimation and inefficient inventory planning. Conventional forecasting approaches depend heavily on past averages and manual decision-making, which often leads to overstocking, spoilage, and financial loss. This research presents a final-phase implementation of an AI-based smart forecasting system aimed at reducing food waste through accurate demand prediction and automated inventory insights.
The proposed system uses a time-series forecasting approach based on the Facebook Prophet model to analyze historical sales patterns, seasonal trends, and holiday effects. Forecasted demand is continuously compared with live stock data to identify potential waste risks such as excess inventory or near-expiry products. The system also provides automated alerts and visual dashboards to support proactive decision-making. Experimental results show that the proposed solution can reduce food waste by approximately 25–30%, while improving inventory efficiency and operational planning. This study demonstrates that AI-driven forecasting can play a vital role in achieving sustainable and waste-aware retail operations.

Introduction

In Food waste is a growing global concern that affects economic stability, environmental sustainability, and responsible resource usage. In retail environments, especially grocery stores dealing with perishable products, waste often occurs due to poor demand forecasting and delayed inventory decisions. Traditional inventory systems mainly focus on recording past transactions rather than predicting future demand, which limits their ability to prevent losses.
With recent advancements in Artificial Intelligence (AI), it has become possible to analyze complex demand patterns more accurately. AI-based forecasting models can capture seasonality, trends, and unexpected variations in customer behavior. This research focuses on the development and evaluation of an AI-powered forecasting system designed to minimize food waste by enabling retailers to anticipate demand more precisely.
The goal of this work is to design a predictive framework that assists retail managers in maintaining optimal stock levels while reducing unnecessary wastage.

Literature Review

Previous research on food waste reduction and retail demand forecasting has explored a wide range of statistical, machine learning, and artificial intelligence–based approaches. Early studies relied on traditional time-series and statistical models, which provided limited accuracy due to their inability to adapt to dynamic demand patterns, seasonal variations, and changing consumer behavior. Machine learning models such as regression and tree-based techniques improved prediction performance by capturing non-linear relationships but often required extensive feature engineering and lacked temporal awareness. More recent research has focused on deep learning models, particularly LSTM networks, which demonstrated strong forecasting capabilities but demanded large datasets and high computational resources, limiting their practical adoption. Time-series models such as Facebook Prophet have gained attention for their ability to effectively handle seasonality, trends, and missing data with minimal complexity.

However, existing studies primarily emphasize forecasting accuracy and rarely integrate real-time inventory
monitoring or automated waste-reduction mechanisms. This research addresses these limitations by combining AI- based demand forecasting with inventory analysis and alert-driven decision support to directly reduce food waste in retail environments.

Methodology

1. Proposed System Architecture

The proposed methodology focuses on developing an AI-driven forecasting framework to reduce food waste by improving demand prediction and inventory planning in retail environments. The system follows a structured, multi- stage approach that integrates data preparation, forecasting, inventory analysis, and decision support.

Data Collection: The initial step involves collecting historical sales data and inventory records for perishable products across different categories such as dairy, bakery, and fresh produce. The data is organized on a daily basis to capture short-term demand variations. In scenarios where real retail data is unavailable, simulated datasets are used to replicate realistic sales and stock behavior.

Data Preprocessing: Raw data is cleaned to remove inconsistencies, missing values, and extreme outliers that could negatively affect forecasting accuracy. Time-related features such as day, week, and seasonal indicators are generated to capture recurring demand patterns. The processed data is then transformed into a time-series format suitable for forecasting models.

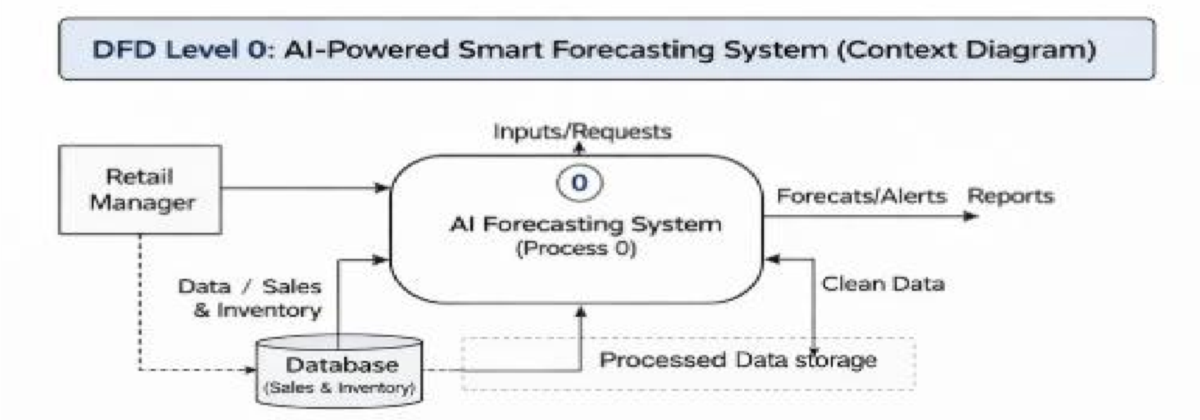
Demand Forecasting: To predict future demand, a time-series forecasting model based on Facebook Prophet is employed. This model is selected due to its capability to handle seasonal trends, holiday effects, and irregular data points. The model is trained using historical sales data and generates short-term demand forecasts, which are critical for managing perishable inventory.

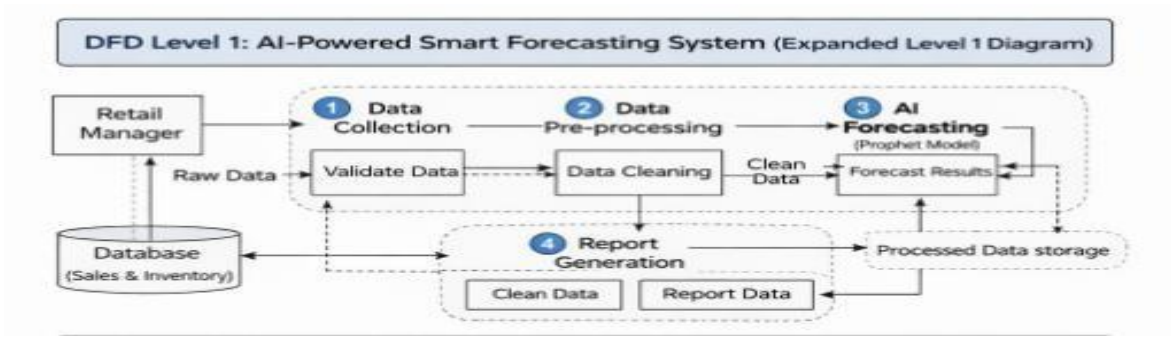
Inventory Risk Analysis: Forecasted demand is compared with current stock levels to identify potential inventory risks. Situations such as overstocking, low stock availability, and near-expiry products are detected at this stage. This comparison enables early identification of waste-prone conditions.

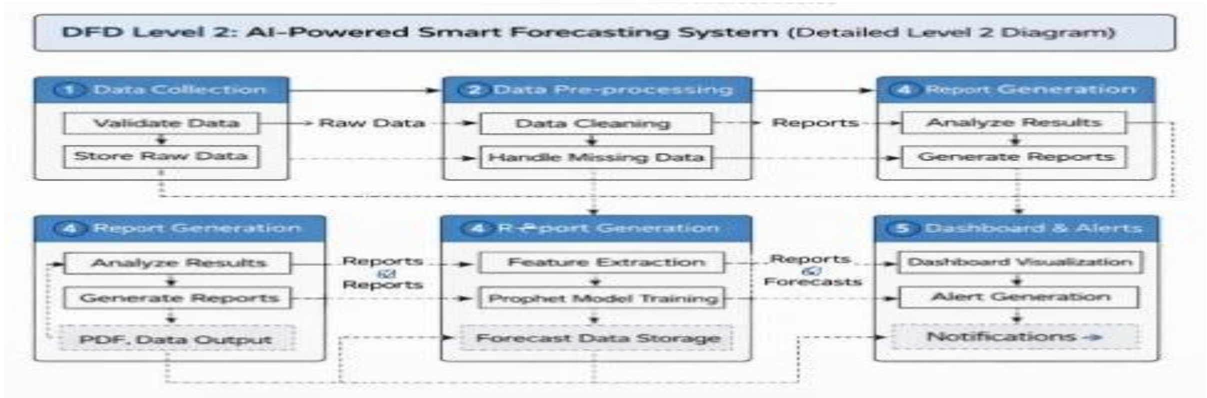
Alert Generation and Decision Support : Based on inventory risk analysis, the system generates automated alerts to notify users about critical situations. These alerts support proactive actions such as stock adjustments, promotions, or redistribution. A visual dashboard presents forecasts, trends, and alerts in an intuitive manner to assist managerial decision-making.

System Implementation: The forecasting logic and data processing are implemented using a Python-based backend framework, while a web-based interface is developed for visualization and interaction. Inventory data, forecasts, and alerts are stored in a database, and periodic reports are automatically generated to summarize system performance.

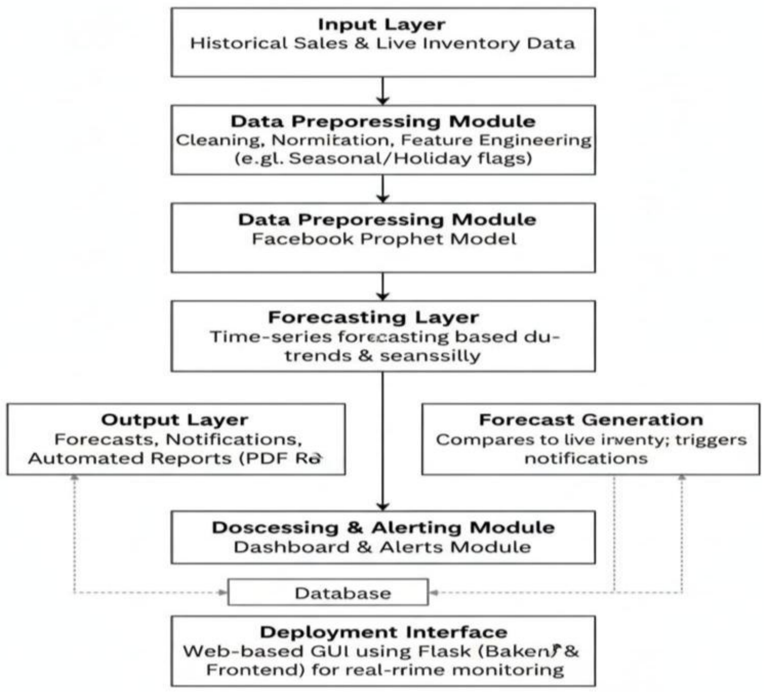
Diagram







System Architecture



The proposed system follows a layered architectural approach to achieve high performance, flexibility, and accurate forecasting for minimizing food waste. Each layer is designed to handle a specific function, ensuring smooth data flow and efficient processing across the system.

1. Input Layer (Data Collection Stage)

This layer is responsible for gathering essential data required for forecasting. Collects past sales records and current inventory details

Ensures continuous and real-time data availability Acts as the foundation for all further processing

Accurate and timely data collection at this stage is crucial for generating reliable predictions.

2. Data Preprocessing Module (Data Preparation Stage)

Raw data often contains inconsistencies, so this layer refines it before analysis. Eliminates errors, duplicates, and irrelevant entries

Handles missing or incomplete values

Applies normalization techniques for consistency

Generates useful features such as seasonal patterns or special events

This step enhances data quality, making it suitable for machine learning models.

3. Forecasting Model Layer (AI Processing Stage)

This layer forms the intelligence of the system. Uses the Prophet time-series forecasting model

Detects trends, seasonal variations, and patterns in data Produces future demand predictions based on historical behavior It enables the system to make accurate and data-driven forecasts.

4. Forecasting & Output Layer (Result Generation Stage)

After prediction, this layer converts outputs into usable information. Generates demand forecasts for upcoming periods

Compares predicted demand with current inventory levels Produces outputs such as:

Forecast summaries Alerts and notifications Automated reports

This ensures that users receive meaningful insights in an understandable format.

5. Processing & Alerting Module (Decision Support Stage)

This module helps in turning insights into actions. Displays results through interactive dashboards Sends alerts for potential overstock or shortages Supports quick decision-making for inventory control

It plays a key role in reducing waste and improving operational efficiency.

6. Data Storage Layer (Database Management)

All system data is securely stored and managed in this layer. Maintains raw, processed, and forecast data

Ensures data consistency and quick retrieval Supports real-time updates and secure access This layer acts as the backbone of the system.

7. Deployment Interface (User Interaction Layer)

This is the interface through which users interact with the system. Developed using Flask for backend and React for frontend Provides dashboards, reports, and real-time monitoring

Ensures a responsive and user-friendly experience

It allows users to easily access insights and manage operations.

Conclusion

The AI-powered smart forecasting system provides a structured and efficient approach to managing sales and inventory through intelligent predictions. By integrating data collection, preprocessing, machine learning, and real- time visualization, the system ensures accurate demand forecasting and timely decision-making. The use of advanced models enables the identification of patterns such as trends and seasonality, helping businesses anticipate future requirements effectively. Furthermore, the inclusion of alert mechanisms and automated reporting enhances operational efficiency and reduces the chances of overstocking or shortages. The modular architecture allows easy scalability and adaptability to different business environments. Overall, this system serves as a practical solution for minimizing food waste, optimizing inventory management, and improving overall business performance through data- driven insights.

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