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Priority-Aware Food Waste Management System using Machine Learning for Efficient Surplus Food Redistribution

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ABSTRACT

Food waste is a major environmental and social challenge, while surplus food remains unevenly distributed among communities. Existing food donation platforms primarily facilitate communication between donors and receivers but provide limited support for determining which donations should be redistributed first. This study proposes a priority-aware Food Waste Management System that integrates a web-based food donation platform with a CatBoost machine learning classifier for donation priority prediction. The system provides separate modules for donors, receivers, and administrators, enabling food donation management, collection requests, monitoring, and priority-based decision support. The machine learning model uses food, storage, demand, and transportation-related attributes to classify donations into High, Medium, and Low-priority categories. The proposed system combines digital food donation management with machine learning-based priority prediction to support the timely redistribution of surplus food. Experimental evaluation demonstrates the effectiveness of the CatBoost classifier for donation priority classification compared with the other machine learning models considered in this study. By integrating machine learning with a web-based donation workflow, the proposed system provides a practical framework for improving coordination and supporting more efficient surplus food redistribution.

KEYWORDS: *Food Waste Management, Food Donation, Machine Learning, CatBoost, Priority Prediction, Food Redistribution, Sustainability.*

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INTRODUCTION

Food waste has become a major global challenge because of its implications for food security, environmental sustainability, and resource efficiency [1], [2]. Food is lost or wasted at different stages of the food supply chain, including production, storage, transportation, retail, food services, and household consumption [2], [4]. At the same time, many communities continue to face food insecurity and limited access to adequate food. This imbalance highlights the importance of recovering and redistributing suitable surplus food before it becomes unsuitable for consumption [1], [5]. Food waste also represents a loss of the resources used in food production, such as land, water, energy, and labour, while the disposal of food waste contributes to additional environmental impacts [1], [2].

The development of digital technologies has created new opportunities to improve the management and redistribution of surplus food. Web-based and mobile-based food-sharing platforms can connect sources of surplus food with charitable organizations, NGOs, community kitchens, shelters, and other potential recipients [6], [7]. Such platforms can support activities including donor registration, food listing, availability management, collection requests, and communication between donors and receivers [6], [7]. Previous research has demonstrated that digitally enabled food-sharing platforms can improve coordination between surplus-food providers and recipients and can contribute to more effective food- sharing practices within circular-economy systems [6]. Food donation

applications such as SeVa have also demonstrated the potential of digital platforms to facilitate communication and surplus-food sharing between food providers and recipients [7]. However, conventional food donation platforms primarily focus on connecting participants and managing available donations, while providing limited support for determining which available donation should receive attention first.

Machine learning has increasingly been explored for food-related applications, including demand forecasting, inventory management, consumption prediction, and food-waste reduction [3], [9], [11]. Machine-learning-based forecasting approaches can identify patterns in historical data and support better planning of food demand and inventory, potentially reducing avoidable food waste [3], [9], [11]. For example, demand forecasting can help food-service organizations estimate future requirements and adjust food preparation and inventory levels accordingly [3]. Similarly, machine-learning-based inventory management can support the reduction of food waste by improving decisions related to stock levels and food availability [11]. Although these approaches demonstrate the usefulness of machine learning in food-waste management, they primarily address prediction and planning before or during food production and consumption rather than prioritizing individual surplus food donations after they become available for redistribution.

Prioritizing surplus food is particularly important because different donations can have different levels of urgency. Factors such as remaining shelf life, food type, quantity, storage condition, demand level, transportation distance, travel time, and receiver availability can influence the feasibility and urgency of redistribution [4], [5], [10]. A food donation with a short remaining shelf life may require immediate collection, whereas a donation with a longer remaining shelf life may have greater flexibility in the redistribution schedule. Similarly, high demand at a particular receiver, longer transportation distances, traffic conditions, or limited receiver availability may affect the time and effort required to redistribute a donation. Therefore, considering multiple food, demand, storage, and transportation-related characteristics together can provide more informed support for determining the order in which donations should be processed.

Existing research has addressed food waste reduction, digital food-sharing, surplus-food redistribution, and machine-learning-based forecasting as important but often separate areas. Studies on food redistribution emphasize coordination among stakeholders and the logistical relationships required to move surplus food efficiently [5], [10]. Digital platforms provide mechanisms for listing, matching, and managing food donations [6], [7], while machine-learning studies have primarily focused on demand forecasting, inventory management, and related predictive tasks [3], [9], [11]. Consequently, there remains an opportunity to integrate machine learning directly into a food donation platform to provide data-driven support for prioritizing available surplus food according to its characteristics and urgency.

To address this gap, this study proposes a web-based Food Waste Management System integrated with a CatBoost machine learning classifier for food donation priority prediction. The proposed system provides separate modules for donors, receivers, and administrators to support the management of the surplus-food redistribution process. Donors can register and submit information about available surplus food, receivers can browse available donations and submit collection requests, and administrators can monitor users, donations, requests, and system activities. The machine-learning component analyses multiple attributes associated with each donation, including food type, food category, quantity, remaining shelf life, preparation time, storage condition, packaging condition, demand level, delivery distance, traffic condition, and receiver availability. Based on these characteristics, the model classifies each donation into three priority categories: High, Medium, and Low.

The CatBoost classifier was selected as the primary prediction algorithm because it is designed to effectively handle datasets containing both numerical and categorical features. CatBoost was introduced as an unbiased boosting method with specific mechanisms for processing categorical features [15]. This characteristic makes it suitable for the proposed food donation dataset, which contains categorical variables such as food type, food category, donor type, traffic level, demand level, weather condition, storage condition, and packaging condition together with numerical variables such as quantity, shelf life, delivery distance, and travel time.

The proposed approach combines digital food donation management with machine-learning-based priority prediction to provide additional decision support during surplus-food redistribution. Instead of relying only on the order in which donations are submitted or their general availability, the system provides a priority classification based on the characteristics represented in the dataset. The

resulting priority information is displayed to authorized receivers and can help them identify donations that require comparatively greater attention. In this way, the proposed system aims to complement existing food- sharing mechanisms by introducing an intelligent prioritization component into the donation workflow.

The main contributions of this study are as follows:

1. Development of a web-based Food Waste Management System that supports donors, receivers, and administrators in managing surplus-food donations and redistribution activities.
2. Integration of a CatBoost machine learning classifier for classifying food donations into High, Medium, and Low-priority categories.
3. Consideration of multiple food, storage, demand, donor, and transportation-related attributes for predicting the priority of surplus-food donations.
4. Evaluation and comparison of machine-learning classification models using standard performance measures, including accuracy, precision, recall, F1-score, and confusion matrix analysis.
5. Demonstration of a practical machine-learning-enabled food donation workflow in which the predicted priority is generated after donation submission and made available to receivers as decision- support information.

Overall, the proposed system demonstrates how machine learning can be integrated with a digital food donation platform to provide priority-based decision support for surplus-food redistribution. The approach combines the coordination capabilities of a web-based donation system with the predictive capabilities of machine learning, providing a structured framework for identifying donations that may require comparatively urgent attention. Although further validation using larger and real-world donation datasets is required, the proposed framework provides a foundation for future developments involving real-time receiver demand, transportation conditions, food-quality assessment, route optimization, and other intelligent functions for improving surplus-food redistribution.

LITERATURE REVIEW

Food Loss and Waste: Causes, Impacts, and Management Needs

Food loss and waste have become major global concerns because of their environmental, economic, and social consequences. Food can be lost or wasted at different stages of the food supply chain, including production, storage, transportation, distribution, retail, and consumption [1], [2], [4]. At the same time, food insecurity remains a significant challenge in many communities. This imbalance highlights the importance of approaches that can recover surplus food and facilitate its redistribution to people and organizations that can use it [1], [5]. Food waste also represents a loss of the natural resources and energy used throughout food production and contributes to environmental impacts associated with the disposal of wasted food [1], [2].

Several factors contribute to food loss and waste across the supply chain. Inadequate storage facilities, improper handling, inefficient transportation and distribution, inaccurate demand estimation, and delays in processing can affect the quality and usability of food [4]. Perishable food is particularly vulnerable because its limited shelf life requires appropriate storage and timely movement. Therefore, reducing food waste requires not only preventing unnecessary disposal but also improving coordination among the different stakeholders involved in recovering and redistributing surplus food [4], [5].

Digital technologies provide opportunities to improve such coordination by enabling information sharing, online management, and faster communication between food providers and potential recipients. The increasing use of digital platforms in food-sharing activities has created new possibilities for connecting surplus food with organizations and individuals who can benefit from it [6], [7].

Digital Food-Sharing and Donation Platforms

Digital food-sharing and donation platforms have been developed to connect sources of surplus food with potential recipients. Restaurants, hotels, supermarkets, bakeries, households, and other food providers can use such platforms to communicate information about available surplus food, while NGOs, community organizations, shelters, and other recipients can identify and request suitable donations. These systems can simplify donation registration, food listing, request management, and communication between participating stakeholders.

Research on digitally enabled food-sharing platforms indicates that digital technologies can support the connection between surplus-food supply and demand and contribute to more coordinated food-sharing activities within a circular economy [6]. Food donation applications have also demonstrated the potential of mobile and web technologies for facilitating communication between food providers and recipients. For example, SeVa was proposed as a food donation application intended to support surplus-

food sharing through a digital platform [7]. Such systems demonstrate how technology can improveaccessibility and coordination in food donation.

Despite these developments, existing food-sharing platforms generally emphasize the listing, matching, and exchange of available food rather than intelligent prioritization of donations. When multiple food items are available at the same time, platforms may provide limited decision support for determining which donation should receive attention first. This is particularly important for perishable food because the urgency of redistribution can vary according to remaining shelf life, storage conditions, demand, and transportation requirements [5], [6].

Consequently, there is an opportunity to extend conventional food-sharing platforms with intelligent decision-support mechanisms that can analyze donation characteristics and provide priority information. Such an extension could complement existing donor-receiver communication by helping stakeholders identify donations that require more immediate attention.

Surplus Food Redistribution and Logistics Coordination

Effective surplus food redistribution requires coordination among donors, recipient organizations, and other stakeholders involved in collection and delivery. Unlike conventional food supply chains, surplus donations can vary considerably in their quantity, type, availability, and timing. A donor may provide food with a short remaining shelf life, while another donation may remain usable for a longer period. These differences create a need for appropriate prioritization during collection and redistribution [5], [10].

Logistics is another important factor in the redistribution of surplus food. Transportation distance, travel time, traffic conditions, pickup scheduling, and transportation availability can influence the time required to move food from a donor to a recipient. Sundgren examined relationships within circular supply chains for food redistribution and emphasized the importance of coordination among stakeholders involved in recovering surplus food [5]. Research on surplus-food redistribution systems also highlights the importance of improving coordination between food providers, recipient organizations, and logistics activities [10].

Food safety and storage capacity also influence the effectiveness of redistribution. Donated food must be appropriately handled, stored, and transported to maintain its quality and suitability for consumption. Recipient organizations may also have different levels of demand, storage capacity, and ability to collect donations. Therefore, considering food characteristics together with demand and logistical conditions can provide more useful information for redistribution decisions.

Existing digital systems can support communication and basic logistics coordination, but many approaches continue to rely on manual decisions when determining which available donations should be processed first. This creates an opportunity for data-driven techniques that can consider multiple characteristics simultaneously and provide additional support for donation prioritization.

Machine Learning for Food Waste Reduction

Machine learning has increasingly been applied to food-related problems because of its ability to identify patterns in structured datasets and support predictive decision-making. Previous research has investigated machine learning for applications including food demand forecasting, inventory management, consumption prediction, and supply-chain planning [3], [9], [11]. Rodrigues et al. examined machine learning models for short-term demand forecasting in food catering services and demonstrated their potential for supporting decisions related to food demand and waste management [3].

Machine learning approaches have also been investigated for broader food-loss and waste management problems. By analysing multiple variables simultaneously, predictive models can provide information that may be difficult to obtain through simple rule-based approaches. Such methods can therefore complement conventional food-management practices by providing data-driven decision support [9], [11].

Several classification algorithms can be applied to structured food-related datasets, including Decision Tree, Random Forest, Support Vector Machine, XGBoost, and CatBoost. The suitability of a particular algorithm depends on the characteristics of the dataset, the types of input variables, and the classification task being addressed. CatBoost is particularly relevant to datasets containing categorical and numerical variables because it is designed to handle categorical features within its learning framework [15].

However, much of the existing machine learning research related to food waste focuses on predicting demand, consumption, or supply-chain requirements [3], [9], [11]. These applications are valuable for preventing or reducing waste before or during food production and distribution, but they do not directly

address the prioritization of surplus food after it has been made available for donation.

In the context of food redistribution, priority can depend on a combination of factors rather than a single variable. Remaining shelf life, food type, quantity, preparation time, storage condition, demand level, delivery distance, traffic condition, and receiver availability can all provide information relevant to the urgency of a donation. A machine learning model capable of analysing these characteristics together can therefore provide an additional layer of decision support for food donation management.

Research Gap

The reviewed literature demonstrates significant progress in three related areas: food-loss and waste management, digital food-sharing platforms, and machine-learning-based decision support. Research has established the importance of reducing food waste and improving the recovery and redistribution of surplus food [1], [2], [4], [5]. Digital platforms have provided mechanisms for connecting food donors and recipients [6], [7], while machine learning has been applied to prediction and optimization problems such as food demand forecasting and inventory management [3], [9], [11].

However, these research directions are frequently addressed separately. Digital food donation platforms primarily focus on registering, displaying, matching, and managing donations, whereas many machine learning studies focus on demand forecasting, inventory management, or other supply-chain applications [3], [6], [9], [11]. Comparatively limited attention has been given to using machine learning directly within a food donation platform to classify the priority of available surplus food according to multiple food, demand, storage, and transportation-related characteristics.

Recent work on intelligent food donation systems indicates increasing interest in applying artificial intelligence to improve donation and receiver-related decisions [12]. Similarly, research on digital solutions for food donation highlights the potential of technology to address coordination challenges in food donation processes [13]. However, there remains an opportunity to further integrate machine-learning-based priority classification into the operational workflow of a food donation platform.

This study addresses this gap by integrating a CatBoost machine learning classifier into a web-based Food Waste Management System. The proposed system considers multiple attributes associated with food donations and classifies them into High, Medium, and Low-priority categories. The resulting priority information is incorporated into the donation workflow involving donors, receivers, and administrators, providing an additional decision-support mechanism for managing available surplus food.

The proposed approach therefore differs from conventional food-sharing systems by combining donor- receiver coordination with machine-learning-based donation prioritization. It also differs from food- waste prediction studies that primarily focus on demand or consumption forecasting by applying classification to the post-generation redistribution stage. This integration provides a practical framework for investigating how machine learning can support more systematic and timely surplus food redistribution.

PROPOSED SYSTEM

The proposed Food Waste Management System is a web-based platform developed to facilitate the collection and redistribution of surplus food. It connects food donors with registered receivers and uses a machine learning model to assign a priority level to each food donation. The system classifies donations as High, Medium, or Low priority based on relevant food, demand, receiver, and delivery-related factors. This priority-based approach helps in identifying donations that may require faster collection and reduces the possibility of edible food becoming waste.

The system consists of three main modules: Donor, Receiver, and Administrator. Donors can register and submit details of available surplus food, including food type, quantity, shelf life, location, and pickup information. Receivers can view available donations along with their predicted priority and submit collection requests for suitable food. The administrator manages users, monitors food donations and collection requests, and oversees the overall activities of the system. The web application is developed using HTML, CSS, JavaScript, PHP, and MySQL, while Python is used for the machine learning component.

The overall process begins when a donor submits food details through the web application. The donation information is stored in the MySQL database, and the required attributes are provided to the trained CatBoost Classifier. The model analyses the available information and predicts the priority of the donation as High, Medium, or Low. The predicted priority is then stored with the corresponding donation record and displayed to receivers. Receivers can use this information to identify important donations and submit collection requests.

The proposed system therefore combines food donation management, database management, and machine learning-based priority prediction in a single platform. By connecting donors and receivers and providing priority information, the system aims to support timely collection, improve redistribution of surplus food, and contribute to reducing avoidable food waste.

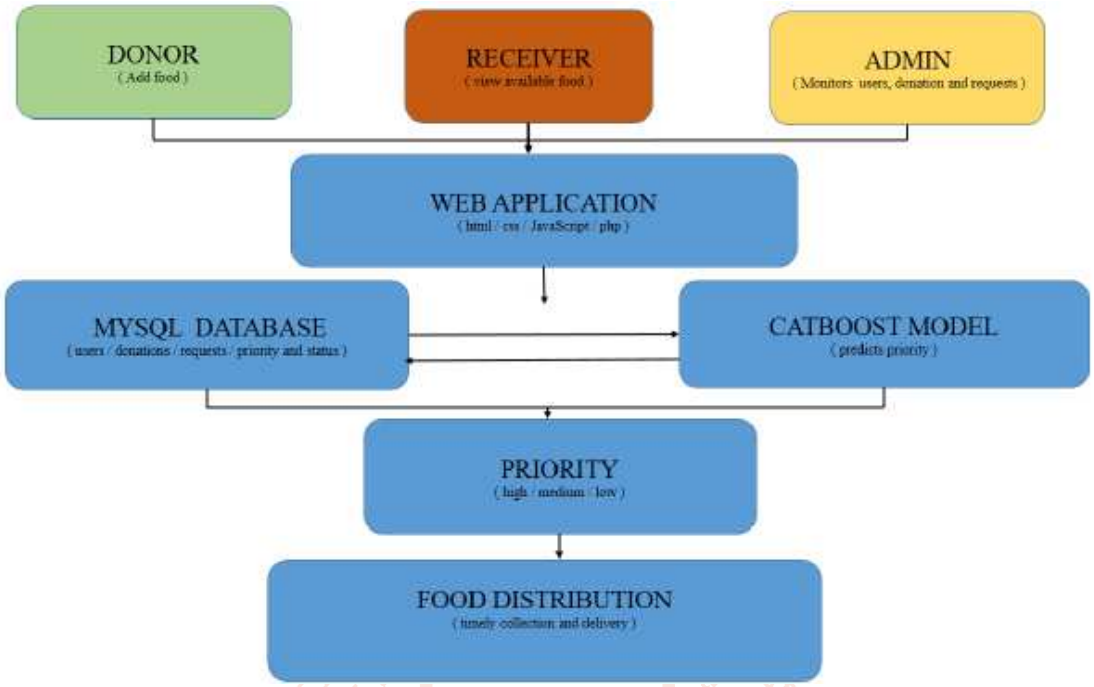


Figure 1. System architecture of the proposed Food Waste Management System.

Dataset Description: The machine learning component was developed using the Food Waste Priority Dataset, which contains 2,000 records and 20 columns. The dataset includes information related to food characteristics, quantity, shelf life, donor details, receiver availability, demand, delivery conditions, storage, and packaging. The target variable is Priority, which represents three classes: High, Medium, and Low. The Donation_ID column was used only as an identifier and was excluded from model training.

Data Preprocessing: The dataset was prepared before training the classification model. The input features consisted of both numerical and categorical attributes. Numerical features included quantity, shelf life, preparation time, donor rating, receiver count, acceptance rate, delivery distance, travel time, and population density. Categorical features included food type, food category, donor type, receiver availability, traffic level, demand level, weather condition, storage condition, and packaging condition. The categorical attributes were provided to the CatBoost model for handling during training.

Dataset Splitting: The dataset was divided into training and testing sets using an 80:20 ratio. A total of **1**,600 records were used for training the model, while 400 records were used for testing. The training data was used to learn the relationship between the input features and donation priority, while the testing data was used to evaluate the model's performance on unseen records.

CatBoost Classification Model. The CatBoost Classifier was selected for predicting the priority of food donations because it can effectively manage datasets containing categorical and numerical features. The model was configured with 1,000 iterations, a depth of 8, and a learning rate of 0.03. The Multiclass loss function was used because the target variable contains three priority classes.

Model Training: The CatBoost model was trained using the 1,600 training records. During training, the model learned patterns associated with the three priority classes from the selected food, demand, receiver, storage, and delivery-related attributes. After training, the model was evaluated using the remaining 400 records. The trained model was then integrated with the web application to predict the priority of newly submitted food donations as High, Medium, or Low.

RESULTS AND DISCUSSION

Descriptive Dataset Results.

The proposed Food Waste Management System was evaluated using a dataset containing 2,000 food donation records and 20 columns. The dataset includes information related to food type, quantity, shelf life, donor type,

receiver availability, demand level, delivery distance, storage condition, packaging condition, and other relevant factors. The Priority column was used as the target variable, while Donation_ID was excluded from model training as it is only an identifier**.**

The dataset was checked before training, and no missing values were found. It contains both numerical and categorical features, making it suitable for the CatBoost classifier. The target variable consists of three priority categories: High, Medium, and Low, which represent the urgency of food redistribution.

Overall, the dataset provides different food donation conditions that help the machine learning model identify patterns related to donation priority and predict the appropriate priority level for new food donations.

Priority Class	Number of Donations	Percentage (%)
Medium	1,077	53.85
High	543	27.15
Low	380	19.00
Total	**2,000**	**100.00**

Table 1. Distribution of food donations by priority class.

Model Performance Results

The performance of the proposed CatBoost classification model was evaluated using the 400 testing records. The model was evaluated using accuracy, macro precision, macro recall, and macro F1-score to measure its ability to correctly classify food donations into High, Medium, and Low-priority categories. The obtained results are presented in Table below.

Performance Metric	Value (%)
Accuracy	95.75
Macro Precision	96.72
Macro Recall	94.09
Macro F1-Score	95.20

Table 2. Performance of the CatBoost classification model on the test dataset.

The confusion matrix shows the classification performance of the CatBoost model for the three priority classes: High, Medium, and Low. The matrix indicates the number of correctly and incorrectly classified food donations for each class. The diagonal values represent the correctly predicted donations, while the off-diagonal values represent misclassifications. The results show that the model is able to distinguish between the different priority levels with good classification performance.

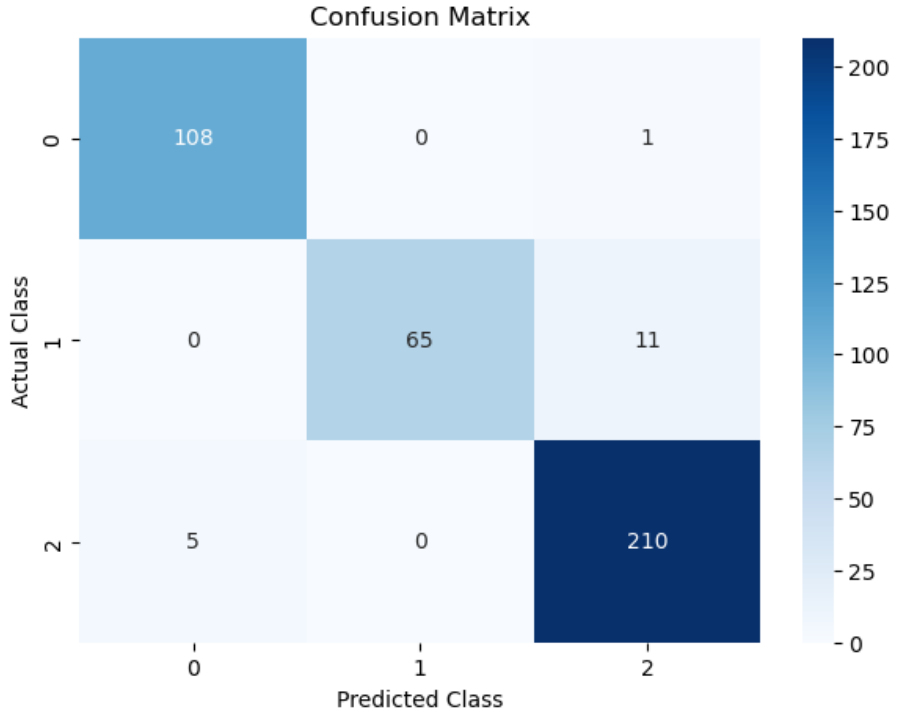


Figure 2. Confusion matrix of the CatBoost classification model.

Feature Importance Analysis

Feature importance analysis was performed to identify the features that had the greatest influence on the CatBoost model's prediction of food donation priority. Theanalysis helps to understand which factors contribute most to classifying donations as High, Medium, or Low priority. The feature importance results are presented in Fig. below.

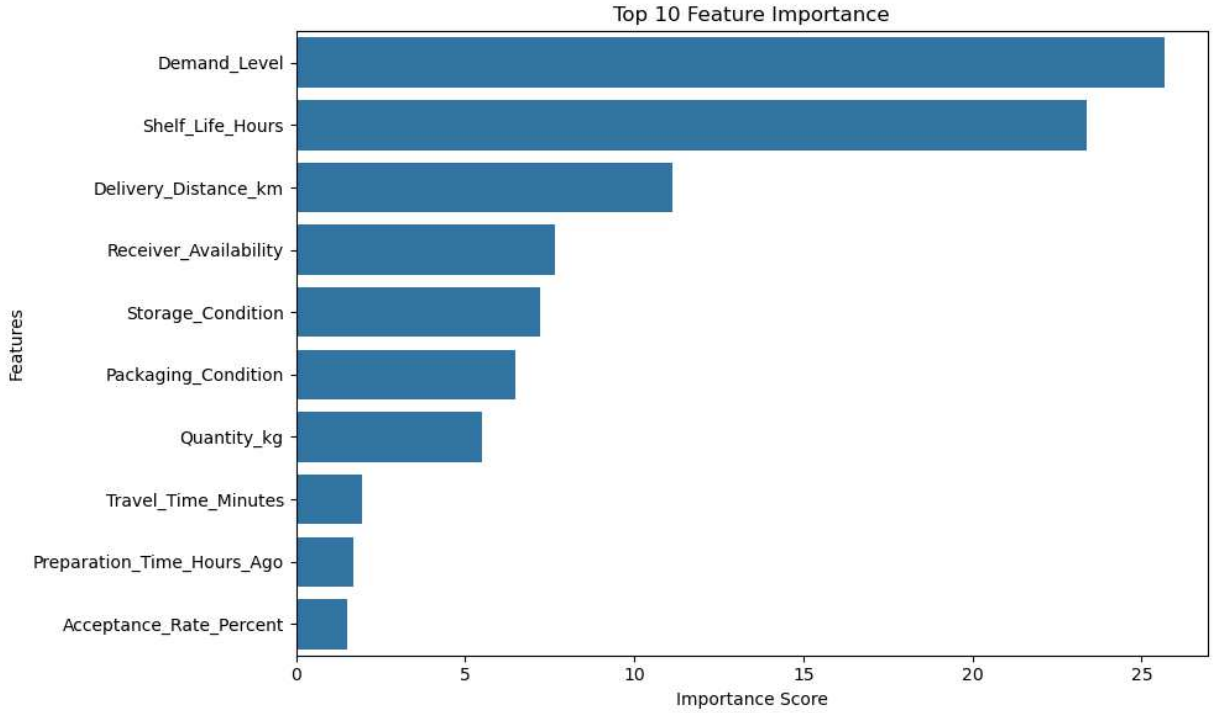


Figure 3. Top 10 feature importance scores for the CatBoost model.

System implementation

Web Application: The Food Waste Management System was implemented as a web-based application using HTML, CSS, and JavaScript for the frontend and PHP for server-side processing. MySQL was used for database management. The system provides separate modules for donors, receivers, and administrators. The donor module allows users to submit surplus food details, includingfood type, food category, quantity, location, and pickup information. The receiver module allows registered receivers to view available food donations along with their predicted priority and submitcollection requests. The administrator moduleis used to manageusers, monitor food donations and collection requests, and manage the overall system.

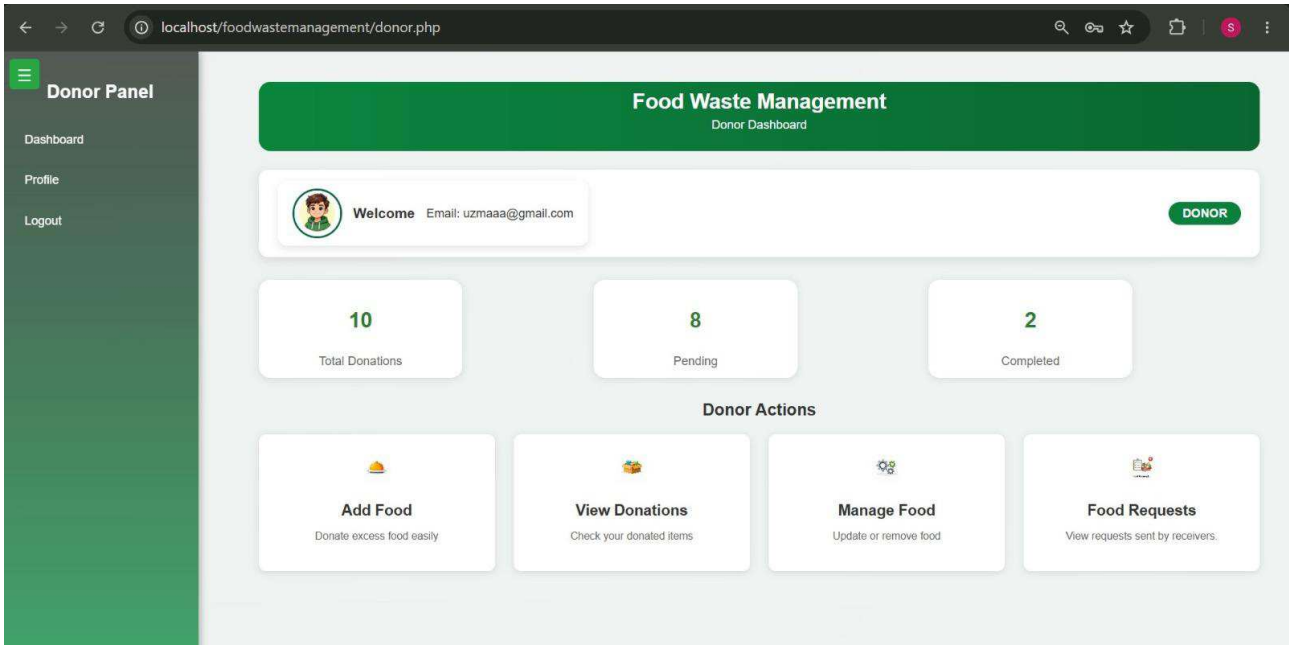


Figure 4. Donor dashboard of the web-based Food Waste Management System.

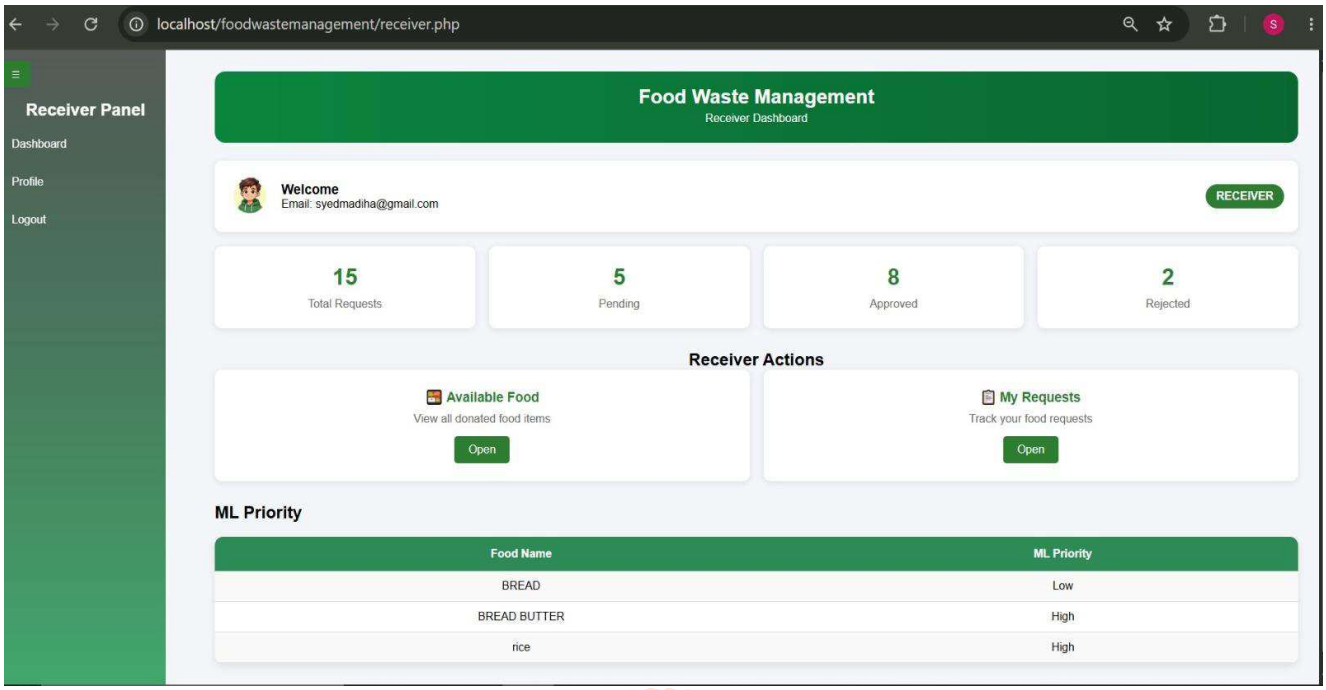


Figure 5. Receiver dashboard displaying available food and predicted ML priority.

Machine Learning Integration: The machine learning component was implemented using Python and the CatBoost Classifier. When a donor submits a food donation, the relevant attributes are processed and provided to the trained CatBoost model. The model predicts the priority of the donation as High, Medium, or Low. The predicted priority is returned to the web application and stored in the MySQL database with the corresponding food donation record. The priority is then displayed to receivers so that they can identify donations according to their urgency and take appropriate collection action.

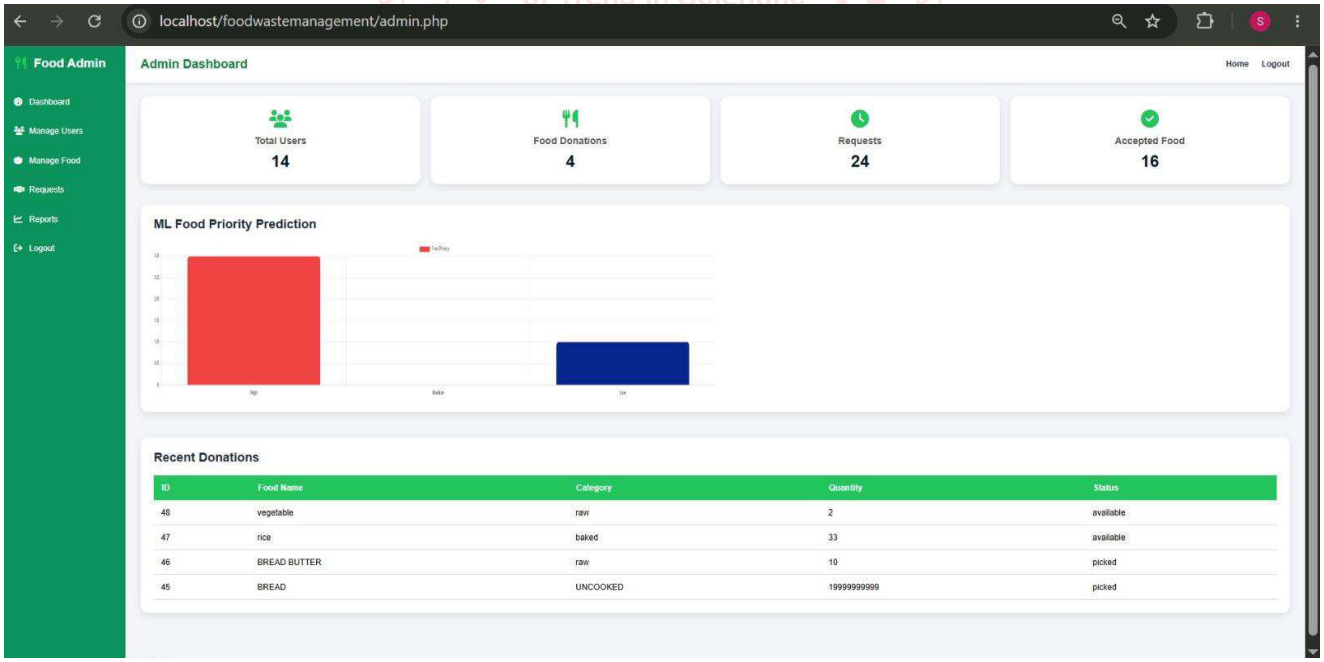


Figure 6. Administrator dashboard for monitoring users, donations, requests, and system activity.

Database Integration: The system uses MySQL to store and manage the data generated by the web application. The database stores user information, food donation details, predicted priority, collection requests, and donation status. PHP is used to communicate with the MySQL database. When a donor submits a donation, the information is stored in the database. After the machine learning model generates the priority, the predicted value is updated in the corresponding donation record. Receivers can then retrieve the updated donation information through the web application.

Functional Evaluation :The implemented system was evaluated by assessing its major functionalities. The testing included donor registration, food donation submission, machine learning-based priority prediction, display of available food to receivers, collection-request submission, and administrator functions. The functional evaluation showed that the web application, database, and machine learning component work together to support the complete food donation process. The system enables surplus food to be submitted, prioritized, viewed by receivers, and managed through an integrated platform.

CONCLUSION

The proposed Food Waste Management System provides an integrated platform for managing and redistributing surplus food by connecting donors with registered receivers. The system combines a web-based food donation platform with a machine learning-based priority prediction mechanism to support timely collection of surplus food. HTML, CSS, JavaScript, PHP, and MySQL were used for the web application, while Python and the CatBoost Classifier were used for priority prediction.

The machine learning model was developed using 2,000 food donation records and achieved an accuracy of 95.75%**,** with a macro precision of 96.72%**,** macro recall of 94.09%**,** and macro F1-score of 95.20% on the test data. Feature importance analysis showed that Demand Level and Shelf-Life Hours were the most influential factors in determining donation priority.

The integration of the machine learning model with the web application enables submitted food donations to be classified as High, Medium, or Low priority. The predicted priority is stored in the database and displayed to receivers, helping them identify donations that may require faster collection. Overall, the proposed system demonstrates the potential of combining web technologies, database management, and machine learning to improve food redistribution and contribute to reducing avoidable food waste.

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