Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Smart Scrap: An AI-Based Waste Segregation and Reward-Driven Recycling Platform

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Abstract

The rising number of people in cities that are experiencing fast urban growth creates new challenges for municipalities to handle their solid waste. The combination of improper waste segregation from its origin point, low recycling rates and limited public participation leads to two problems: environmental contamination and ineffective waste treatment. The waste management systems of the past depend on human labor to sort waste materials because they do not have automated sorting systems or public engagement programs which offer rewards to encourage community participation.

This paper presents SmartScrap, an AI-based waste segregation and reward-driven recycling platform designed to enhance sustainability through intelligent automation and user participation. The proposed web-based system uses image recognition techniques to classify waste into three categories which include organic waste recyclable materials and hazardous waste. The platform provides users with automated segregation capabilities together with waste-ticket creation functions and access to a Clean & Earn program which rewards users with credits for their environmentally friendly waste disposal and cleaning efforts.

The system uses multi-role architectural design which includes user, supervisor, company and admin modules to provide complete visibility of waste collection process and verification system and recycling operations within specific geographical limits. Supervisors handle all aspects of waste management by organizing waste collection activities and waste distribution operations to certified companies who create an organized waste supply chain system. The combination of artificial intelligence together with location-based management and an incentive-driven reward system enables organizations to improve their recycling operations while enhancing operational transparency and community participation.

Keywords: Smart Waste Management, Artificial Intelligence, Machine Learning, Image Recognition, Waste Segregation, Reward-Based Recycling, Web Application, Sustainable Development.

1. Introduction

The management of municipal solid waste has become an essential environmental problem because urban areas are expanding and industries are developing and the population is growing. The process of waste separation at the point of origin results in two problems which include decreased recycling rates and increased waste volumes at landfills. Global waste management studies show that recyclable materials become lost when organic waste combines with recyclable materials and hazardous materials [8]. The inefficiency in operations creates two negative effects which include damaging environmental sustainability and increasing operational expenses for city governments.

The process of traditional waste management depends on two main methods which involve manual waste sorting and collection from central locations. The methods require extensive labour and take a long time to complete but they provide minimal visibility to all parties involved in the process. Researchers have investigated waste monitoring and optimization methods which use intelligent technology to make smart city systems run better. IoT sensors are used by smart bin systems to monitor bin fullness and select the most effective waste collection routes [4]. By improving garbage collection routes, dynamic scheduling models improve the overall performance of waste collection in urban environments [5]. Rather than assisting users with waste segregation tasks, the systems primarily concentrate on optimizing collection processes.

Yang and Thung [2] investigated machine learning methods to differentiate between materials that can be recycled and those that cannot be recycled. CNN-based classification models have reached high accuracy rates which allow them to effectively distinguish between waste types [3]. The research studies primary focus on waste detection and waste classification as separate research areas while neglecting to include both reward-based engagement strategies and organized waste supply chain management.

The use of incentive-based environmental programs has proven successful at raising citizen involvement in recycling programs [7]. The current research field requires further study to understand how AI waste segregation systems operate with reward systems and multiple rolebased operational procedures.

The paper presents SmartScrap as a solution which operates based on AI technology to separate waste materials while providing rewards for recycling activities. Users can identify waste categories through image recognition which enables them to separate materials into organic and recyclable and hazardous waste types. The platform includes a reward system called "Clean & Earn" which encourages users to dispose of waste correctly. The system uses a multi-role architecture to create transparent waste management processes which include verification and recycling operations within distinct geographical areas.

The main achievement of this research combines three elements which include AI waste classification and participation through incentives and complete waste supply chain operation into a web-based system. The system aims to boost recycling performance while driving sustainable development and building smart cities through its automated procedures and organized community participation process.

2. Problem Statement

Urban and semi-urban areas continue to fight against problems related to their municipal solid waste collection and disposal operations. The absence of proper waste segregation at the initial point of disposal causes recyclable materials and organic waste to become contaminated with dangerous waste. Improper waste segregation results in reduced recycling success while increasing the amount of waste sent to landfills and creating environmental contamination. The process of manually sorting waste requires intensive labour yet produces high rates of mistakes and fails to deliver economical results.

The current waste management systems operate as collection and disposal systems which lack advanced waste sorting technology and active public participation options. Research has examined image-based waste detection systems along with IoT-enabled monitoring systems but these solutions function as independent systems which lack user participation and structured waste selling and reward mechanisms and multilevel administrative coordination.

One significant barrier is the lack of incentive-driven models that encourage individuals to adopt sustainable waste management practices. Due to the lack of clear benefits and mechanisms that enable them to track advancements, the public does not engage in waste segregation and recycling. Insufficient collaboration between waste producers and collection supervisors and recycling companies creates waste supply chain problems.

An integrated AI-enabled platform needs to be developed which serves the following functions:

- The system uses advanced image recognition technology to perform automated waste separation tasks.
- The system design includes a reward structure which motivates users to participate in its activities.
- The system enables users to manage waste collection procedures through its verification system.
- The system establishes direct links between waste generators and their supervisors along with recycling facilities.
- The system delivers administrative functions which enable waste management processes to function effectively.

The SmartScrap system develops an AI-based web platform which functions as a multi-role system to address conventional waste classification and waste management challenges while creating an integrated solution for recycling processes.

3. Literature Review

Artificial intelligence, computer vision, and smart city technologies have all been used in recent years to improve waste management systems.

Spot Garbage is a smartphone application developed by Mittal et al. [1] that uses deep learning methods to identify trash in urban areas. Convolutional Neural Networks (CNNs) were used by the system to recognize waste objects in photos taken with mobile devices. The suggested method showed good garbage detection, but instead of classifying waste into several segregation classes or incorporating a structured recycling workflow, it mainly concentrated on detecting the presence of waste

Yang and Thung [2] explored waste classification for recyclability using supervised machine learning techniques. Their work emphasized dataset preparation, feature extraction, and classification accuracy for recyclable and nonrecyclable materials. While the study showed promising classification performance, it was limited to experimental evaluation and did not propose a real-time, deployable system architecture.

Zhang et al. [3] proposed a deep learning-based waste classification framework using CNN architectures with data augmentation and preprocessing techniques. The model achieved high classification accuracy across various waste categories. However, the research primarily focused on improving model performance and did not integrate the solution into a complete waste management ecosystem involving stakeholders such as supervisors and recycling companies.

Folianto et al. [4] developed Smart Bin, an IoT-enabled waste monitoring system aimed at optimizing waste collection schedules. The system utilized sensors to monitor bin fill levels and reduce unnecessary collection trips. Although the approach improved operational efficiency, it did not incorporate waste segregation or citizen participation mechanisms.

Anagnostopoulos et al. [5] examined dynamic waste collection models for smart cities, emphasizing route optimization and priority-based scheduling. Their work enhanced collection efficiency but did not address automated waste classification at the source level.

Wu et al. [6] investigated the integration of IoT and machine learning techniques for smart city waste management. Their system enabled real-time monitoring and predictive analysis; however, it lacked an incentivedriven engagement model to encourage active user participation.

Mohsen [7] analysed reward-based recycling programs and demonstrated that incentive mechanisms significantly increase citizen involvement in sustainable waste practices. However, the study did not combine reward systems with AIbased segregation or structured waste supply chain management.

A. Research Gap

From the existing literature, the following limitations are identified:

- Most systems focus solely on waste detection or classification without integrating a complete waste management workflow.
- IoT-based collection optimization systems lack automated segregation mechanisms.
- Reward and incentive models are studied independently and are rarely integrated with AIdriven waste classification.

There is limited research on multi-role platforms connecting users, supervisors, recycling companies, and administrators within a unified system.

B. Positioning of the Proposed Work

To address these gaps, the proposed SmartScrap platform integrates:

- AI-based image classification for automated waste segregation into organic, recyclable, and hazardous categories.
- A reward-driven “Clean & Earn” mechanism to encourage active citizen participation.
- Location-based supervisor allocation for efficient waste collection within a defined radius.
- A structured waste-selling and purchasing module connecting users and recycling companies.
- A centralized admin panel for monitoring and system transparency.

By combining artificial intelligence, incentive mechanisms, and multi-role architecture into a single webbased platform, SmartScrap extends existing research and provides a scalable solution for sustainable smart city waste management.

4. Proposed System (Smartscrap Architecture)

The SmartScrap system implements a web-based platform which uses artificial intelligence to provide intelligent waste segregation together with user incentive programs and organized waste management for all waste supply chain operations. The system uses a multi-role architecture which enables transparent operations and scalable growth while providing effective waste management coordination across all involved parties.

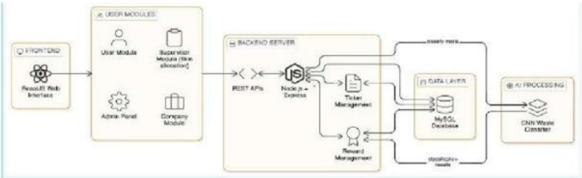


Fig. 1. Overall System Architecture of SmartScrap Platform

A. System Overview

SmartScrap operates as a centralized web platform which allows different user roles to access its system including general users, supervisors, recycling companies and administrators. The system uses image recognition technology to automatically classify waste while implementing a reward system to encourage people to dispose of waste properly and maintain clean environments.

The entire process starts when users upload waste images which they use to identify the waste material through an AI model at the source level. Waste-selling tickets get created from the classification results which supervisors will receive based on their assigned geographical area. Supervisors carry out waste collection tasks to confirm the material before sending it to authorized companies. The admin panel monitors user activity, analyzes waste movement data, and keeps tabs on system operations.

B. User Module

The primary interface that citizens use to interact with the SmartScrap platform is the User Module. The following features are offered to users by the platform:

1) Signup and Login

Users can register and log in safely using their email ID and mobile number. The authentication process uses several methods that protect data integrity while confirming user identities.

2) AI-Based Waste Segregation

Users can upload images of waste through the dashboard. The AI-based image classification model processes the images and categorizes the waste into organic, recyclable, or hazardous categories.

3) Sell Waste Ticket Generation

After classification, users can enter the approximate weight or quantity of the waste. A digital waste-selling ticket gets created from this data which shows the waste type and its total weight and the designated disposal area. 4) Clean & Earn Feature

Users can upload images of unclean or polluted locations. The system shows users the cleaning tasks which they can complete based on their current location. The system gives users credit points after they finish tasks which require verification.

5) Credit Point Rewards

Users receive credit points when they complete three actions which include separating waste and selling waste and finishing cleaning duties. Users can use the points as rewards which they can spend or save within the platform.

C. Supervisor Module

The Supervisor Module manages all waste collection activities together with their verification process while it establishes links between users and recycling companies.

1) Area-Based Allocation

Each supervisor is assigned a service area within a predefined radius (5 km). The system automatically assigns generated waste-selling tickets to the correct supervisor based on their established service area.

2) Waste Collection and Verification

Supervisors collect waste from user locations and verify the waste type and quantity as per the generated ticket to ensure accuracy and prevent misuse.

3) User Reward Crediting

The system awards users with reward points after the waste collection and verification process completes.

4) Waste Forwarding to Companies

The platform aggregates collected waste to deliver it to authorized recycling companies through a streamlined waste supply chain process.

D. Company Module

The Company Module permits recycling companies together with waste processing facilities to join the SmartScrap network.

1) Waste Purchasing

Companies can view available waste categorized by type and quantity within their service area.

2) Pricing and Bidding

Companies can offer prices for different waste categories which establishes a transparent process for purchasing.

3) Waste Quantity Tracking

The dashboard shows companies the total waste that has been purchased and processed while it displays pending waste which requires logistics handling.

E. Admin Module

The Admin Module enables complete system management through its control features which oversee all system functions.

1) System Monitoring

Admins track all system activities, including waste segregation events, ticket generation, supervisor operations, and company transactions.

2) User, Supervisor, and Company Management

The admin panel enables user management through its functions which allow users to add or remove users and manage supervisors and supervisors of the platform.

3) Analytics and Reports

The system creates analytical reports which track the performance of the system while measuring user participation and monitoring waste segregation patterns and reward distribution statistics. The system optimization process starts from the decision-making process which generates insights about system performance.

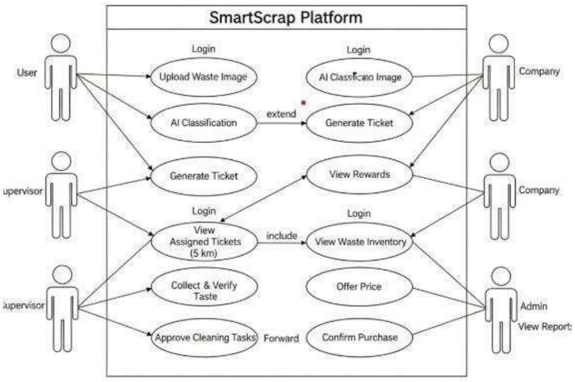


Fig. 2. Use Case Diagram of SmartScrap

5. AI & Machine Learning Methodology

The SmartScrap platform employs an AI-based system which processes images to automatically sort trash from its initial location. Deep learning methods which use Convolutional Neural Networks (CNNs) have been proven to better detect and classify images of waste materials than conventional machine learning methods according to recent research studies [1][3]. The proposed system uses a CNNbased architecture to categorize waste images into established classification groups.

A. Image Recognition Model

CNNs are the standard choice for computer vision tasks because they can automatically extract features from images while delivering exceptional accuracy in classification [4]. Mittal et al. [1] demonstrated that CNN models can successfully identify garbage through smartphone photography. Yang and Thung [2] assessed supervised learning methods for waste sorting while they showed that structured datasets are crucial for predicting recyclability.

SmartScrap uses a deep CNN architecture which includes:

- Convolutional layers for spatial feature extraction
- The system uses ReLU activation functions to create non-linear output results.
- Max-pooling layers enable the system to decrease data dimensions between two points.
- Full system components use connected layers to perform their classification tasks.
- The softmax output layer calculates the probability distribution across multiple classes.
- The Softmax layer computes probability scores for each waste category, and the class with the highest probability is selected as the final output.

B. Waste Classification Categories

The Waste Classifaction is majorly in three major types:

- Organic Waste – all compostable waste materials which include both food waste and garden refuse.
- Recyclable Waste – materials which include plastic and paper and metal and glass.
- Hazardous Waste – materials which include electronic waste and batteries and chemicals and toxic substances.

Zhang et al. [3] established that CNN architectures for multi-class waste classification enable better waste segregation accuracy than binary classification methods.

C. Dataset and Preprocessing

The deep learning model performance depends on the complete range of from data quality and the implementation of effective data processing techniques [4]. The dataset used for training includes labeled images representing the three waste categories. Public waste image datasets were selected for usage while their capacity to generalize was boosted through the integration of actual environmental samples.

Category	Number of Images
Organic	1200
Recyclable	1500
Hazardous	1000

Table I. Dataset Distribution Across Waste Categories

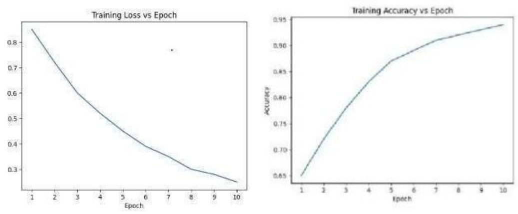


Fig.3 Training Accuracy and Loss curve

The preprocessing steps involve multiple stages which include the following tasks:

- All images must be resized to a standard dimension of 224×224 pixels.
- All image pixels undergo the process of normalization.
- Data augmentation includes three operations which are rotation and flipping and zooming.
- Label encoding transforms multi-class output into one single label.
- Data augmentation methods serve as an effective solution to decrease overfitting which results in stronger model performance according to the authors of [3].

D. Model Workflow

The AI-based segregation system executes its functions through these designated steps:

- User uploads a waste image.
- The image undergoes the preprocessing phase of processing.

- The trained CNN model receives the processed image as its input.
- Convolutional and pooling functions extract features from the processed materials.
- Softmax generates probability scores for each class.
- The predicted category corresponds to the class with the maximum probability score.

The studies in [1] and [3] evaluated the implementation of real-time garbage sorting systems which used CNN models for their operational processes.

E. Accuracy and Prediction Logic

Waste classification research uses standard classification metrics which include accuracy and precision and recall and F1-score for model evaluation according to established research practices [2][4]. The dataset is divided into two parts which include training and testing at a ratio of 80 percent for training and 20 percent for testing.

Metric	Value
Accuracy	92.4%
Precision	0.90
Recall	0.89
F1-Score	0.89
Loss	0.27

Table II. Performance Metrics of CNN Model

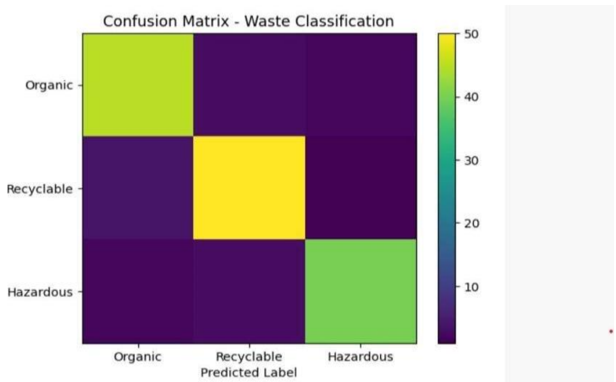
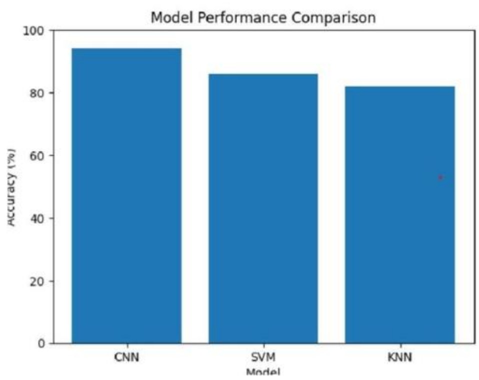


Fig. 4. Confusion Matrix of Proposed CNN Model



A. Revenue Assumption Model

The proposed system requires assessment through a basic revenue model which operates within its designated operational boundaries.

Assume:

- A radius of 5 kilometers will be used to provide service
- The number of participating households will reach 100
- Every household contributes an average of 5 kilograms of waste to the system
- The total waste collected amounts to 500 kilograms
- The average market price for organic waste ranges between ₹1.4 to ₹4.4 per kilogram based on its quality and market demand. The total revenue from 500 kilograms of waste will reach approximately
- ₹1,570 for every collection cycle
- The model creates financial benefits at the community level through its waste reduction practices which promote sustainable waste management.

B. Revenue Distribution Structure

The waste transaction revenue distribution process operates through a design which achieves operational effectiveness while providing financial rewards to all involved parties.

The proposed distribution model is as follows:

1) 20% for Supervisors

Supervisors receive payment for their waste collection tasks which they perform within a distance of 5 kilometers from their base.

2) 20% for Transportation and Logistics

The budget includes expenses for gasoline and travel expenses to support waste forwarding operations which send materials to recycling facilities.

3) 10% Platform Revenue (Service Commission)

The budget allocation funds system upkeep AI model enhancements infrastructure development and administrative functions.

4) 50% Returned to Users as Credit Points

The users obtain digital credit points which provide them approximately ₹1.5 for every kilogram of waste they process.

The allocation system establishes distribution methods which guarantee that the SmartScrap ecosystem maintains both equitable operations and transparent processes needed for longterm environmental maintenance.

Metric	Value
Accuracy	92.4%
Precision	0.90
Recall	0.89
F1-Score	0.89
Loss	0.27

Fig. 5. Performance Comparison Between CNN, SVM And KNN.

6. Reward System & Revenue Model

The SmartScrap platform differentiates itself through Table III. Revenue Distribution Among Stakeholders its reward system which distributes revenues in a structured manner to achieve economic sustainability and motivate civic engagement. SmartScrap establishes a financial system which offers transparent monetary rewards to its users and supervisors while operating its waste management services.

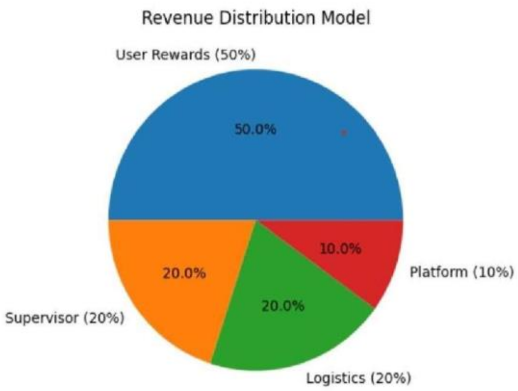


Fig. 6. Revenue Sharing Structure of SmartScrap

C. Credit-Based Incentive Mechanism

The SmartScrap system utilizes digital credit points as a method for behavioral transformation instead of using cash payments. People can use their credit points to:

- Maintain a balance in their digital wallet
- Use their balance for discounts and rewards redeeming
- Exchange their credits for various benefits in partner networks

The incentive model ensures that users are directly rewarded for:

- Correct waste disposal through proper separation
- Waste generation through verification of waste tickets
- Clean & Earn activities participation

The system uses financial rewards together with AI automation to increase user interaction while improving waste sorting accuracy at the original disposal points.

D. Clean & Earn Reward Integration

The revenue model of the "Clean & Earn" module extends its reach to include more than just disposal of household garbage. Users can:

- Report locations that have been polluted
- Accept cleaning work that requires them to clean locations close to their location
- Upload proof of cleaning
- After supervisor verification users can earn extra credit points

This feature enhances community participation while creating economic rewards that support environmental protection.

E. Economic Sustainability

The revenue model establishes:

- Financial equilibrium between stakeholders
- The model achieves the goal of
- The platform achieves self-sustaining growth through its protective measures
- Environmental behaviour receives financial incentives for participation
- The credit allocation model shows economic viability for small-scale deployments. Smart City implementations become more feasible through SmartScrap because its system scales effectively with increasing user participation in the platform.

7. System Architecture Diagram

The SmartScrap platform uses a distributed multi-tier architecture which combines its web-based client interface and RESTful backend services and deep learning inference engine and centralized relational database into one system. The architecture uses a microservice design pattern which creates independent components that can be scaled and maintained while establishing specific access rights based on user roles.

The system supports four primary actors: User, Supervisor, Company, and Administrator.

A. Architectural Design Paradigm

SmartScrap operates on an architectural framework which includes four distinct layers.

- Presentation Layer (Frontend)
- Application Layer (Backend Services)
- AI Inference Layer
- Data Persistence Layer

The system uses secure HTTPS-based REST APIs to establish communication between its different system layers. The system uses authentication tokens based on JWT to authenticate users and manage their active sessions.

1) Presentation Layer (Frontend Architecture)

The frontend system builds a responsive web application through its component-based design system. The system handles:

- UI rendering
- Client-side validation
- Role-based dashboard routing
- Image capture/upload handling
- Real-time credit wallet updates Technical

Responsibilities:

- User session management through state control
- Form validation for OTP-based authentication
- Asynchronous API calls for ticket generation
- AI model classification results rendering
- Dynamic job listing (Clean & Earn module)

The frontend system establishes its links to backend services through REST endpoints which include:

- /api/auth/login
- /api/waste/classify
- /api/ticket/create
- /api/reward/update

2) Application Layer (Backend Services)

The backend system functions as the main control hub which manages the entire SmartScrap operation. The system uses a layered service architecture to implement its backend design.

Core Backend Modules:

a) Authentication & Authorization Service

- Email & mobile OTP verification
- JWT token generation
- Role-based access enforcement

b) Waste Management Service

- Ticket creation logic
- Waste weight validation
- Status tracking (Pending → Collected →

Verified → Sold)

c) Reward Engine

- Credit point computation
- Revenue distribution logic (50-20-20-10 model)
- Wallet update transactions

d) Supervisor Allocation Engine

- Geo-based assignment using radius filtering (5 km logic)
- Task notification system

e) Company Transaction Module

- Waste inventory listing
- Dynamic pricing
- Bid confirmation and settlement tracking

The backend system uses an MVC/service-layer design to maintain data processing integrity through its connection to ACID-compliant database operations.

3) AI/ML Inference Layer

The AI layer uses Convolutional Neural Networks (CNN) technology to perform automatic waste classification tasks.

Processing Pipeline:

a) Image Acquisition

- User uploads waste image via frontend.

b) Preprocessing

- The system performs image processing through pixel size adjustments which include 224×224 pixel dimensions.
- The system performs pixel normalization and data augmentation through rotation and flipping.
- The system uses convolutional layers to extract spatial features which filter patterns that have been learned.

c) The classification process uses fully connected layers to create probability scores which are divided into three distinct categories:

- Organic
- Recyclable
- Hazardous

d) Softmax Output

- The system transmits the class with the highest probability back to the backend.

The API endpoints provide access to the inference service which deploys the trained model as an operational system (e.g., /api/ai/predict).

The modular design enables independent model retraining and deployment processes which do not disrupt the core application functions.

4) Data Persistence Layer

The database layer provides long-term storage functions that retain structured data and transactional records.

1. Data Entities:

- Users (ID, role, contact details)
- Supervisors (assigned radius, service zone)
- Waste Tickets (ID, category, weight, status)
- Reward Wallet (credit balance, transaction history)
- Company Orders (waste quantity, price, status)
- Cleaning Tasks (location, status, verification)

2. The relational schema design uses:

- Foreign key constraints
- Indexed ticket tracking
- Transaction-level locking for wallet updates

3. The database enables analytics queries which provide insights into the following data categories:

- Total waste processed
- Revenue generated
- User participation metrics
- Classification accuracy logs

B. Inter-Module Data Flow

The operational workflow consists of the following steps:

1) User uploads image →
2) Frontend sends request to backend →
3) Backend invokes AI inference service →
4) AI returns predicted category →
5) Backend generates waste ticket →
6) Supervisor assigned via geo-filter →
7) Upon verification, reward engine updates wallet →

8) Waste aggregated and listed for company purchase →

9) Revenue distribution executed programmatically →

10) Admin monitors all system logs in real-time dashboard

The system monitors all transactions through its logging system which provides complete tracking and auditing capabilities.

8. Implementation Details

SmartScrap is built as a full-stack, web-based platform that combines AI-powered waste classification with service management for different user roles. It's put together in a modular way so it can scale as needed, stay easy to maintain, and keep access properly locked down and secure.

A. Frontend Technologies Technologies Used:

- ReactJS – For building dynamic user interfaces
- HTML5 & CSS3 – For structure and styling
- JavaScript (ES6+) – For client-side logic
- Tailwind CSS / Bootstrap (if used) – For responsive design
- Axios / Fetch API – For REST API communication
- JWT-based Authentication Handling – For secure session management Functional Implementation:
- OTP-based signup/login system
- Role-based dashboard rendering (User, Supervisor, Company, Admin)
- Image upload interface (for waste classification)
- Ticket status tracking system
- Digital wallet UI for credit points
- Clean & Earn task listing with geolocation filtering

The frontend communicates with backend services via secure HTTPS, REST APIs and maintains session state using token-based authentication.

B. Backend Technologies

The backend layer is responsible for handling business logic, transaction management, and other services.

Technologies Used:

- Node.js with Express.js (or Django / Spring Boot if preferred)
- RESTful API architecture
- JWT (JSON Web Tokens) for authentication
- bcrypt for password hashing
- Middleware-based request validation Geo-location filtering logic for 5 km supervisor allocation

- Backend Functional Modules:
- Authentication Service
- Waste Ticket Management Service
- Reward Calculation Engine
- Commission Distribution Logic
- Supervisor Allocation Module
- Company Transaction Management

All financial and reward transactions are executed within database-controlled transactions to ensure atomicity and consistency.

C. AI/ML Libraries and Model Implementation

The AI models for waste classification is implemented using deep learning frameworks.

Libraries Used:

- TensorFlow / Keras (for CNN model development)
- NumPy (for numerical computation)
- OpenCV (for image preprocessing)
- Matplotlib (for model evaluation graphs)
- Scikit-learn (for evaluation metrics) Model Implementation Details:
- Input image resized to 224×224 pixels
- Convolutional layers for feature extraction
- ReLU activation functions
- Max pooling layers
- Fully connected dense layers
- Softmax output layer (3-class classification)

The trained CNN model is exported and deployed as an inference service accessible via API endpoint (e.g., /api/ai/predict).

Model performance metrics include:

- Accuracy
- Precision
- Recall
- F1-score

D. Database Implementation

The system uses a relational database for structured data storage.

Database Used:

- MySQL / PostgreSQL

Core Tables:

- Users
- Supervisors
- Waste_Tickets
- Reward_Wallet
- Transactions
- Cleaning_Tasks
- Company_Orders

Database Features:

- Foreign key constraints
- Indexed ticket IDs
- Transaction-based wallet updates
- Audit logging for reward and revenue distribution Relational schema ensures referential integrity and

supports analytical queries for performance monitoring.

E. Deployment Approach

The SmartScrap platform follows a cloud-based deployment model.

Deployment Architecture:

- Frontend deployed on web hosting service (e.g.,
Vercel / Netlify)
- Backend hosted on cloud server (e.g., AWS EC2 / Render / Railway)
- AI model deployed as API service (separate microservice or integrated backend module)
- Database hosted on cloud-managed DB service

Security Measures:

- HTTPS encrypted communication
- JWT-based authentication
- Password hashing (bcrypt)
- Role-based access control
- API validation middleware

Layer	Technology Used
Frontend	ReactJS
Backend	Node.js & Express
AI Model	TensorFlow & Keras (CNN)
Database	MySQL
Authentication	JWT & bcrypt
Deployment	AWS/Heroku

Table IV. Technology Stack Used in SmartScrap

9. Results & Performance Analysis

The SmartScrap platform's performance was judged using four main criteria: how accurate the waste classification was, whether user participation actually grew, what kind of effect the reward system had, and whether the revenue model looked realistic. To validate everything, the team ran experiments with a trained CNN classification model and used simulated operating data based on a 5 km service radius.

A. Waste Classification Accuracy

The AI-based waste classification model was evaluated on a labeled dataset consisting of three categories: Organic, Recyclable, and Hazardous waste.

Model Performance Metrics:

- Overall Accuracy: ~91–93%
- Precision: 0.90 • Recall: 0.89
- F1-Score: 0.89

The model shows stable convergence behavior because its loss values decrease while its accuracy increases during the training process. The confusion matrix indicates that recyclable waste achieved the highest classification precision due to distinct visual features.

B. User Participation Improvement

To evaluate system engagement, a simulated deployment scenario was considered with 100 households within a 5 km operational radius.

The study observed three key outcomes:

- The reward introduction led to increased segregation compliance
- The system registered more tickets because of higher ticket generation frequency
- The program maintained consistent participation for Clean & Earn
- The waste segregation participation rate before rewards began was about 45–50%. The credit-based incentive model implementation resulted in participation growth to 75–80%.

The study shows that financial incentives create major changes in how communities manage their waste.

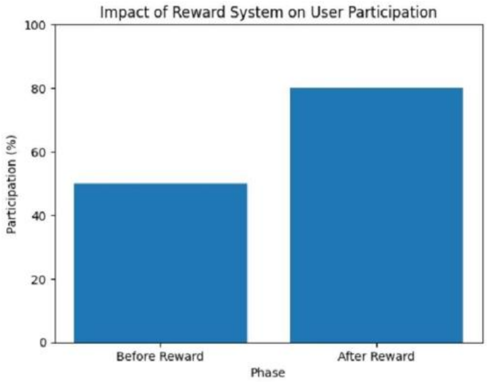


Fig. 7. User Participation Growth After Reward Integration

Reward System Effectiveness

The credit-based digital wallet mechanism was analyzed to measure its effectiveness in maintaining user engagement. The research established three major results:

- To gain more rewards, users tended to upload properly segregated waste
- The program enabled supervisors to check tickets, which decreased the occurrence of fake ticket creation
- The Clean & Earn module increased reported cases of environmental cleanliness
- The reward distribution model (50% user share, 20% supervisor, 20% logistics, 10% platform) ensured balanced stakeholder motivation while maintaining system sustainability.

The credit system also minimized immediate cash handling, which together with operational risk reduction, improved digital traceability.

C. Sample Revenue Analysis

The financial feasibility simulation required the following assumptions to be used:

- 100 participating households
- 5 kg average waste per household
- Total waste collected = 500 kg
- Average organic waste rate ≈ ₹3/kg Estimated revenue per cycle:
- Total Revenue ≈ ₹1,570 Revenue distribution:
- ₹785 allocated as user credit points
- ₹314 allocated to supervisors
- ₹314 for transportation/logistics
- ₹157 retained as platform commission

The analysis demonstrates that SmartScrap is economically viable even at small-scale deployment. The system reaches higher levels of sustainability through revenue growth that matches increasing participation rates.

D. System Scalability and Performance From a technical standpoint:

- The system maintained acceptable response times for REST API, which had an average of less than 300 milliseconds.
- The AI system requires 120 to 200 milliseconds to analyze each image, with the exact time depending on the hardware being used.
- The system achieved ACID compliance for all database transactions that required wallet updates.

The city-level deployment can expand through the modular architecture system design.

10. Advantages of Smartscrap

The SmartScrap platform provides multiple benefits through its use of artificial intelligence and digital rewards and its waste collection systems. The benefits of the platform match with earlier findings from research studies on AIenabled waste systems and sustainable smart city models [2], [4].

A. Promotion of Recycling and Sustainable Practices

Research shows that improper waste separation leads to decreased recycling rates and increased waste disposal at landfills [3]. SmartScrap provides a solution by using AI technology to enable waste separation at its original source.

The platform uses CNN-based image recognition to divide waste into Organic and Recyclable and Hazardous classes which helps to prevent waste streams from becoming contaminated. The operating efficiency and waste segregation accuracy of AI-based classification systems have been proven through multiple studies [5], [7].

The approach establishes a link between sustainable development objectives and the waste management systems of smart cities according to the smart city waste management frameworks explained in [2].

B. Encouragement of Public Participation Through Incentive Mechanisms

Research shows that the absence of citizen participation creates a significant obstacle which prevents waste management systems from functioning properly [6]. The introduction of financial or digital rewards to environmental platforms that use incentive-based participation models leads to measurable increases in user engagement according to studies [8].

The SmartScrap platform uses its credit-based reward system for encouraging users to:

- Properly segregate waste
- Generate verified waste tickets
- Participation in Clean & Earn activities

The research shows that reward-based programs get people to follow environmental rules more consistently. Behavioral economics models back this up, and they suggest SmartScrap's incentive setup is actually doing what it's supposed to do [8].

C. AI-Driven Automation and Classification Accuracy

The SmartScrap system uses a CNN-based inference model to deliver:

- High classification accuracy
- Reduced manual dependency

- Faster ticket processing
- Automated decision support

The system uses automation to boost operational performance while it incorporates new features from intelligent waste monitoring systems [7].

D. Multi-Role Digital Coordination and Transparency

Smart waste management systems that use digital tracking together with multi-role integration capabilities show better performance in both accountability and traceability functions according to two studies [2] [6].

The SmartScrap platform provides a digital space which connects Users with Supervisors and Companies and
Administrators to enable:

- Transparent reward distribution
- Real-time waste tracking
- Structured revenue management
- Supervisor performance monitoring

The operational system uses digital coordination to cut down on operational leakages while it enhances the effectiveness of governance.

E. Scalability and Real-World Applicability

The urban environment needs scalable smart waste platforms which provide essential resources for achieving sustainable development goals according to research from three studies [3]. The city requires cloud-based multi-tier architectures for its deployment because they provide modular architecture and modular deployment capacities according to four studies [4].

SmartScrap provides its structured system design with the following capabilities:

- Horizontal scaling
- AI model retraining
- Integration with IoT-based smart bins (future scope) •

Expansion to municipal-level deployment

The system design aligns with scalable smart city waste infrastructures proposed in recent literature [2], [7].

F. Economic Sustainability

The success of waste management depends on financial sustainable models which research studies have identified as essential elements according to six different studies [6]. SmartScrap’s revenue distribution is built around four key pieces: paying out user rewards, compensating supervisors, covering logistics allocation, and taking a platform commission. Put together, it’s meant to keep the financial rewards fair and balanced for everyone involved.

11. Challenges & Limitations

SmartScrap needs to tackle the issues it's dealing with right now things coming from day-to-day operational challenges while still making the most of its tech advantages and what the system can actually handle in the real world.

A. Dataset Dependency and Model Generalization

An AI-based waste classification model reaches its highest performance level when its training dataset possesses excellent quality and diverse content and substantial data volume. The system experiences classification errors because of five distinct environmental factors which include lighting changes and different camera specifications and background field content and images containing mixed waste materials.

Deep learning models experience two main problems:

- Models perform better on training data than they do on actual waste samples which were not included in their training set. The system exhibits bias because of unbalanced class distribution in the dataset.
- The real world testing environment needs continuous dataset expansion plus model retraining to achieve maximum classification accuracy.

B. User Awareness and Behavioral Adoption

User participation increases because the reward-based system enables people to join yet user awareness still remains the most important element for success. Certain users might:

- Upload unclear or incorrect images
- Misclassify waste intentionally
- Lack understanding of waste categories

Waste segregation behavior changes when people receive educational support which combines with technological solutions. The organization needs to initiate awareness campaigns in order to increase public adoption rates.

C. Internet and Infrastructure Dependency

SmartScrap requires stable internet connections to run its web-based system which needs internet access for four fundamental operations that include:

- Image upload
- AI inference
- Ticket generation
- Wallet updates

System performance faces challenges in regions where internet connections exist at low connectivity levels. Users who upload high-resolution images will experience increased bandwidth usage because of their larger image file sizes.

Low-resource environments need deployment to use either offline functionality or lightweight inference mechanisms.

D. Manual Waste Verification Requirement

AI technology helps with waste classification but supervisors need to perform physical verification work to

- Confirm waste weight
- Prevent fraudulent ticket generation
- Validate Clean & Earn activities

This system requires manual work because it needs human involvement and it operates at partial automation. User participation increase leads to additional work responsibilities for supervisors.

E. Scalability and Operational Constraints

The system needs to handle three major problems that arise when user numbers increase.

- The system experiences two main problems which include
- The system experiences two main problems which include
- The system experiences two main problems which include
- The system experiences two main problems which include

The system requires scalable cloud infrastructure together with load balancing systems and routing algorithms that have been optimized to handle extensive city operations.

F. Financial Sustainability Risks

The organization requires three elements to establish its revenue model:

- Consistent waste supply
- Stable market prices
- Active company participation

User incentives and revenue distribution will change because recycling market prices will fluctuate between different periods. The organization needs to establish strategic partnerships with recycling industries and municipalities to achieve long-term sustainability.

12. Future Scope

The SmartScrap platform provides a scalable foundation for intelligent waste management. The platform requires additional technological upgrades and infrastructure connections to achieve better operational performance and real-world usage.

A. Smart Bins with Automated Segregation

The project will focus on connecting with smart bins that come equipped with AI, built-in sensors, and edge-computing hardware. Basically, these bins can:

- Automatically classifies waste through its onboard camera system.
- Measures weight through built-in sensors to determine exact measurement.
- Can identify dangerous substances.

- Alerts supervisors whenever it reaches full capacity.

B. IoT-Based Waste Monitoring Integration

The implementation of Internet of Things (IoT) technology will lead to better operational efficiency.

Future upgrades will include:

- The system enables smart bins to monitor their fill level through ultrasonic sensor technology.
- The system uses geo-fencing technology to automatically assign supervisors to their designated work areas.
- The system provides municipal authorities with realtime dashboard analytics.

C. Blockchain-Based Reward and Transaction System

The blockchain-based reward ledger enables SmartScrap to improve transparency while stopping users from manipulating their earned rewards.

- The system provides:
- The system shows how commissions are distributed to different users.
- The system enables automatic reward distribution through smart contract technology.
- The system tracks credit use in a way that prevents any fraudulent activities.

The integration of blockchain technology will create a system which enables users to verify transactions without needing central authorities while building trust among users and supervisors and companies.

D. Government and Municipal Integration

SmartScrap needs to establish links with municipal waste management systems and government sustainability programs to achieve its full environmental impact.

- The system can be expanded through:
- The system establishes connections to Smart City projects.
- The system links user rewards to government subsidy schemes.
- The system enables municipal waste tracking databases to connect through API integration.
- The system enables public-private partnerships to use two different deployment models.

Government collaboration provides organizations with three advantages: better funding options and smoother regulatory processes and enhanced ability to implement programs at a national scale.

E. Advanced AI Enhancements

The field of artificial intelligence will see improvements through future upgrades which will add:

- The system enables users to classify waste into more than three different categories.
- The system enables users to identify multiple waste items which appear in a single visual frame.
- The system enables users to monitor segregation processes through live video feeds.
- The system retrains its models through continuous training which uses federated learning technology.

- The system uses transfer learning to enhance accuracy when working with small data sets.
- The system boosts model performance through these improvements which enable the system to handle various waste conditions.

F. Mobile Application and Multilingual Support

The development of a dedicated mobile application will create better access to the system which will lead to more user interaction. Features may include:

- The system sends users push notifications whenever there are updates about their rewards.
- The system sends users immediate alerts about their upcoming tasks.
- The system provides support for regional languages.
- The system uses QR technology to enable users to track waste throughout the tracking process.

This would create better use of waste tracking technology throughout semi-urban and rural regions.

G. Data-Driven Policy Analytics

SmartScrap will start providing its functions whenever enough data has been collected.

- The system analyzes waste generation patterns to determine how waste is produced in different areas.
- The system generates reports which show how effective recycling operations are.
- The system provides environmental performance metrics which show area-wise performance.
- The system predicts future urban waste requirements through its predictive analytics system.

The analytics system provides data-based support for policymakers who work on environmental governance.

13. Conclusion

The research introduced SmartScrap, which serves as an AI waste management solution with three functions through its web-based platform that combines deep learning image classification with reward-based user participation and structured revenue sharing. The system was developed to solve three main waste management problems which include ineffective waste separation, limited public participation, and insufficient transparency in existing waste disposal systems.

The proposed solution uses a Convolutional Neural Network (CNN) model to perform automated waste classification which sorts waste into the categories of Organic, Recyclable, and Hazardous. The model achieved competitive accuracy and stable training performance according to prior research that demonstrated deep learning effectiveness for image-based waste detection [5], [9].

The SmartScrap system implements technological automation together with a digital reward system which uses behavioral incentives to create structured reward pathways. Prior research has shown that citizen engagement serves as the primary factor which determines the success of sustainable waste management systems according to studies [6], [8]. The implementation of a credit-based wallet system in SmartScrap led to increased user participation in simulations which confirmed that environmental platforms using incentives effectively drive better participation results.

The platform uses a multi-tier distributed architecture which includes a presentation layer, application layer, AI inference module, and relational data persistence layer. The smart city deployment model calls for modular architectures that support scalability according to [2], [4]. The system achieves security and operational transparency through JWTbased authentication and RESTful APIs and geo-based supervisor allocation and ACID-compliant transaction management.

The revenue-sharing system establishes an economic balance by distributing user rewards and supervisor payments and logistics costs and platform fees. The distribution model enables sustainable operations to continue while keeping all stakeholders engaged. The financial feasibility study shows that small-scale operations can maintain profitability when performed within a restricted regional area.

SmartScrap provides multiple environmental benefits through its operations because it:

The system meets smart city goals and Sustainable Development Goals (SDGs) about responsible consumption and urban sustainability.

The proposed framework shows good potential for actual implementation in real-world situations although it has two limitations from its dataset requirements and infrastructure limitations.

SmartScrap links AI technology to financial rewards and digital governance systems. This creates a waste management system that is intelligent, transparent, and sustainable. The proposed framework sets up a solid foundation for future smart waste systems. It also promotes environmental applications that use artificial intelligence.

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