



SMART WASTE MANAGEMENT SYSTEM

R26-IT-126





TEAM MEMBERS



- **Supervisor** – Mr. Uditha Dharmakeerthi
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INTRODUCTION

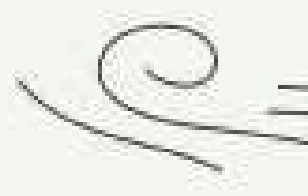
Rapid urbanisation has significantly increased municipal waste generation, creating challenges for city waste management systems.

Traditional waste collection relies on fixed schedules, often leading to overflowing bins and inefficient routes.

This problem affects municipal authorities, waste collection services, and urban communities, causing environmental and operational issues.

This project proposes a Smart Waste Management System using IoT and Machine Learning to predict bin overflow and enable priority-based waste collection.





RESEARCH PROBLEM

- Cities generate large amounts of municipal waste due to urbanization
- Waste collection often relies on fixed schedules
- This leads to bin overflow, inefficient routing, and higher operational costs

AFFECTED STAKEHOLDERS

- Municipal councils
- Waste collection service providers
- Urban communities
- Recycling Facilities and Waste Processing Centers



Current smart waste management systems mostly focus on monitoring bin status and sending alerts, but they lack predictive, adaptive, and integrated intelligence. Our proposed system is introduced to fill this gap by combining IoT, machine learning, waste composition analysis, and predictive routing support for more efficient and proactive waste management.



PROPOSED SOLUTION

The proposed Smart Waste Management System integrates sensing, monitoring, prediction, and analytics to move waste operations from reactive management to proactive decision-making.

The system combines:

- **IoT-based environmental sensing smart bins**
- **Smart fill-level and occupancy monitoring**
- **ML-based waste composition prediction**
- **Predictive analytics and dynamic routing**

Together, these components improve collection efficiency, recycling readiness, and sustainable waste handling.





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Machine Learning Based Waste Composition Forecasting Engine
Predicts next-day waste composition for better planning
Forecasts waste composition before collection

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RESEARCH PROBLEM



Existing waste management systems can monitor waste conditions and support collection operations, but they do not predict waste composition in advance. This limits early recycling preparation and efficient waste processing.

PROPOSED SOLUTION (NOVELTY)

Introduces a machine learning-based approach to forecast waste composition before collection, moving beyond traditional systems that mainly monitor waste after disposal. By providing advance insight into expected waste categories, it supports proactive recycling preparation, better resource allocation, and more efficient waste management decisions.

RESEARCH GAP

Features	Waste Forecasting Research [1][2]	Smart Waste Monitoring Research [3][4]	Proposed Project
Waste Volume Prediction	✓	✗	✓
Waste Composition Prediction	✗	✗	✓
Machine Learning-Based Forecasting	✓	✗	✓
Data-Driven Recycling Preparation	✗	✗	✓
Integration of Contextual Data (Weather, Calendar)	✗	✗	✓

OBJECTIVE

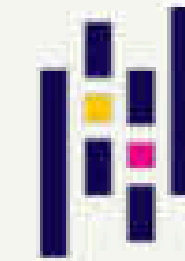
To develop a machine learning based waste composition forecasting system capable of predicting the next-day distribution of major waste categories

SUB OBJECTIVES

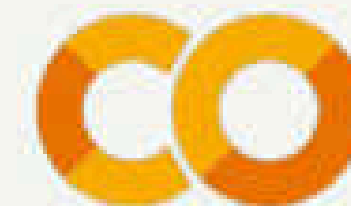
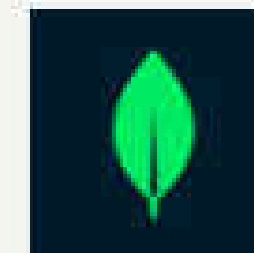
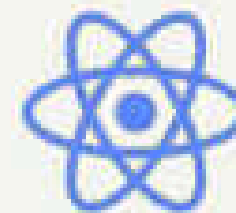
- To develop a machine learning based waste composition forecasting system capable of predicting the next-day distribution of major waste categories
- Identify features affecting waste composition
- Train and compare ML models
- Evaluate prediction accuracy
- Visualize forecast results for decision-making

TOOLS AND TECHNOLOGIES

- **Programming Language:** Python
- **Data Processing Libraries:** Pandas, NumPy
- **Machine Learning Frameworks:** Scikit-learn, XGBoost, TensorFlow
- **Data Visualization:** Matplotlib, Seaborn, Plotly
- **Visualization Dashboard:** React
- **Data Storage:** MongoDB
- **Development Environment :** Jupyter Notebook, Google Colab, VS Code



XGBoost



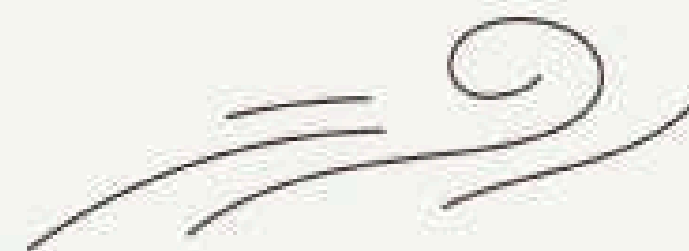


How to Validate and Evaluate the Proposed Solution

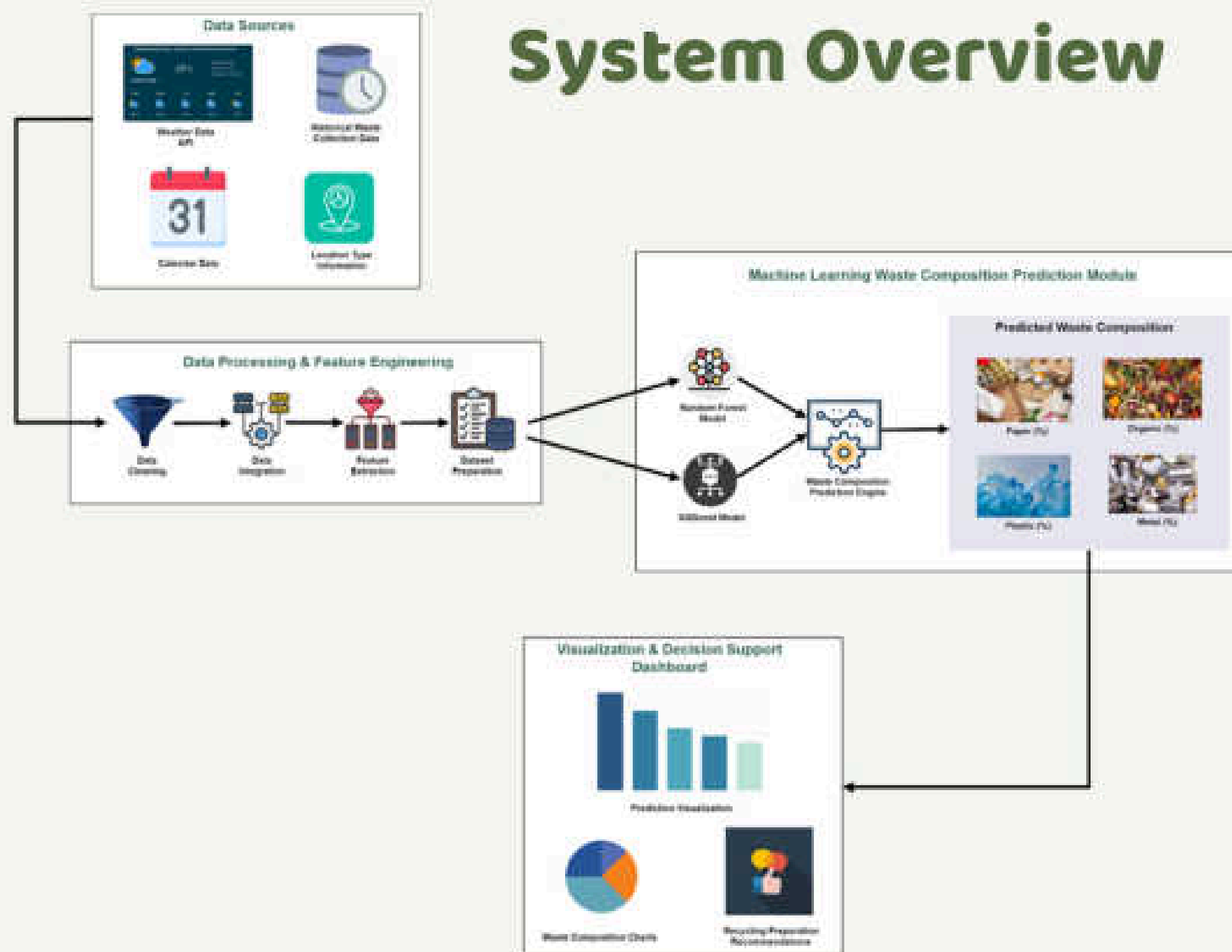
The proposed solution will be validated through experimental machine learning evaluation by comparing Random Forest and XGBoost models. Performance will be measured using MAE, RMSE, and cross-validation to ensure prediction accuracy and reliability.

Data Availability, Security and Ethical Clearance

The system will use historical waste records, weather data, calendar data, and location characteristics. Since it mainly processes environmental and operational data, privacy concerns are limited; however, secure APIs, access control, backups, and responsible data handling are required to ensure security and ethical compliance.



System Overview



Dependencies and Common Components

Uses common data resources such as **waste collection records**, **environmental data**, and **operational context**, while its prediction output supports wider system functions such as planning, recycling preparation, and decision-making. The dashboard, storage environment, APIs, and cloud-compatible tools also act as common supporting components across the solution.

REFERENCES

- [1] M. Abbasi and A. E. Hanandeh, "Forecasting municipal solid waste generation using artificial intelligence modelling approaches," Waste Management, vol. 56, pp. 13-22, 2016.
- [2] M. Kannangara, R. Dua, L. Ahmadi and F. Bensebaa, "M. Kannangara; R. Dua; L. Ahmadi; F. Bensebaa," Waste Management, vol. 74, p. 3-15, 2018.
- [2] Bigbelly, "Smart Trash Cans & Recycling Bins," [Online]. Available: <https://www.bigbelly.com>.
- [3] Sensoneo, "Smart Waste Management," 2026. [Online]. Available: <https://www.sensoneo.com>.



IT22202772 | GAMAARIYA C. C.

Smart Fill-Level & Occupancy Monitoring

Acts as the core sensing layer by generating real-time fill and occupancy intelligence for downstream analytics.
Transforms passive fill sensing into behavior-aware smart waste monitoring

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Research Problem

- 
- Fixed schedules ignore real-time bin status → inefficient routing.
 - No continuous visibility into bin state → overflows before collection.
 - Unnecessary collection trips increase operational cost and emissions.
 - Hygiene, odor, and public-health issues from unexpected overflow.
 - Problem statement: Decisions are made without real-time physical bin data.

Research Gap

Existing smart bins only measure how full they are. Our system also watches how the bin is being used - detecting illegal dumping, unusual lid activity, and overflow risks before they happen.

Existing Systems

- Fill-level measurement only
- Limited behavioral context and usage pattern analysis
- Static threshold-based alerts
- Limited anomaly detection

VS

Proposed Solution

- Integrated fill-level and occupancy monitoring
- Real-time usage anomaly detection
- Alerts for unusual bin usage
- Identifies abnormal waste disposal

Novelty of the Component



Real-time fill-level monitoring

Continuously measures waste level inside the bin.

Lid activity-based occupancy tracking

Monitors bin usage through lid opening events.

Detects unusual waste disposal

Identifies sudden fill changes and abnormal dumping.

It watches how people behave and senses the bin to detect waste more smartly.

OBJECTIVE

Develop an IoT-based smart bin module to monitor fill-level and occupancy in real time

SPECIFIC OBJECTIVES

- Detect internal waste fill levels (Low / Medium / High / Critical)
- Track lid activity and occupancy behavior
- Detect abnormal disposal patterns (illegal dumping, sudden fill spikes)
- Send real-time data to cloud for prediction and routing



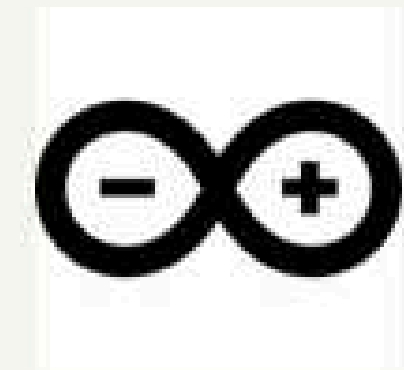
Tools and Technologies

Hardware Platform

- ESP32 microcontroller
- HC-SR04 ultrasonic sensor (fill-level)
- Magnetic reed switch (lid activity)

Software / Cloud

- Firebase Realtime Database
- Microsoft Azure
- MQTT / HTTP for communication



Methodology & Validation

Sensor Layer → ESP32 → Firebase → Azure → Dashboard

Methodology

- Sensor reads waste fill level continuously
- Lid activity is detected through reed switch
- ESP32 processes sensor data locally
- Data is uploaded to cloud for monitoring

Validation

- Fill detection accuracy target >95%
- Alert response time <3 seconds
- Detects abnormal waste disposal events

Expected Outcomes & Operational Benefits

- **Operational efficiency:** Fewer waste collection trips by using accurate bin fill data and smart route planning
- **Cost savings:** Lower fuel and labor costs from demand-driven pickups.
- **Improved service levels:** Faster response to Critical fill and illegal dumping incidents.
- **Data value:** Real-time data helps prediction modules plan future waste collection better

REFERENCES

- [1] World Bank, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, Washington, DC, USA, 2018.
- [2] M. A. Mamun, M. A. Hannan, A. Hussain, and H. Basri, "Integrated sensing systems and algorithms for solid waste bin state management automation," IEEE Sensors Journal, vol. 16, no. 14, pp. 5614–5624, 2016.
- [3] K. J. Pardini, J. J. P. C. Rodrigues, S. A. Kozlov, N. Kumar, and V. Furtado, "IoT-based solid waste management solutions: A survey," Journal of Sensor and Actuator Networks, vol. 8, no. 1, pp. 1–25, 2019.
- [4] Microsoft, "Azure IoT Hub Documentation," Microsoft Learn, 2024.



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IoT-Based Environmental Sensing Smart Bin

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Research Problem



Existing Waste Management Challenges

- Lack of real-time bin monitoring
- Overflowing waste bins
- Inefficient collection scheduling
- Increased fuel and labor costs
- Environmental hazards due to unmanaged waste

RESEARCH GAP

	Gas Detection	Weight Measurement	Multi-Parameter Sensing	Environmental Monitoring
Research [4] Mamun et al., 2016	✗	✗	✗	✗
Research [8] Pardini et al., 2019	✗	✗	✗	✗
Proposed System	✓	✓	✓	✓

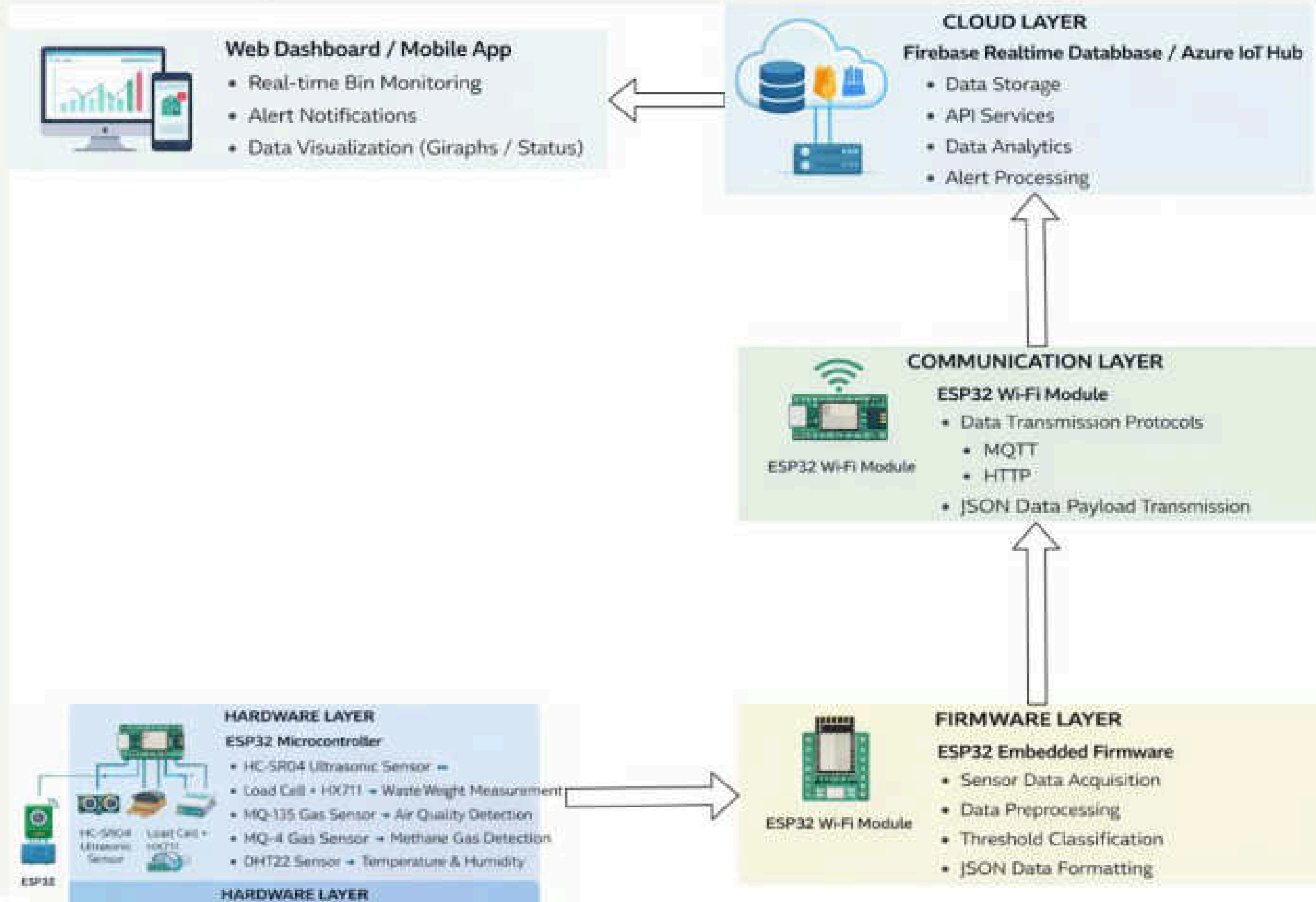
Main Objective

To design and implement a multi-parameter IoT smart bin system capable of monitoring waste conditions and transmitting real-time data to cloud platforms for intelligent waste management.

Sub Objectives

- Develop a sensor-based smart bin using ESP32 microcontroller
- Measure waste fill level using ultrasonic sensor
- Measure bin weight using load cell sensor
- Detect harmful gases using MQ-series sensors
- Monitor environmental conditions using temperature and humidity sensors
- Transmit real-time data to cloud platforms

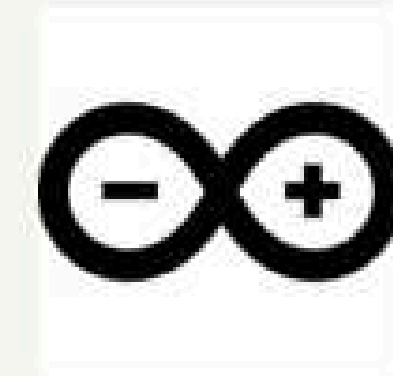
System Architecture



Tools and Technologies

Hardware Platform

- ESP32 Microcontroller
- IoT Sensor Modules



Sensors

- HC-SR04 Ultrasonic Sensor
- Load Cell + HX711 Amplifier
- MQ-135 Gas Sensor
- MQ-4 Methane Gas Sensor
- DHT22 Temperature & Humidity Sensor



Software Development

- Arduino IDE
- C++ Embedded Programming



Cloud Platforms

- Firebase Realtime Database
- Microsoft Azure IoT Hub

Communication Protocols

- MQTT
- HTTP



References

- [1] K. Pardini, J. J. P. C. Rodrigues, S. A. Kozlov, N. Kumar, and V. Furtado, "IoT-based solid waste management solutions: A survey," *Journal of Sensor and Actuator Networks*, vol. 8, no. 1, p. 5, 2019, doi: 10.3390/jsan8010005.
- [2] S. Longhi, D. Marzioni, E. Alidori, G. Di Buò, M. Prist, M. Grisostomi, and M. Pirro, "Solid waste management architecture using wireless sensor network technology," in *Proc. IEEE Int. Conf. on New Technologies, Mobility and Security*, 2012, pp. 1–5. doi: 10.1109/NTMS.2012.6208700.

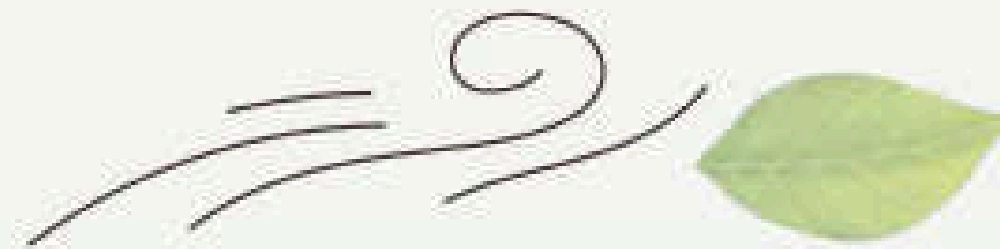


IT22088482 | WIJESIRI A. M

Develops ML model-Predictive Analytics and Dynamic Routing for Smart Waste Collection

Contribution: Develops ML model to predict bin overflow risk
Uses historical and real-time IoT data
Generates priority-based dynamic routes
Improves waste collection efficiency

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Predictive Analytics and Dynamic Routing for Smart Waste Collection

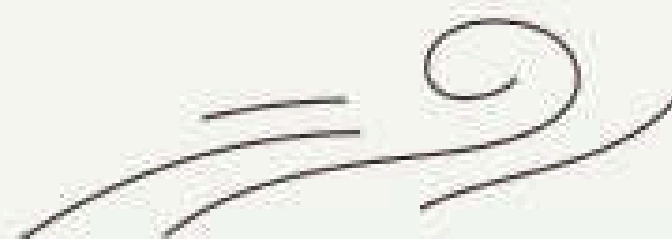
Novelty:

Uses machine learning to predict bin overflow risk and time-to-overflow before it happens using historical and real-time IoT sensor data.
The system enables priority-based dynamic waste collection routing, allowing waste trucks to collect high-risk bins first instead of following fixed schedules.



Problem Definition:

- Waste collection in many cities still follows fixed schedules, ignoring the real fill level of bins.
- Some bins overflow before collection, causing environmental and public health issues.
- Other bins are collected while still partially empty, wasting fuel and operational cost.
- Current smart bin systems mostly provide real-time monitoring but lack predictive intelligence.





Research Objective & Sub-Objectives:

Objective

Develop a machine learning–based predictive analytics and dynamic routing system that forecasts bin overflow risk and optimizes waste collection routes.

Sub-Objectives

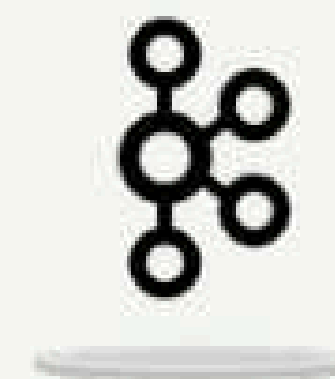
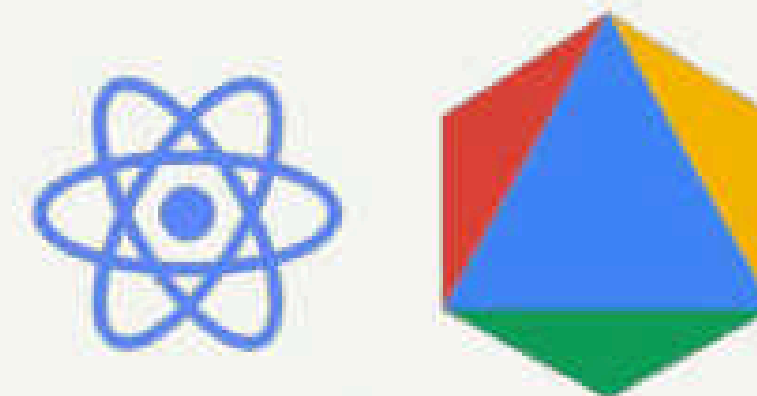
- Collect historical and real-time IoT bin data.
- Predict bin overflow risk and time-to-overflow using ML models.
- Classify bins into priority levels (Green / Yellow / Red).
- Generate optimal dynamic collection routes for waste trucks.
- Provide decision support through a visual dashboard for waste management authorities.





LATEST TECHNOLOGIES USED TO DEVELOP THE PROPOSED SOLUTION

- **Machine Learning Models**
Random Forest, XGBoost – bin overflow prediction
- **Data Streaming Platform**
Apache Kafka – real-time IoT data processing
- **Route Optimization Algorithm**
Google OR-Tools (Vehicle Routing Problem)
- **Data Storage System**
PostgreSQL database
- **Visualization Dashboard**
React dashboard for monitoring & alert
- **AI Explanation Module**
LLaMA for decision explanation





How to Validate and Evaluate the Proposed Solution

Prediction Accuracy:

Evaluate the ML models by comparing predicted bin overflow risk / time - to-overflow with actual bin fill-level data.

Model Evaluation Metrics:

Assess model performance using MAE, RMSE, and R^2 score for prediction accuracy.

Routing Efficiency:

Measure improvements in distance traveled, collection time, and number of overflow incidents compared with traditional fixed waste collection schedules.



Data Availability, Security and Ethical Clearance

Data Availability:

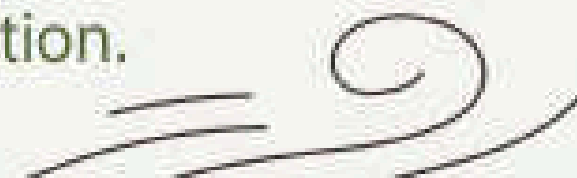
Historical waste bin data and real-time IoT sensor readings collected from smart waste bins.

Security:

Bin data, prediction outputs, and routing results are stored securely in the PostgreSQL database with controlled system access.

Ethical Considerations:

The system processes environmental and operational waste data only, without collecting personal or sensitive user information.





System Overview

- IoT smart bins send real-time fill level data and bin events to the system.
- Data is streamed through Apache Kafka and stored in the system database.
- Machine learning models (Random Forest / XGBoost) analyze historical and real-time data to predict bin overflow risk and time-to-overflow.
- Predicted risk levels classify bins into Green, Yellow, and Red priority categories.
- Route optimization using Google OR-Tools generates dynamic collection routes for waste trucks.
- Results are displayed in the dashboard with bin alerts, risk indicators, and optimized routes.

Dependencies and Common Components

Hardware:

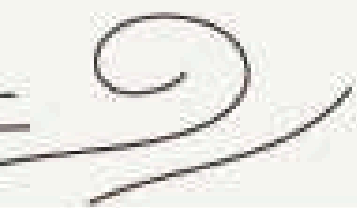
IoT smart bins with fill-level sensors (provided by other system components).

Software:

Python, Machine Learning libraries (Scikit-learn, XGBoost), Apache Kafka, Google OR-Tools.

Common Components:

PostgreSQL database, shared IoT data pipeline, system monitoring dashboard, alert notification system.



SMART WASTE MANAGEMENT SYSTEM

Commercialization

Sell as a smart waste monitoring and prediction platform

Investment/Cost

Development, cloud, hardware, and maintenance costs

Pricing

Subscription-based plans for different customer types

Target Market

Municipalities, campuses, waste companies, recycling facilities

Customer Profile

Waste management authorities and facility managers

Value Proposition

Lower cost, better planning, improved recycling

IP Rights

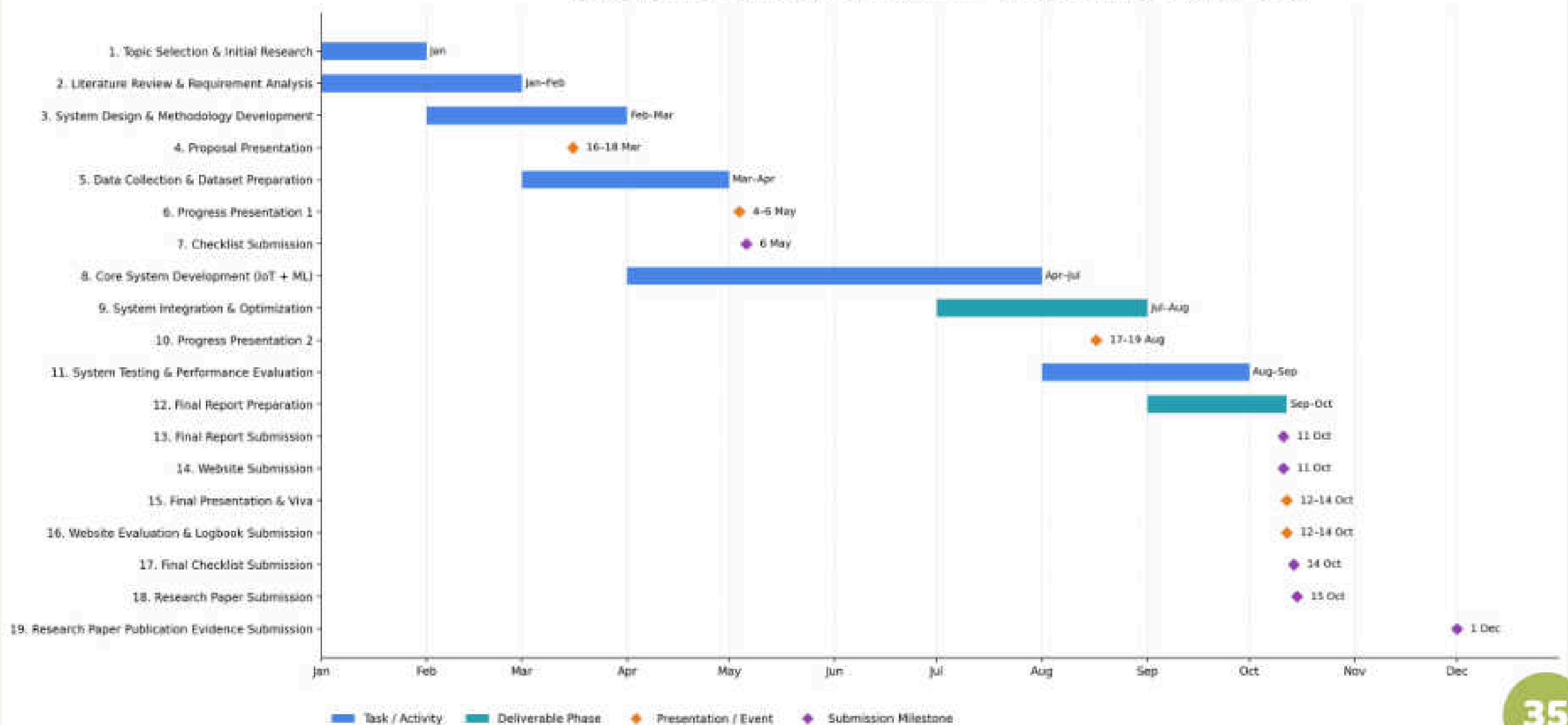
Software, ML models, and analytics dashboard



GANTT CHART

Final Year Research Project - Department of Information Technology

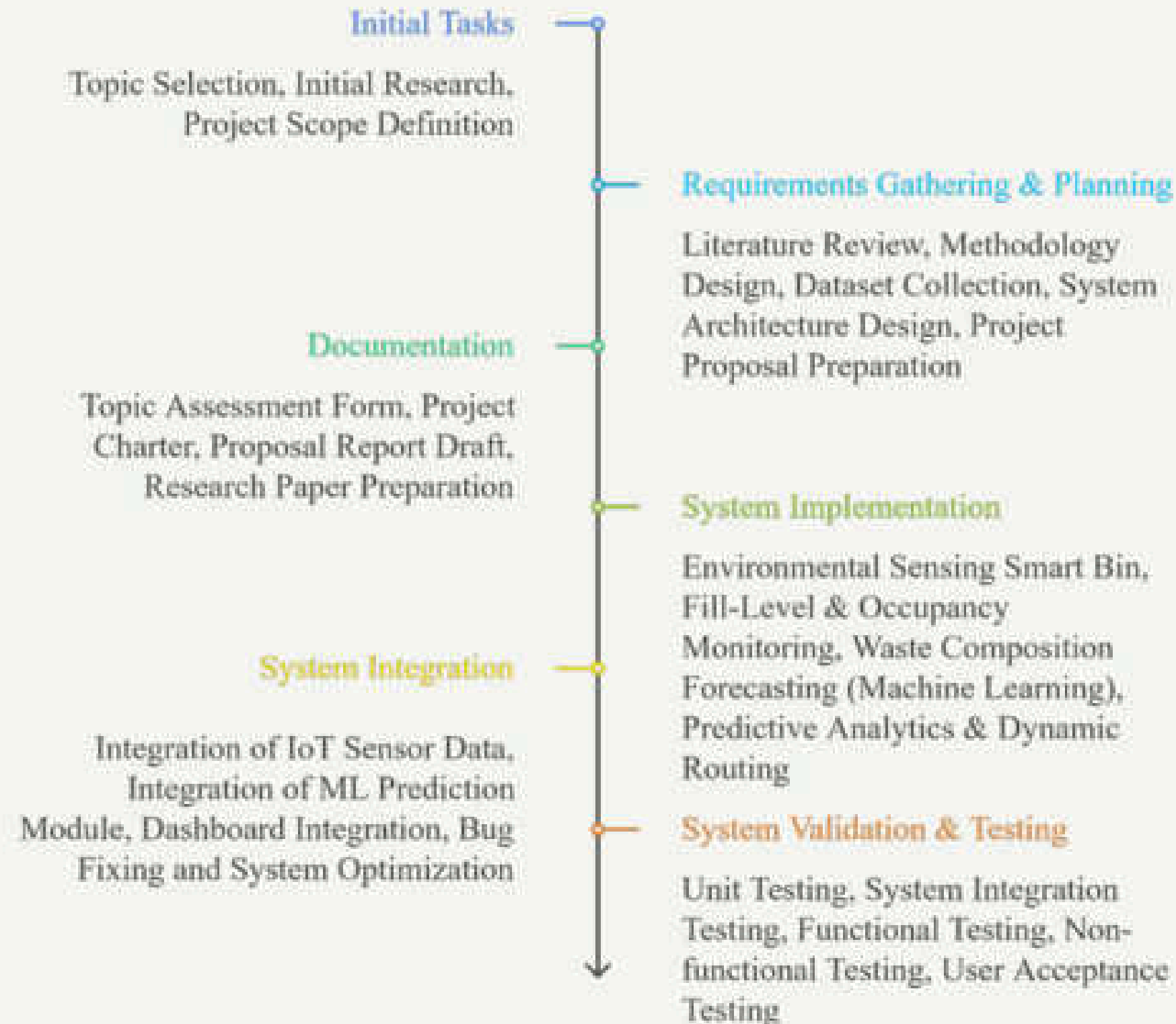
Smart Waste Management System - Project Gantt Chart (2026)



WORK BREAKDOWN

Smart Waste Management System

Data-Driven System Integrating IoT Monitoring and Machine Learning-Based Waste Forecasting





**THANK
YOU**