

Project ID:

R26-IT-126

1. Topic (12 words max)

Smart Waste Management System

2. Research group the project belongs to

TIM - Technology Integration and Management

3. Specialization of the project belongs to

Information Technology (IT)

4. If a continuation of a previous project:

Project ID	
Year	

5. Brief description of the research problem including references (300 words max) – references not included in word count.

Traditional waste management systems are widely recognized as inefficient and unsustainable, particularly in the context of rapidly urbanizing cities and the escalating volume of waste generation. Conventional approaches typically depend on predetermined collection schedules and fixed routes, lacking real-time visibility into bin conditions or waste generation patterns. Consequently, service providers remain unaware of actual waste accumulation until bins overflow, rendering the process reactive rather than proactive. Such inefficiencies result in unnecessary collection trips, elevated fuel and labor costs, environmental hazards including pest proliferation, and suboptimal adherence to sustainability and hygiene standards [1]. Moreover, the absence of data-driven decision support limits the ability of municipal and private operators to plan effectively for peak demand periods and to optimize recycling operations [2] [3] .

The primary research problem addressed in this study is the lack of an integrated, intelligent system capable of simultaneously capturing real-time sensor data, analyzing user behavior, forecasting waste composition, and dynamically optimizing collection routes. Although recent advances in the Internet of Things (IoT) and artificial intelligence (AI) demonstrate considerable potential, existing solutions predominantly address isolated aspects of the waste management lifecycle such as fill level monitoring or route optimization without offering a comprehensive, end-to-end predictive framework [4].

Scholarly research emphasizes that real-time monitoring combined with predictive analytics is essential to transitioning waste management from a reactive to a proactive paradigm. IoT-enabled sensors can continuously collect multi-parameter data including

fill levels, weight, temperature, and gas concentrations which, when integrated with machine learning models, can facilitate accurate forecasting of waste accumulation patterns and composition. Such predictive capabilities have the potential to significantly reduce operational costs, enhance recycling efficiency, and prevent overflows and associated environmental risks [5].

Despite these technological advancements, critical gaps remain in integrating heterogeneous data streams into a unified predictive and optimization platform and in validating these systems at scale in real-world operational environments. Addressing these gaps is vital for achieving smarter, sustainable, and cost-efficient waste management practices.

References

- [1] *Waste Management (Elsevier)*.
- [2] "National Waste Management Policy documents".
- [3] "Colombo Municipal Council (CMC) Reports," 2020-2030.
- [4] M. S. a. P. D. Kumar, "Wireless Sensor Networks and IoT," *Smart City Waste Management Using Sensor-Driven IoT Architecture and Predictive Analytics,* **Journal of Wireless Sensor Networks and IoT*.
- [5] T. E. L. B. S. N. A. C. V. K. a. N. S. H. L. Yadav, *Smart Waste Management Systems: IoT And AI Approaches To Sustainable Urban Sanitation,* **International Journal of Environmental Sciences*.

6. Brief description of Existing Research and Systems (300 words max)

Current waste management systems predominantly operate in a reactive manner, relying on fixed-route schedules without real-time monitoring of bin conditions. Such approaches result in inefficiencies including unnecessary collection trips, overflowing bins, environmental hazards, increased operational costs, and limited recycling performance. Existing studies highlight that conventional systems lack integration of IoT sensing, predictive analytics, and dynamic routing, limiting their ability to make data-driven operational decisions.

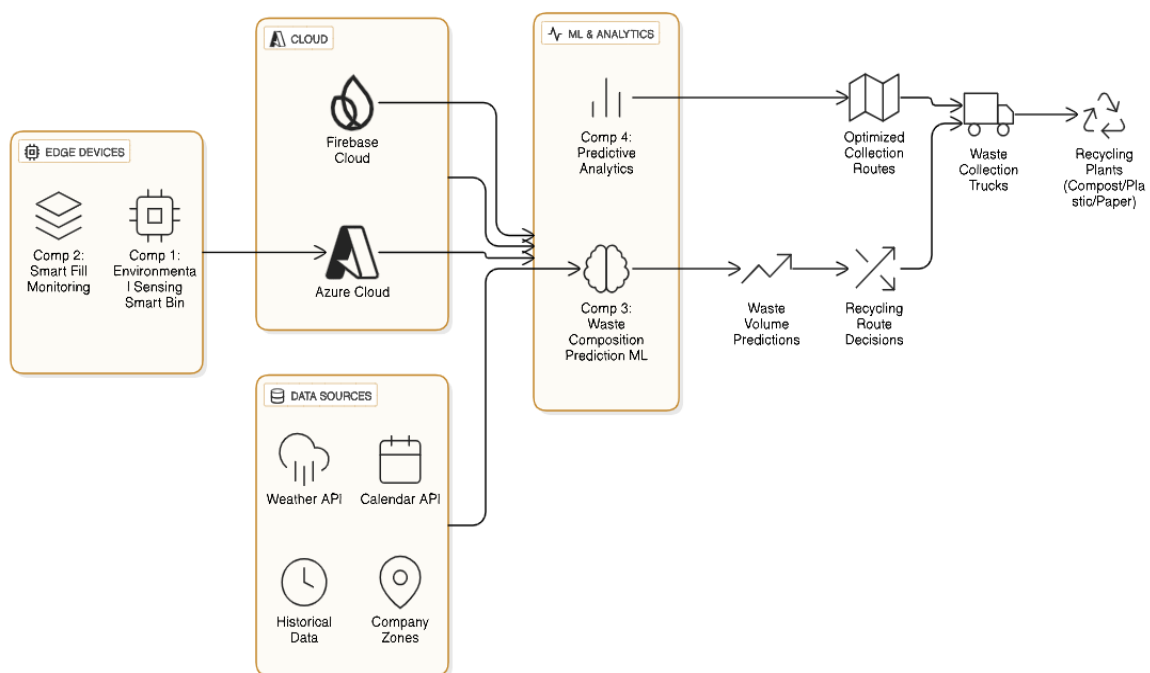
Recent research has explored the potential of IoT-enabled smart bins, equipped with sensors to measure fill level, weight, temperature, humidity, and hazardous gas concentrations. These systems provide real-time environmental monitoring and early detection of unsafe or overflowing bins, improving operational visibility and reducing hygiene risks. Studies demonstrate that combining multi-level fill sensing and lid-opening tracking allows detection of irregular waste disposal patterns, illegal dumping, and high-frequency usage, which can inform behavior-based planning and preventive collection.

Machine learning approaches, such as Random Forest and XGBoost, have been employed to predict waste composition based on historical collection data, area type, date information, and weather forecasts. Predictive models enable pre-collection planning for different waste types, increasing recycling efficiency and reducing sorting costs. Furthermore, integration of predictive analytics with dynamic routing algorithms facilitates selection of only bins requiring service and optimization of collection routes, resulting in lower fuel consumption, reduced labor costs, and minimized missed pickups.

Despite these advancements, most existing solutions address isolated components of the waste management lifecycle rather than offering a comprehensive, end-to-end framework. There remains a research gap in integrating multi-parameter IoT data streams, predictive waste composition models, and dynamic route optimization into a single system validated at scale. Addressing this gap is critical to transforming waste collection into a proactive, cost-effective, and environmentally sustainable process, providing operational, social, and academic value.

7. Brief description of the solution's nature, including a conceptual diagram (maximum 500 words).

The proposed system is a cloud-centric smart waste management framework designed to integrate instrumented bins, external contextual data sources, and machine learning services to enable data-driven operational planning for waste management companies. At the edge layer, environmental sensing smart bins and smart fill-level monitoring units continuously capture parameters including fill level, weight, gas concentrations, temperature, humidity, and lid-open events. These measurements are timestamped, structured, and transmitted to the cloud using standard network protocols, ensuring real-time visibility of bin status.



Within the cloud layer, incoming data from all bins is consolidated into platforms such as Microsoft Azure and Firebase Cloud, where it is integrated with auxiliary contextual information from sources including weather APIs, calendar APIs, historical collection records, and company-defined zone boundaries. This comprehensive data lake forms the foundation for subsequent advanced analytics and predictive modeling.

The machine learning and analytics layer comprises two principal modules: a waste composition prediction module and a predictive analytics engine. The waste composition module leverages historical waste patterns, meteorological data, calendar information, and zone characteristics to forecast upcoming waste volumes and material fractions (e.g., organic, plastic, paper, and metal) for each collection period. Concurrently, the predictive analytics engine estimates the critical status of individual bins and identifies zones with imminent service requirements, facilitating proactive resource allocation.

At the decision and action layer, these predictions are translated into optimized collection and recycling routes, which are communicated to waste collection vehicles and downstream

recycling facilities. This ensures that operational decisions are informed by real-time data and predictive insights, thereby enhancing service efficiency and resource utilization.

Conceptually, the system operates as a sequential flow: edge devices (environmental and fill-level sensors) transmit data to the cloud; cloud storage is enriched with external datasets; machine learning models generate waste volume forecasts and routing decisions; and these outputs are applied to optimize collection and recycling operations. This closed-loop framework effectively integrates sensing, predictive analytics, and operational execution, promoting a proactive, efficient, and sustainable waste management process.

8. Brief overview of the availability of necessary specialized domain expertise, knowledge, and data. (500 words max)

The proposed smart waste management system integrates knowledge from municipal waste operations, embedded systems, cloud computing, and machine learning. While undergraduate project team members are unlikely to possess extensive expertise in all these domains at the outset, the requisite knowledge is realistically attainable within the project timeframe through structured learning, guided consultation, and practical experimentation with existing datasets and tools.

A comprehensive understanding of waste management operations is essential for designing realistic and effective system prototypes. Team members can acquire domain knowledge through desk-based research, including the study of government reports, municipal waste management plans, and industry white papers. These resources provide insights into typical collection practices, bin typologies, route planning constraints, cost structures, and regulatory requirements regarding hygiene, overflow prevention, and recycling targets. In addition, short, semi-structured consultations with waste collection supervisors, facility managers, or private contractors can contextualize these findings, providing practical perspectives on operational constraints such as truck capacities, shift patterns, and limitations of conventional fixed-route systems. This combination of literature review and practitioner input enables the project team to define realistic operational scenarios, select appropriate system parameters (e.g., bin sizes, collection frequencies), and establish meaningful evaluation criteria for prototype testing.

Gaining Technical Knowledge and Skills

The technical implementation leverages widely used and well-documented technologies, ensuring accessibility for undergraduate developers. For the edge layer, team members can develop expertise in ESP32 programming, sensor interfacing, and communication protocols (MQTT/HTTP) through online tutorials, prior coursework, and open-source examples for ultrasonic, gas, load cell, and temperature sensors. For cloud and analytics components,

resources from platforms such as Microsoft Azure, Firebase, and Python-based data science communities provide stepwise guidance for database configuration, API integration, and dashboard development. Machine learning modules, including Random Forest and XGBoost models for waste composition prediction and criticality estimation, can be implemented using scikit-learn following standard workflows for data preprocessing, feature engineering, model training, and evaluation using metrics such as MAE, RMSE, and classification accuracy. Internal knowledge sharing, through peer programming sessions, code reviews, and technical presentations, ensures equitable distribution of technical expertise across team members.

Data Collection and Availability

The project relies on three primary data sources

- (1) real-time sensor streams from prototype smart bins, capturing fill levels, weight, gas concentration, temperature, humidity, and lid-open events
- (2) historical or simulated waste collection records, including date, zone type, collection volume, and approximate waste composition
- (3) contextual data such as weather conditions and calendar features (e.g., weekdays, weekends, and public holidays).

Pilot deployment of a limited number of instrumented bins in controlled environments (e.g., campus zones) allows the collection of authentic time-series data. Where comprehensive historical records are unavailable, realistic synthetic datasets can be generated based on published waste statistics and patterns, clearly labeled as simulated. Publicly available or freemium APIs for weather and calendar information further enrich the dataset at minimal cost.

Ethical Considerations

The project primarily involves environmental and operational data and does not process personal or sensitive information, thus representing a low-risk scenario from an ethical perspective. Nonetheless, it is advisable to seek institutional review or expedited ethical clearance to formally document data collection, storage, and management practices. This ensures compliance with institutional guidelines and promotes responsible research conduct.

9. Objectives and Novelty

Main Objective Design and evaluate an integrated, intelligent smart waste management framework that shifts waste handling in workplaces, campuses from reactive, fixed-route collection to a data-driven, predictive, and optimized operation, by combining IoT sensing, overflow analytics, ML-based waste composition prediction, and predictive routing.			
Member Name with Registration No	Sub Objective	Tasks	Novelty
Hemsara K.D.S IT22548528	Environmental Sensing Smart Bin Real-time monitoring of fill level, weight, gas, temperature, humidity and send to cloud for safety visibility.	• Select required sensors (fill, weight, gas, temperature, humidity) and plan mounting positions • Integrate sensors with ESP32 and implement stable sensor reading logic • Calibrate sensors (baseline + threshold values) and reduce noise (basic filtering) • Push sensor data to cloud (Azure/Firebase) with timestamps and bin ID • Set safety/alert thresholds (e.g., hazardous gas, high temperature, high fill/weight) • Test with controlled scenarios and validate data accuracy	This work's innovation lies in the integration of environmental monitoring with intelligent trash bin management. Unlike existing systems that mainly measure the fill level of waste bins, this system also monitors gas emissions and surrounding environmental conditions. This makes it possible to identify dangerous circumstances early and send out timely alerts before major problems arise. By using multiple sensor inputs together, the proposed solution improves safety,

			system awareness, and the overall effectiveness of smart waste management.
Gamaariya C.C IT22202772	Smart Fill-Level & Occupancy Monitoring Multi-level fill sensing + lid-opening event tracking to detect overflow, abnormal usage, illegal dumping and trigger alerts.	• Implement multi-level fill sensing (stages like low/medium/high/critical) • Track lid-opening/usage events (open frequency, time patterns) • Detect abnormal patterns (illegal dumping, sudden fill jumps, unusual opening rates) • Trigger real-time alerts at critical thresholds (overflow risk / abnormal usage) • Store event + fill history for analytics (daily/weekly usage insights) • Validate detection rules using simulated normal vs abnormal use cases	Behavior-aware bin monitoring: adds usage pattern + event evidence (lid events) to interpret why overflow happens (misuse/illegal dumping), not only that it happened, stronger for compliance and accountability in offices/campuses.
Jayawardhane K.G.M.S IT22213358	Waste Composition Prediction (ML-Based) Predict next-day composition (plastic/organic/paper/metal) using historical data + weather + date type + area	• Collect and preprocess historical waste composition data • Prepare features: area type, date type (weekday/weekend/holiday/event), weather, past patterns	This component proposes a next-day waste composition forecasting model that predicts the types of waste expected to arrive, enabling proactive recycling setup and resource allocation one day in advance, a capability not

	type for better recycling planning.	• Train ML model (e.g., Random Forest / XGBoost) and tune parameters • Predict next-day composition percentages (plastic/organic/paper/metal) • Generate recommended pre-collection actions (sorting/recycling preparation) • Evaluate model performance and show results on dashboards/planning outputs	addressed by existing sensor-driven or reactive waste management systems.
Wijesiri A.M IT22088482	Predictive Analytics & Dynamic Routing Predict when each bin becomes critical, select only required bins, and generate an optimized route shown on a dashboard; compare static vs AI routes.	• Collect bin/app data into cloud (Azure/Firebase) and prepare it for analysis • Build ML prediction for “when each bin becomes critical” (time-to-critical / status) • Select only necessary bins for collection (based on predicted criticality) • Implement route optimization algorithm/heuristic for daily collection order • Build dashboard view: map + bin statuses (green/yellow/red) + suggested route	Decision-to-action pipeline: converts predictions into an operational plan (which bins + in what order) and proves impact via before/after evaluation many works predict status but don’t close the loop into routing + measurable operational improvement.

**10. This part is to be filled by the
Supervisor and the Co-supervisor of the Project.**

- a) This research topic possesses a comprehensive scope suitable for a final-year project.

Yes	☒	No	☐
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- b) The proposed topic exhibits novelty.

Yes	☒	No	☐
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- c) The student group can successfully execute the proposed project.

Yes	☒	No	☐
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- d) The proposed sub-objectives reflect the students' areas of specialization.

Yes	☒	No	☐
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- e) Any other comments:



	Title	First Name	Last Name	Signature
Supervisor	Mr.	Uditha	Dharmake	
Co-Supervisor	Mr	Kanishka	Yapa	
External Supervisor				
Summary of external supervisor's (if any) experience and expertise				