SMART WASTE MANAGEMENT SYSTEM WITH TRUCK DEPOT ROUTE OPTIMIZATION

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Abstract—**Urban waste generation has increased significantly due to rapid population growth and lifestyle changes. Traditional collection systems based on fixed schedules lead to bin overflow, inefficient routing, fuel wastage, and poor hygiene. This project proposes a Smart Waste Management System that simulates IoT-enabled bins, monitors fill levels, and dispatches trucks automatically when thresholds are exceeded. Route optimization is performed using OSRM, ensuring realistic road navigation and improved efficiency. A comprehensive literature review highlights existing IoT-based smart bins [4], sensor-based data-analysis techniques [2], multi-agent simulations [3], and optimization strategies [5], aligning this work with modern smart-city requirements. The system demonstrates reduced operational cost, improved responsiveness, and suitability for large-scale urban deployment.**

Index Terms—**Smart Waste Management, IoT Bins, Route Optimization, OSRM, Vehicle Routing, Solid Waste Collection, Smart Cities, Automation**

I. INTRODUCTION

Cities across the world face increasing challenges in managing solid waste due to urbanization and rising consumption. Conventional waste collection operates based on fixed schedules without real-time bin monitoring, causing overflowing bins and inefficient fuel usage. Smart waste management systems using IoT, automation, and mapping technologies are emerging to address these inefficiencies.

This project introduces a simulated smart waste management ecosystem where bins monitor their fill status, and trucks are dispatched from a depot only when necessary. Route optimization is implemented through OSRM, ensuring that trucks follow actual city roads instead of static or straight-line paths. This approach reduces travel distance and fuel consumption while improving waste collection efficiency.

II. PROBLEM STATEMENT

Conventional waste-management systems suffer from:

1. Lack of real-time bin fill-level monitoring
2. Fixed truck schedules irrespective of need
3. Overflowing bins causing foul odor and pollution
4. Inefficient collection routes
5. High operational and fuel costs
6. No centralized visualization of waste status

Therefore, a smart, automated, and data-driven model is required to optimize collection frequency and routing.

III. OBJECTIVES

A. To automate waste collection by monitoring bin fill levels

This objective focuses on creating a system that continuously tracks the fill percentage of each waste bin. Instead of relying on manual inspection or fixed schedules, the system automatically identifies bins that need immediate attention, improving accuracy and reducing human effort.

B. To minimize unnecessary truck movements by dispatching vehicles only when bins exceed 70 percentage fill level

The aim here is to ensure trucks are deployed only when a bin reaches a critical capacity threshold. This prevents wasteful trips, reduces fuel consumption, and ensures that collection efforts are directed where they are actually needed.

C. To visualize bins, trucks, and depot operations on an interactive map

This objective is about providing a real-time visual interface where users can monitor the locations and status of bins, the position of trucks, and the central depot. The goal is to improve situational awareness and simplify decision-making.

D. To optimize truck routes using OSRM so vehicles follow real city roads

The purpose of this objective is to generate the shortest and most efficient paths for trucks using the Open Source Routing Machine (OSRM). Instead of straight-line or random navigation, trucks follow actual road networks, reducing travel time and operational costs.

E. To simulate depot operations where trucks begin their journey and return after servicing bins

This objective focuses on modeling real-world waste-collection workflows. Trucks start from a central depot, collect waste from the required bins, and then return to the same station. This helps replicate real municipal operations and improves route planning.

F. To build a system that supports both automatic and manual truck dispatching

This objective ensures flexibility in the system. While the system automatically sends trucks when bins exceed the threshold, administrators can also manually dispatch trucks based on special needs, emergencies, or prioritization.

G. To design a scalable architecture suitable for real-world smart city integration

The goal here is to ensure that the system's structure can be expanded easily—supporting more bins, multiple depots, bigger fleets, or real IoT sensor hardware—making it future-ready for actual city-level deployment.

IV. Literature Review

Recent advancements in smart waste management have largely focused on IoT-enabled bins and automated monitoring systems. Several studies propose the use of ultrasonic sensors, GSM modules, and microcontrollers to detect waste levels and notify authorities when bins are full. Works such as those by Balashanmugam et al. and Teja et al. emphasize how sensor-based smart bins help prevent overflow and improve cleanliness by sending timely alerts. Other improvements include smart-trash-bin designs equipped with waste segregation features using moisture sensors and NodeMCU controllers, demonstrating the growing trend toward automation and classification of waste at the source.

Research has also expanded into sensor accuracy and intelligent fill-level detection. Cetkin et al. introduced an acoustic sensing and machine-learning approach to determine bin fullness with higher precision while keeping hardware costs low. This expands the potential of smart waste bins beyond simple ultrasonic detection, showing that advanced sensing techniques can significantly improve reliability, especially in noisy or outdoor environments.

Optimization of collection routes has been a major research area. A systematic review by Alshaikh et al. highlights optimization strategies ranging from exact and heuristic models to hybrid IoT approaches for improving waste transportation, scheduling, and vehicle routing. Similarly, Vats et al. demonstrate the benefits of using CVRP models and Google OR-Tools to reduce travel distance and adapt waste-collection patterns based on real data. These studies show that routing optimization plays a crucial role in reducing fuel costs and improving operational efficiency.

In addition to sensing and routing, researchers have explored simulation-based and agent-based waste-monitoring architectures. Likotiko et al. presented a multi-agent IoT system capable of coordinating bin monitoring, vehicle dispatching, and data analytics. Such simulation frameworks are valuable for understanding waste-collection behavior and designing scalable systems. Meanwhile, solar-powered bin designs, such as the one proposed by Gharage et al., demonstrate how renewable energy can reduce operational cost and support sustainable smart-city waste solutions.

Finally, broader studies on smart-city waste management, including work by Ganesh et al., discuss the real-world challenges faced by urban areas, particularly in Tamil Nadu. These include low segregation rates, infrastructure limitations, and inefficient collection systems. Their findings highlight the importance of adopting smart technologies, stronger planning strategies, and sustainable infrastructure to overcome existing municipal waste challenges.

V. Methodology

A. System Initialization

The system begins by loading the locations of all bins and the depot into the database. Each bin is assigned an initial fill level, and trucks are set to an idle state at the depot.

B. Fill-Level Simulation

Each bin's fill percentage increases automatically at fixed time intervals. This simulates real-world waste accumulation as seen in IoT-based bins.

C. Threshold Detection

The system continuously checks whether any bin has exceeded the 70 percentage capacity threshold. Bins crossing this limit are flagged for immediate collection.

D. Truck Assignment

When a bin exceeds the threshold, the system selects an available truck and assigns it to service that bin. Only free trucks are chosen to avoid route overlap.

E. Route Generation (OSRM)

The system sends the bin and depot coordinates to the OSRM engine, which generates an optimized route following actual city roads. The route covers: Depot → Bin → Depot

F. Real-Time Visualization

The generated route and truck movement are displayed on a map using Leaflet.js. Bin colors are updated to indicate fill status and collection progress.

G. Waste Collection and Resetting

When the truck reaches the bin, the bin is considered emptied and its fill level is reset to 0 percentage. The truck then follows the route back to the depot.

H. System Update and Repeat Cycle

Truck status is updated to "available," and the system continues checking for other bins exceeding the threshold, repeating the entire process.

VI. Outcomes

The Smart Waste Management System produced significant improvements in the overall efficiency, responsiveness, and sustainability of waste collection operations. The system accurately simulated real-world bin behavior through continuous fill-level generation, enabling timely identification of bins requiring immediate attention. Automated threshold detection ensured that trucks were dispatched only when necessary, reducing unnecessary trips and minimizing fuel consumption. The integration of OSRM allowed trucks to follow optimized, realistic road routes rather than static or linear paths, resulting in shorter travel distances and improved operational precision.

The map-based visualization provided a clear and intuitive interface to monitor truck movements, bin status, and depot activity in real time, allowing administrators to oversee the entire waste collection workflow effortlessly. Through these com- bined features, the system effectively prevented bin overflow, reduced human intervention, improved collection timing, and demonstrated how smart-city technologies can significantly enhance municipal waste management practices. Overall, the project highlights the potential of IoT-inspired automation and route optimization to create cleaner, more efficient, and environmentally responsible urban waste systems.

VII. Results

The Smart Waste Management System was successfully tested using simulated bins and trucks. It accurately detected when bins were more than 70 percentage full and only then dispatched trucks, which helped avoid unnecessary trips. This approach reduced fuel use and saved time compared to regular fixed-route waste collection.

Using OSRM, the system generated optimized routes that followed actual city roads. This made truck movements more realistic and efficient. The visual map interface clearly showed bin locations, truck paths, and depot status, making the system easy to monitor and manage.

The simulation showed that bins were cleared on time, preventing overflow and improving cleanliness. Even when multiple bins needed service, the system managed truck as- signments without delays. Overall, the system proved to be efficient, fast, and suitable for smart city waste collection. It also has potential to be expanded with real sensors and more advanced features in the future.

VIII. Case Study

This case study evaluates the practical impact and real-world feasibility of the Smart Waste Management System by analyzing its advantages, limitations, and recommended future enhancements. The system was tested in a simulated urban environment, where bins increased their fill levels au- tomatically and trucks were dispatched based on real-time threshold detection. The outcomes provide insight into how such a solution performs in modern smart-city settings.

The *Advantages Observed in the Case Study* During simu- lation, the system showed significant operational advantages. By sending trucks only when bins exceeded the 70 percentage threshold, unnecessary trips were avoided, resulting in lower fuel consumption and reduced wear on vehicles. This selective dispatching also helped maintain cleaner surroundings, as bins were emptied before overflowing. The integration of OSRM- generated road routes ensured that trucks followed realistic and efficient paths, which shortened travel time and improved response speed. Additionally, the interactive map interface allowed administrators to easily track bin status, truck location, and depot operations, making the system user-friendly and improving overall visibility. These advantages demonstrate that the system can save resources, enhance efficiency, and support smarter municipal waste management.

The *Limitations Identified in the Case Study* Despite its strengths, the system also revealed certain limitations during testing. Since the project uses simulated IoT data, it does not capture the full complexity of real-world sensor behavior, envi- ronmental noise, or hardware failures. The routing engine does not consider real-time traffic, road blockages, or emergency- based rerouting, which may affect real-world performance. The system currently supports only a single depot and a limited number of trucks, making it less suitable for large cities with extensive waste zones. Furthermore, the web map relies on internet connectivity for rendering tiles, which may limit use in areas with unstable network access. These constraints highlight the need for improved scalability, sensor integration, and dynamic routing capabilities.

The *Future Enhancements Proposed* Based on the analysis, several enhancements can significantly improve system per- formance and readiness for real-world deployment. Integrating actual IoT sensors—such as ultrasonic, infrared, or machine learning–based vision sensors—would enable accurate, real- time waste detection. Implementing multi-depot support and advanced routing algorithms would allow better load distribu- tion across larger cities. Adding a mobile application for field workers could streamline communication and tracking. Cloud deployment would make the system scalable and accessible to multiple city departments. Incorporating traffic-aware routing using APIs like Google Maps or Mapbox would further optimize travel time, while predictive analytics could help forecast waste levels and prepare for peak collection periods. These enhancements would transform the prototype into a fully operational smart-city waste management solution.

IX. Conclusion

The Smart Waste Management System developed in this project demonstrates how automation, real-time monitoring, and optimized routing can significantly improve the efficiency of municipal waste collection. By simulating IoT-enabled bins, the system successfully detects fill-level thresholds and dispatches trucks only when necessary, reducing fuel con- sumption and unnecessary vehicle movement. The integration of OSRM ensures that trucks follow realistic and efficient road routes, which shortens collection time and enhances opera- tional accuracy. The interactive map interface provides clear visibility of bin status, truck locations, and depot operations, making the entire waste-collection process easier to manage and more transparent.

Overall, the results show that the proposed system is a practical and effective step toward building smarter, cleaner, and more sustainable urban waste-management practices. With future enhancements such as real IoT sensors, multi-depot support, and AI-driven prediction, the system has strong potential for large-scale deployment in modern smart cities.

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