

From Reactive to Predictive: A Predictive Urban Waste Management System using Delay-Based Priority Approach.

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Abstract - In many cities, waste management remains reactive, with actions taken only after bins become overfilled. Such delays create unhygienic conditions, bad smell, and significant health risks. The main problem is not the waste generation, but the delays in its timely collection. This paper proposes a Predictive Urban Waste Management System that shifts focus from reacting to problems to preventing them. The system monitors essential factors such as time since last collection, waste accumulation patterns, past delays, and environmental conditions like temperature, humidity, and population density, which critically influence health risks in urban areas.

The proposed system is powered by a low-cost rechargeable battery, enabling sensors and IoT devices to operate efficiently with minimal energy cost. Field visits to hospitals revealed that hazardous medical waste was collected only once daily, often leading to delays and potential health hazards. By analyzing such real-world data, the predictive system predicts high-risk areas in advance and prioritizes waste collection accordingly, ensuring timely cleaning even before bins reach critical levels.

To reduce delays in waste collection, we have introduced a predictive priority system. In this Smart Waste Delay Prediction System, dustbin sensors monitor how long waste has been stored and automatically assign priority levels to bins, which are classified as "Safe", "Warning," or "Emergency" to ensure timely cleaning .

This proactive system keeps cities cleaner, prevents overflowing bins, reduces health risks, and saves costs. By using real-time data and low-cost rechargeable battery, it shows how traditional waste management can become smarter, safer, and more efficient.

Keywords- Predictive Waste Management, Sensor-based Monitoring, Real-time Alerts, Waste Collection Priority, Low-Cost Rechargeable Battery.

II. INTRODUCTION:

Rapid urbanization and population growth have significantly increased the amount of solid waste generated in cities. Managing this waste efficiently has become a major challenge for municipal authorities. In many urban areas,

waste collection is still carried out using fixed schedules or complaint-based systems. As a result, dustbins are often cleaned only after they overflow, leading to unhygienic surroundings, bad smell, and serious health risks for citizens. The problem is not the lack of waste collection systems, but the delay in taking timely action.

Traditional waste management systems focus on reacting to problems rather than preventing them. Municipal staff usually respond only after receiving complaints from residents, which causes unnecessary delays. During this waiting period, waste continues to accumulate, increasing the risk of disease spread, especially in crowded areas such as markets, hospitals, and public places. This reactive approach also leads to inefficient use of manpower, fuel, and time.

To overcome these challenges, there is a strong need for a smart and proactive waste management solution. Predictive Urban Waste Management using a Delay-Based Priority System aims to address this issue by identifying waste collection delays before bins overflow. Instead of depending on complaints, the system monitors how long waste remains in each dustbin and assigns priority levels based on delay time. Bins with higher delay receive immediate attention, ensuring timely cleaning and improved hygiene.

By shifting from a complaint-based model to a prediction-based approach, cities can maintain cleaner environments, reduce health hazards, and optimize municipal resources. This system highlights that the real issue in urban waste management is not waste generation itself, but delayed action. Predicting delays and prioritizing collection can lead to more efficient, reliable, and sustainable urban cleaning.

In recent years, smart waste management has received increasing attention due to rapid urbanization and growing waste generation. Several studies have explored the use of IoT, sensors, and wireless communication to improve waste collection efficiency and monitoring in urban environments [1]-[3].

III. LITERATURE REVIEW:

With rapid urbanization and increased solid waste generation, researchers have explored various smart waste management solutions to improve collection efficiency and reduce environmental impact.

Folianto, Low, and Yeow developed a Smart bin system that monitors waste fill levels using sensors and transmits the information through a wireless mesh network [4]. The system employs a duty cycle mechanism to reduce power consumption and analyze waste usage patterns. While this approach is effective for monitoring bin status, it strongly depends on fill level sensor and does not include any intelligent mechanism to prioritize bins that remain uncollected for extended periods.

Chowdhury and Chowdhury proposed an RFID-based real-time waste management system that automates waste identification, weight measurement, and detection of stolen bins using RFID tags and load cell sensors [5]. This system improves automation and traceability in waste handling. However, it requires additional hardware infrastructure and does not emphasize intelligent decision-making or priority-based waste collection.

Ali et al. introduced an IoT-based smart waste bin monitoring system designed for smart cities, offering features such as real-time monitoring, fire detection, and waste level prediction [6]. The system helps reduce overflow and enhances municipal waste management efficiency. Despite its advantages, the solution depends on complex IoT infrastructure, which may not be suitable for semi-urban or resource-limited regions.

Hasan et al. presented an IoT-based waste management system aimed at minimizing manpower, time, and energy consumption, particularly in developing countries [7]. Although the system improves operational efficiency, it mainly focuses on sensor fill level monitoring and does not support adaptive prioritization for bins that experience delayed collection.

Abdullah et al. proposed an IoT-enabled waste management framework to strengthen communication between waste bins and municipal authorities [8]. While the framework improves overall collection efficiency, it does not consider historical waste accumulation data or priority-based decision-making mechanisms.

Sosunova and Porras conducted a systematic review of IoT-enabled smart waste management systems and highlighted major challenges such as high deployment cost, scalability issues, and heavy dependence on sensors [9]. The study also

pointed out the absence of intelligent waste collection strategies as a significant limitation in existing systems.

IV. IMPACT ANALYSIS OF IMPROPER WASTE MANAGEMENT:

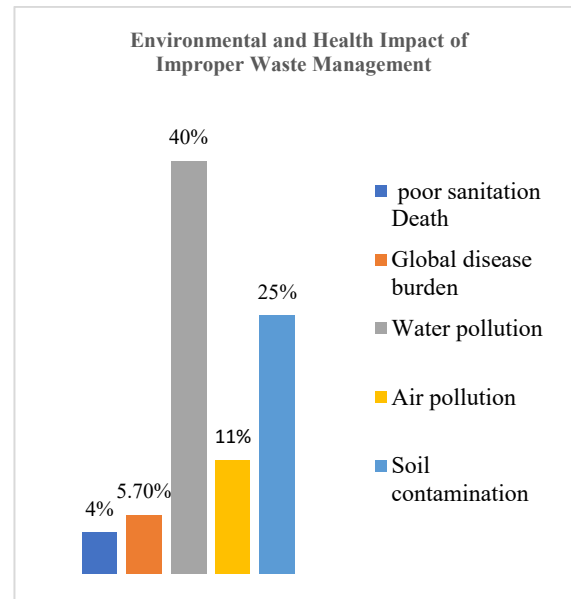


Fig. 1. Impact of Improper Waste Management on Environment and Public Health

India generates nearly 62 million tonnes of municipal solid waste every year, with urban residents producing about 0.5 kg per person per day. Poor waste disposal not only harms the environment but also affects public health. Globally, unsafe sanitation and improper waste management are responsible for around 4% of deaths and 5.7% of the disease burden. In India, nearly 38 million people suffer from waterborne diseases each year due to contaminated waste and water sources. Improper handling of waste also contributes significantly to environmental pollution, causing roughly 40% of water pollution, 11% of air pollution from open burning, and about 25% of soil contamination. These statistics highlight the urgent need for a smart and efficient waste management system.[10]-[11].

V. RESEARCH GAP:

Most existing urban waste management systems are reactive and mainly depend on sensor-based fill-level detection. They focus on collecting waste only after bins become full. However, these systems often ignore the issue of cleaning delays and do not prioritize bins based on urgency.

There is limited research on a priority-based approach that considers the delay since the last collection to decide which bin should be serviced first. Hence, there is a need for a

predictive and priority-based system that ensures timely waste collection and better resource management.

VI. PROBLEM STATEMENT:

Waste collection in urban areas still often follows fixed schedules and predefined routes, requiring cleaning staff to visit bins regardless of whether they are empty, partially filled, or overflowing. This leads to inefficient use of time, manpower, and resources, while overflowing bins may remain uncleaned, causing unhygienic conditions, bad smell, and increased risk of disease. Many current systems depend on citizen complaints and follow a reactive

approach, which delays cleaning and fails to address urgency.

Although some sensor-based systems exist, they mainly focus on detecting fill levels and do not carefully consider factors such as urgency, cleaning delays, or the relative importance of different areas. Supervisors often have limited visibility into whether tasks have been completed on time, which reduces transparency and responsibility.

These challenges highlight the need for an intelligent, predictive, and priority-based waste management system that can monitor bin status in real time, identify high-risk or overflowing bins, prioritize urgent locations, and schedule cleaning efficiently. Implementing such a system would reduce unnecessary trips, optimize manpower, prevent hygiene issues, and improve overall efficiency in urban waste management.

Previous studies indicate that existing smart waste management systems face several practical challenges. Although they use advanced technologies, these systems often require high installation and maintenance costs. In addition, complex infrastructure and operational difficulties make large-scale implementation challenging, especially in developing regions. [7]-[9].

Table 1. Comparison of existing waste collection approach with the proposed system.

Aspect	Existing System	Proposed System
Collection method.	Fixed schedule and predefined routes.	Collection based on urgency and priority.
Use of sensor data.	Depend only on sensor readings.	Considers sensors data & collection delay.
Handling of overflow.	Overflow often detected late.	Overflow risk identified.
Staff time utilization.	Time wasted on empty or low-priority bins.	Staff time used efficiently.
Priority handling.	No priority mechanism.	Clear priority levels.
Monitoring.	Limited supervision.	Dashboard monitoring.

VII. OBJECTIVES OF THE PROPOSED SYSTEM:

- To develop a smart waste management system that supports efficient and timely waste collection.
- To reduce unnecessary waste collection by avoiding fixed schedules and fixed routes.
- To introduce a priority-based approach that identifies areas needing urgent cleaning.
- To minimize waste overflow, bad smell, and health risks caused by delayed collection.
- To save time and effort of cleaning staff by directing them only to required locations.
- To provide better monitoring and control to supervisors through a centralized dashboard.

VIII. METHODOLOGY:

The proposed system is a smart waste management solution designed to improve waste collection efficiency by using a priority-based approach. Each waste bin is provided with sensors to monitor the waste level. Along with sensor data, the system also considers the time for which waste remains uncollected. Instead of following fixed schedules, the system identifies bins that require cleaning based on urgency.

All collected information is sent to a central server where it is processed and displayed on a dashboard. The dashboard is accessible to both cleaning staff and supervisors, allowing better monitoring and decision making.

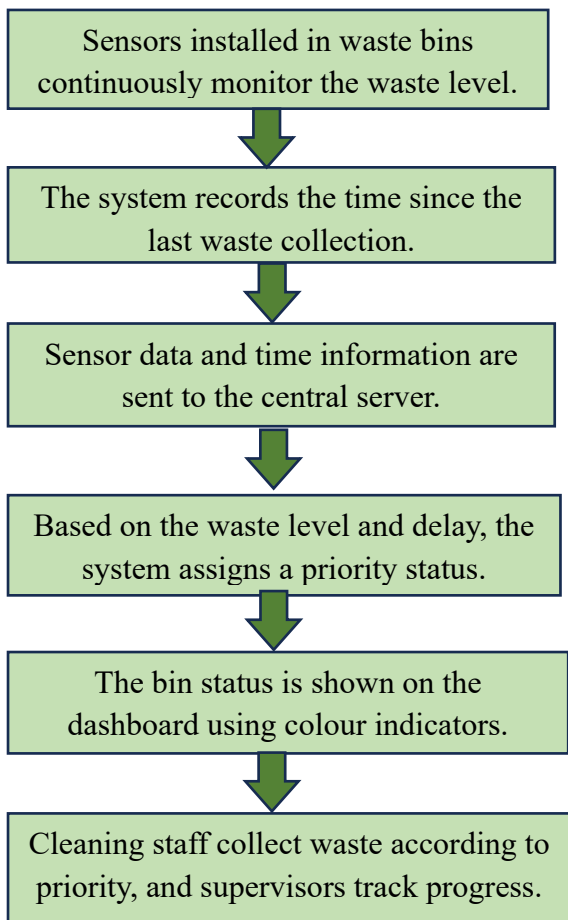


Fig 2: Flow diagram of the proposed priority-based waste management system.

The proposed system does not depend only on sensor readings. It also considers how long waste has remained uncollected. Even if a bin is not completely full, it is marked as high priority when the delay exceeds a defined limit.

The bins are categorized into three priority levels:

- Green (Safe): Low waste level and short delay
- Yellow (Warning): Moderate waste level or increasing delay
- Red (Emergency): High waste level or long delay

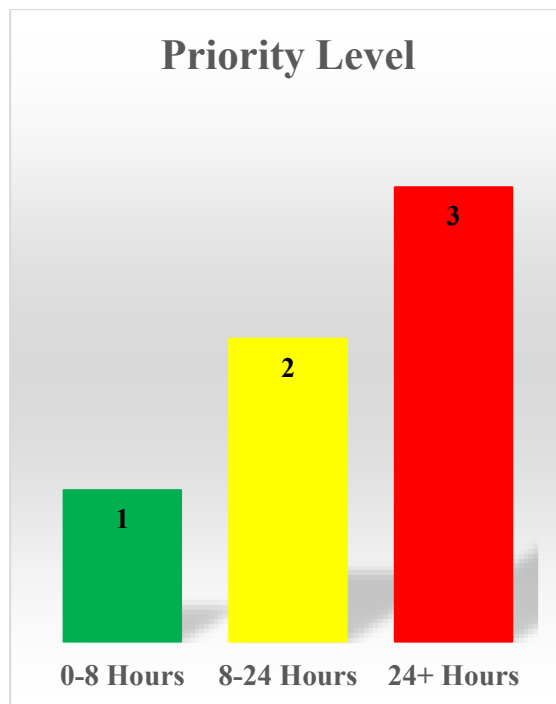


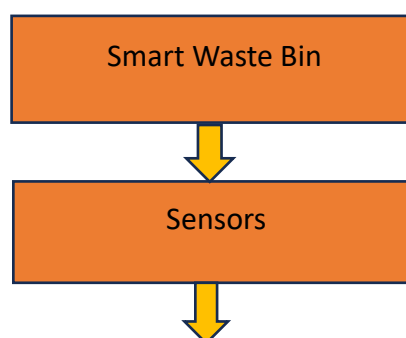
Fig. 3. priority-based classification of waste bins.

As shown in Figure 2, bins are classified into different priority levels based on delay. If the waste remains uncollected for 0 to 8 hours, the bin is considered Safe. When the delay increases to 8 to 24 hours, the bin is marked as Warning. If the waste remains uncollected for more than 24 hours, the bin is classified as Emergency and requires immediate cleaning.

This logic ensures that areas requiring urgent cleaning are attended to first. It reduces unnecessary cleaning in low-priority areas and prevents overflow, bad odor, and health risks.

System Architecture:

The proposed system architecture shows how different components of the smart waste management system work together. Sensors installed in waste bins collect waste level and time-related data and send it to a central server through wireless communication. The server processes this data using priority logic and displays the bin status on a dashboard for cleaning staff and supervisors. This structure helps in timely waste collection and better monitoring.



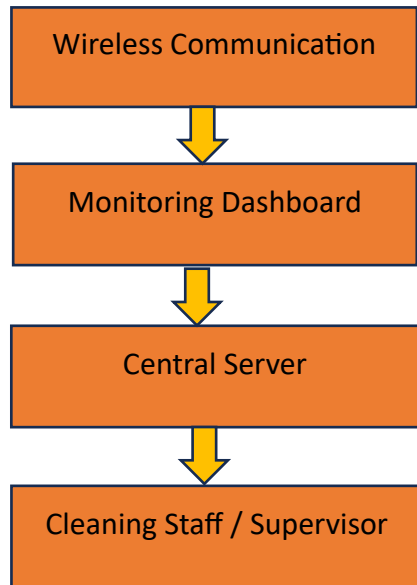


Fig. 4. Architecture of the proposed system.

Description of System Components:

A. Smart Waste Bin

This is the physical bin where waste is collected. It holds the sensors required for monitoring waste.

B. Sensors

Sensors detect the waste level inside the bin and help track how long waste remains uncollected.

C. Wireless Communication Module

This module sends the collected data from bins to the central server.

D. Central Server

The server receives data from all bins and applies delay-based priority logic to decide urgency.

E. Priority Logic

This logic classifies bins into Safe, Warning, or Emergency based on time delay.

F. Monitoring Dashboard

The dashboard displays bin status using color indicators and helps staff plan waste collection.

G. Cleaning Staff and Supervisor

Cleaning staff act based on priority, while supervisors monitor the overall system.

IX. CONCLUSION:

This study presents a predictive and priority-based urban waste management system that shifts from a reactive approach to a smarter decision-making model. Instead of depending only on fill-level sensors, the proposed system prioritizes waste collection based on delay time since the last cleaning. This ensures that bins which are neglected or delayed receive immediate attention.

The delay-based priority approach improves operational efficiency, reduces unnecessary trips, and lowers infrastructure and maintenance costs. It is especially suitable for semi-urban and developing areas. By focusing on timely service and optimized resource allocation, the system enhances cleanliness and overall waste management performance.

Thus, the proposed model offers a cost-effective, practical, and scalable solution for modern urban waste management.

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