

IoT-Based Smart Waste Collection and Route Optimization in Urban Areas: A Secondary-Data Study of Mumbai and Maharashtra

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Abstract

Handling municipal solid waste remains an ongoing issue in big and fast-growing cities. Collecting waste on predetermined schedules does not necessarily take into account the differences in fill rates at various locations, while a lack of visibility can result in excessive use of vehicles, bin overfill, and inefficient conveyance of the waste to the treatment plants. The present review assesses the potential benefits of IoT sensing and route optimization for waste collection in Mumbai and Maharashtra. This is achieved by summarizing available data on this issue from literature and secondary sources, including the Central Pollution Control Board (CPCB), Maharashtra Pollution Control Board (MPCB), Government of Maharashtra, and Brihanmumbai Municipal Corporation (BMC). The cited documents provide figures of waste generation of 22,632.71 tonnes per day (TPD) in Maharashtra during 2020-21 and 24,299.43 TPD in the MPCB document for 2023. The amounts of waste treated scientifically were 15,056.10 TPD and 19,877.12 TPD, respectively.

For the city of Mumbai, the MPCB report has indicated a generation of 6,690 TPD with a treatment/processing capacity of 5,976 TPD, giving a computed value of the ratio as 89.33%. This paper has discussed the concepts of sensor-based monitoring, data platforms, prioritization scores, and vehicle routing models and has provided the structure for an urban pilot project. In the absence of any local sensor measurements, GPS measurements, or field trials, this paper does not claim any measured savings in distance, fuel, and time.

Keywords: Internet of Things (IoT); smart waste management; municipal solid waste; route optimization; Mumbai; Maharashtra; vehicle-routing problem

1 Introduction

Solid waste management for municipal use involves a series of inter-related functions ranging from waste creation, segregation, storage, collection, transportation, processing, and eventual disposal. It becomes increasingly difficult to coordinate all these processes as populations in urban areas increase and consumption rises. In big cities, it is apparent that the rate at which waste is generated is not uniform for every neighborhood; hence, a pre-planned route for garbage collection will end up taking the collection trucks to bins with some space left while other places need earlier attention.

IoT technology provides a means through which data available to municipal managers can be improved. Bins can be fitted with sensors that measure the level of waste in the bins. With data on geography and route optimization, managers will be able to know the right bins that need their attention.

The use of Mumbai and Maharashtra would provide a relevant scenario in which this approach can be considered due to the fact that the governmental organizations make public statistics related to waste management in the state and city. In this study, secondary data analysis is used to evaluate how IoT-based monitoring and routing could improve current services. The study is a literature review based on secondary data analysis.

2 Review objective and problem context

The key objective of this research is to determine the possible use of the Internet of Things (IoT) and route optimization in the urban waste collection process, taking into account a particular case study of Mumbai and Maharashtra state. The goals of this research include the following points

- to present selected official statistics relating to the processes of waste generation, collection, and treatment;
- to consider the status of Mumbai in relation to other urban areas of Maharashtra state;
- to define operational and management problems mentioned in official documents;
- to analyze how the use of sensors and route optimization can influence the collection process;
- to develop a concept and identify the prerequisites for testing it.

The difficulty is not only in the amount of waste that is being produced. The municipal workforce must determine collection locations, collection times, the types of vehicles to use, and how to monitor the process. The MPCB's 2023 report highlights several areas for improvement, such as waste measurement, management capability, and optimization of waste collection and transport.

3 Literature review

3.1 Sensor information and dynamic collection routes

Ramos et al. (2018) examine the intelligent waste collection routing problem while highlighting the approaches that may take into consideration information on the levels of bin filling. This research provides evidence of the hypothesis that collection routes may be modified according to varying demand instead of following a specific schedule. In practice, sensors may be used for the identification of filled bins that may require earlier collection.

3.2 Adoption barriers in the Indian context

The research conducted by Sharma et al. (2020) presents challenges faced in the implementation of IoT technology in waste management in Indian smart cities. These challenges range from costs and returns on investment, standards diversity, policy gaps, internet access, security, transparency, and information technology infrastructure. These challenges show that the presence of sensors alone is not enough; there must also be effective communication, operating guidelines, sufficient staffing, and a cost-effective maintenance process.

3.3 Broader smart-collection technologies

A review published in Science of the Total Environment (Mousavi et al., 2023) evaluates the technology used in smart waste collection, which includes sensors, RFID, information and communication technology, spatial technology, and data communication technology. They can improve the efficiency

of the use of vehicles and resources, but their success depends on the local conditions and the data they gather.

In summary, all of the studies reveal that the use of IoT technology in monitoring and route optimization is a promising decision-making aid and not a stand-alone solution. Local validation is required based on the identified literature, especially in cases where road conditions, patterns of service, infrastructure, and local resources differ.

4 Methodology

4.1 Research design

The current study uses the descriptive review method along with the secondary data analysis method. This research does not use surveys, interviews, sensor data, or fabricated observations. The quantitative data used are collected from government publications and are employed to define the extent of the waste management problem and identify the gaps in its generation and treatment.

4.2 Sources reviewed

The sources used in this research include the CPCB Annual Report on Solid Waste Management for 2020-21; the MPCB report on Maharashtra for 2023; the Maharashtra Economic Survey for 2024-25; and the BMC documents such as the Environment Status Report (BMC, 2025), the Climate Budget, and the budget estimates. The peer-reviewed articles that discuss smart waste collection and IoT implementation were used to address the technology issues.

4.3 Indicators used

The treatment ratio is the amount of scientific treatment of waste relative to the amount of generated waste, multiplied by 100. The collection ratio is the amount of collected waste relative to the amount of generated waste, multiplied by 100. The generation-treatment gap is derived from the difference between the generated and treated or processed waste amounts. The data used, which are from various reports, do not imply the creation of a completely consistent time series due to possible differences in reporting periods, definitions, and methods.

5 Findings from secondary data

5.1 Maharashtra: Selected reported figures

Table 1. Selected statewide municipal solid waste figures for Maharashtra.

Source / period	Generated (TPD)	Collected (TPD)	Treated (TPD)	Treatment ratio
CPCB, 2020–21	22,632.71	22,584.40	15,056.10	66.52%
MPCB, 2023	24,299.43	23,974.73	19,877.12	81.80%
Economic Survey, 2023–24	25,278.00	Not reported here	20,532.00	81.22%

According to the CPCB data, in 2020–21, there were 22,632.71 TPD generated in Maharashtra; 15,056.10 TPD was reported to be treated, resulting in a calculated treatment ratio of 66.52% (CPCB, 2021; Table 1). MPCB's data for 2023 (MPCB, 2024) reports that there were 24,299.43 TPD generated

and 19,877.12 TPD treated scientifically, resulting in a treatment ratio of 81.80%. The Economic Survey ([Government of Maharashtra, 2025](#)) reports that in 2023–24 there were 25,278 TPD generated and 20,532 TPD treated in the state of Maharashtra, resulting in a treatment ratio of 81.22%.

This data indicates an increase in the amount of waste reported to be treated from the selected sources. Nevertheless, the data refers to different periods of time and uses varying reporting definitions. Therefore, it needs to be viewed in its context and cannot be used as evidence of a coherent trend indicating an improvement.

5.2 Collection and disposal in the MPCB 2023 report

In the case of Maharashtra, the total amount of waste collected, according to the MPCB 2023 report, is 23,974.73 TPD out of 24,299.43 TPD generated, constituting about 98.66%. The quantity of scientifically treated waste is 19,877.12 TPD, which is 81.80% of the generation. Furthermore, the report highlights 3,549.59 TPD as sanitary or simple landfilling and 872.71 TPD as unscientifically disposed of. The report further highlights transport and segregation at 98.23% and 98.66%, respectively.

Moreover, the report uses an aggregated treatment number where scientifically treated waste and sanitary-landfilled waste are aggregated into one. In this paper, the numbers have been kept separate for both scientific treatment and sanitary landfill because they come from different sources.

5.3 Mumbai and selected urban regions

Table 2. Generation and treatment in selected urban regions of Maharashtra (MPCB, 2024).

Urban region	Generated (TPD)	Treated / processed (TPD)	Calculated ratio
Mumbai	6,690.00	5,976.00	89.33%
Pune	3,846.05	3,408.00	88.61%
Thane	2,082.70	1,807.39	86.78%
Nashik	1,529.06	1,167.06	76.33%
Kalyan	1,325.00	801.35	60.48%
Navi Mumbai	730.00	672.00	92.05%
Amravati	376.00	376.00	100.00%
Kolhapur	545.20	502.20	92.11%
Chhatrapati Sambhajanagar	1,075.00	875.80	81.47%
Chandrapur	126.00	125.80	99.84%
Raigad	470.00	423.00	90.00%
Nagpur	1,286.00	200.00	15.55%

The generation in Mumbai was estimated to be 6,690 TPD, whereas the treatment or processing was 5,976 TPD. This gives a ratio of 89.33% and a generation-treatment gap of 714 TPD (Table 2). The numbers for each region show wide variations: Amravati 100%, Navi Mumbai 92.05%, Mumbai 89.33%, Pune 88.61%, Kalyan 60.48%, and Nagpur 15.55%.

These numbers can be compared to those given by the MPCB source. These numbers cannot be considered a definitive indicator of the performance of different municipalities. Differences in reporting,

definitions, treatment facilities, and data quality may affect comparative analysis. Moreover, the numbers do not necessarily reflect the efficiency of waste collection routes.

5.4 Waste composition and municipal initiatives

The BMC Climate Budget (BMC, 2024a) cites NEERI (2016) for the average composition of municipal solid waste, which includes food and wet waste (72.60%), wood and clothes (3.51%), sand, stones, and soil (17.37%), plastics (3.24%), and paper and other recyclables (3.28%). Considering the preponderance of organic waste, the need for proper segregation and treatment becomes clear. Since these figures are for 2016, they cannot be treated as current values for 2024-25.

The BMC budget (BMC, 2024b) mentions a 600-ton-per-day (TPD) waste-to-energy plant in Deonar to produce about 4 MW of power, along with a plan to treat the accumulated waste at Mulund. Together, these measures point to the fact that the waste problem in Mumbai not only involves waste generation and collection but also the management of accumulated waste.

6 Proposed IoT-based collection framework

From the analysis of the problems mentioned in the sources being reviewed, there is a possible system design which would combine the data at the bin level with a dashboard and route planning module (Table 3). This is more of a concept than an existing system being used by BMC.

Table 3. Layers of the proposed IoT-based collection framework.

Layer	Main function	Possible output
1. Smart bin	Measure fill level; optionally record temperature or tilt	Fill estimate, time stamp and bin ID
2. Connectivity	Transmit readings using a suitable network	Updated readings from field locations
3. Data platform	Store, validate and organize readings	Bin status and alerts
4. Priority engine	Identify which bins need attention first	Collection priority score
5. Route optimizer	Select bins and plan vehicle sequence	Suggested route and estimated distance
6. Operations dashboard	Show bins, vehicles and exceptions	Map, alerts and service indicators
7. Analytics	Review past patterns and service history	Demand forecasts and maintenance indicators

6.1 Example priority score

An obvious model would use the formula $P = 0.60F + 0.25T + 0.15R$, where F refers to the normalized fill level, T is the time passed since the last pick-up, and R indicates a normalized index of risk or importance. The stated weightings are merely suggestions and do not correspond to any established norms and have to be verified with the city's personnel.

6.2 Route optimization

The routing problem may be modeled as the capacitated vehicle routing problem or the dynamic vehicle routing problem. Here, each bin is a location that needs to be visited, and the depots and treatment facilities are other locations. The routing process includes consideration of the travel

distance or travel time, capacity of the vehicle, priorities in collecting waste, and other relevant constraints.

7 Discussion

The presented figures indicate that there are serious operational challenges related to waste management and treatment in the state of Maharashtra, and the presented figures for the chosen urban area show variations in the percentage of processed waste. Taken in isolation, these figures do not prove that the introduction of IoT can improve performance. However, they provide evidence for exploring the possibility of using information about the state of bins and increased flexibility of routes to help municipal workers coordinate the waste collection process.

One of the possible advantages of sensor-based waste collection may consist in the fact that the decision-making process is based on information about the current state of the bins instead of the schedule. In addition, a centralized dashboard can help employees notice any failures in waste collection and understand their patterns. Therefore, route optimization can be performed taking into account the priority information as well as capacity and road network information.

Implementation issues should also be addressed from the outset. Sensors need regular upkeep and calibration; communication can be inconsistent in some places; and wrong measurements might lead to unwarranted site visits or failures to visit. Local authorities have to consider the cost of the system, training of personnel, data ownership, cybersecurity, integration, and compatibility of the proposed system with local collection processes. The issues raised by [Sharma et al. \(2020\)](#) are therefore relevant to any local pilot project.

8 Limitations and future research

The current review is based on secondary data. Bin-level sensor readings, vehicle GPS movements, fuel consumption data, or even interviews with municipal employees are not available here. This means that the study will be unable to measure any savings in terms of distance covered, fuel used, costs, or response time that could be achieved through the IoT system in Mumbai.

Data obtained from government sources vary in terms of the reporting year and can even use various definitions/aggregation approaches. This means that the comparison made here is descriptive and not longitudinal or controlled. Also, waste composition percentages used by BMC are based on NEERI 2016 and not on a current one.

A pilot project at the ward level will also prove to be beneficial. The pilot project will involve recording bin fill levels, collection times, GPS paths of vehicles, travel distance, fuel use, missed collections, and overflow. Comparisons can be done between the present routes and the routes derived from sensor inputs while holding similar service levels, capacity of vehicles, and traffic conditions constant.

9 Conclusion

This review suggests that IoT-enabled monitoring and route optimization represent relevant approaches to consider in the case of municipal waste management in Mumbai and Maharashtra. According to official documents, there is a significant daily workload in waste management, a lack of balance between the amount of waste produced and its scientifically grounded treatment, as well as

differences among chosen urban locations. Furthermore, the MPCB document highlights the operational and information management issues, which include the necessity to improve waste measurement together with the collection and transport processes.

The smart collection system may include such components as fill-level sensors, data transmission, dashboard, priority ranking, and vehicle route optimization. However, the present study does not imply the completion of such an approach. It is possible to confirm claims about reducing the travel distance, fuel consumption, and time only after evaluation based on real-world data. A thorough municipal pilot project will serve as a basis for a more accurate assessment of the approach in question.

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