# Cost-Benefit Analysis of Waste Collection Systems in India: A Case Study on Specific Area of Jaipur

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**Abstract**: - Waste collection and transportation constitute a significant portion, often up to 70%, of the overall waste management costs. While separated collection of recyclables adds expenses that recycling revenues might not offset, there's a growing imperative to meet long-term recycling goals mandated by regulations. Accurate estimation and monitoring of waste collection costs are crucial in determining the most economically viable waste collection system. This study aims to propose and implement a management tool for assessing waste collection costs across different collection schemes. Utilizing input data such as waste volume, composition, number of bins, collection nodes' locations, vehicle types, crew, routes, and more, the tool calculates time and costs associated with waste collection—per vehicle, collection node, or ton of waste collected. The tool offers utility for municipal solid waste management (MSWM) entities, facilitating benchmarking and variance analysis. In the context of the municipal waste management system in Jaipur, India, a case study was conducted to analyze both residential and commercial areas. This specific area generates approximately 1500 tons/day of municipal solid waste (MSW), of which 1000 tons/day (with a collection efficiency of 67%) are collected by the municipal cooperation. The remaining uncollected waste poses significant health and environmental challenges. The analysis reveals weaknesses in the collection system, including organizational inefficiencies, inadequate collection methods, insufficient vehicles, and foreign exchange limitations for vehicle imports and spare parts. Efforts to identify improved collection systems compatible with the existing conditions were undertaken. Employing an economic costing approach, the study sought the least-cost option and conducted a cost-benefit comparison between the proposed and current systems. The study's findings propose an enhanced collection system, projected to decrease up to 80% of the municipal cooperation's current expenditure on collection services in Jaipur and payback time within 5 years.

**Keywords: -** Municipal solid waste, Cost-benefit analysis; Payback time, Costs of waste collection, Cost effectiveness

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## Introduction

The escalating urbanization and population growth have led to a significant surge in solid waste generation, imposing substantial challenges on conventional waste management systems. As waste collection and transportation can constitute a significant portion of total costs, there is a growing need to develop efficient and cost-effective waste collection systems. In this context, this study aims to address the critical research gaps that exist in waste collection systems in India [1]. By conducting a comprehensive cost-benefit calculation and analysis, the study seeks to provide insights into optimizing waste collection processes, particularly in the context of the city of Jaipur.

The importance of accurate cost estimation and monitoring of waste collection operations cannot be overstated. The separation of recyclables and the pressure to meet recycling objectives set by regulations add complexity to waste collection systems. While recycling goals are crucial for sustainability, the associated costs often challenge the economic feasibility of waste management strategies [2]. Therefore, it becomes imperative to develop tools that accurately assess waste collection costs based on various parameters, including waste quantity, composition, collection points, vehicle types, and crew.

In light of these challenges, this study proposes the implementation of a management tool that can effectively calculate waste collection costs for different scenarios [3,4]. By utilizing data-driven approaches and advanced analytics, this tool has the potential to revolutionize the way waste collection systems are designed and operated. Through the application of Excel spreadsheets and case studies, the study aims to demonstrate the tool's effectiveness in evaluating the costs of waste collection in practical scenarios.

Additionally, this study delves into the case of Jaipur, India, as a representative example of a region grappling with waste management challenges. By analyzing the existing waste collection system in Jaipur, the study sheds light on the inefficiencies and weaknesses in the current approach. It explores critical aspects such as organizational structure, collection methods, vehicle availability, and financial constraints that hinder the effectiveness of waste collection operations [5].

Furthermore, this research endeavors to identify alternative waste collection systems that are tailored to the specific conditions of Jaipur. Employing economic costing procedures and rigorous cost-benefit analyses, the study aims to recommend a more efficient and cost-effective waste collection strategy. Such a strategy, if successfully implemented, could lead to significant cost savings for the municipal cooperation of Jaipur and contribute to improved waste management practices [6-8].

By addressing these research gaps, this study aspires to contribute valuable insights and practical solutions to the field of waste management in India. The findings of this research have the potential to inform policy decisions, guide waste management companies, and ultimately lead to a more sustainable and economically viable waste collection system that aligns with the long-term recycling goals of the nation.

## 1. Related Background

The background of this study is rooted in the growing challenges posed by rapid urbanization and population growth, which have led to a substantial increase in solid waste generation. As urban areas expand, waste management systems are under considerable strain to efficiently and effectively collect, transport, and dispose of waste. Conventional waste management practices often face limitations in handling the escalating volumes of waste, resulting in environmental, economic, and health-related issues [9].

One of the key challenges in waste management is the high cost associated with waste collection and transportation. In many cases, these costs can account for a significant portion of the overall waste management budget [10]. As recycling goals and regulations come into play, the complexities of waste collection increase, requiring different approaches for handling recyclables and non-recyclables. The cost implications of these approaches necessitate accurate cost estimation and monitoring to design and implement cost-effective waste collection systems [11].

The emerging concept of the Internet of Things (IoT) presents opportunities to address these challenges through innovative solutions [12]. IoT technology offers real-time monitoring, data-driven decision-making, and enhanced efficiency in various domains, including waste management. By integrating intelligent sensors, communication protocols, and data analytics, IoT-based waste management systems have the potential to revolutionize the way waste is collected, managed, and processed [13].

In the context of India, where the study is focused, waste management challenges are particularly pronounced. Many cities in India struggle with inadequate waste management infrastructure, leading to problems like flooding, health hazards, and environmental degradation due to improper waste disposal and drainage blockages [14]. The cost-benefit analysis becomes critical in such scenarios to identify solutions that provide optimal outcomes while being economically viable [15].
This study endeavors to fill crucial research gaps by proposing and implementing a comprehensive cost-benefit analysis of waste collection systems in India, focusing on the city of Jaipur as a case study. By evaluating existing collection methods, identifying weaknesses, and recommending alternative systems, the study aims to contribute to the ongoing efforts to enhance waste management practices in India and address the challenges posed by urbanization, population growth, and sustainability goals.

## 2. Mathematical Model

A mathematical model is a formal representation of a real-world system using mathematical equations and relationships. In the context of waste management and the study's focus on cost-benefit analysis for waste collection systems, a simplified mathematical model could involve variables and equations that represent various aspects of the waste collection process and associated costs.

### 3.1 Variables use in mathematical model

$C_{total}$: total cost of waste collection system
$C_{collection}$: Coste of waste collection
$C_{transportation}$: Cost of waste transportation
$C_{disposal}$: Cost of waste disposal
$R_{revenue}$: Revenue from recycled waste materials
$R_{usercharge}$: Revenue from users charged as waste collection
$V_{collected}$: Total volume of waste collected (in tons)
$V_{non-recyclable}$: Volume of non-recyclable waste (in tons)

### 3.2 Assumptions and constraints

$C_{collection}$ is related to the number of collection nodes and frequency of collection.
$C_{transportation}$ is determined by the distance travelled and fuel costs.
$C_{disposal}$ depends on the waste disposal method and associated fees.
$R_{revenue}$ is generated from selling recyclable waste materials

### 3.3 Mathematical Equations

The mathematical equations given below are for cost calculation of one year

***Total Cost of waste collection***

$$C_{total} = C_{collection} + C_{transportation} + C_{disposal} - R_{revenue}$$

Cost of Collection

$$C_{collection} = Cost\ per\ collection\ node \times Number\ of\ collection\ nodes \times Frequency\ of\ collection$$

***Cost of Transportation***

$$C_{transportation} = Cost\ per\ kilometer \times Distance\ traveled \times Number\ of\ collection/year$$

***Cost of Disposal***

$$C_{disposal} = Cost\ per\ ton\ of\ waste\ disposal \times V_{collected}$$

***Revenue from Recycled Waste Materials***

$R_{revenue} = Price\ per\ ton\ of\ recyclables \times V_{recycled}$

***Net total revenue generated from the proposed model for one year***

$T_{revenue} = R_{revenue} - C_{netcost}$

***Total net cost***

$C_{netcost} = C_{total} + C_{installation}$

The model can be refined by incorporating more detailed variables, factors, and equations to accurately represent the waste collection and management process. Real-world data and parameters specific to the study area (such as costs, distances, waste composition, recycling rates, etc.) would need to be collected and integrated into the equations to generate meaningful results. The mathematical model serves as a tool to quantitatively analyze different waste collection scenarios, evaluate their costs and benefits, and guide decision-making for optimizing waste management systems.

## 3. Cost Analysis

A simplified cost analysis for a waste collection system over the course of one year using the provided variables and equations are performed on a specified area of Jaipur city. For cost analysis, assume the following values:

Cost per collection node: Rs. 100
Number of collection nodes: 50
Frequency of collection: daily (365 days in a year)
Cost per kilometre of transportation using EV: Rs. 02
Distance travelled per collection: 100 km
Cost per ton of waste disposal: Rs. 50
Price per ton of recyclables: Rs. 5000
Total volume of waste collected in one year: 3650 tons
Volume of recyclable waste in one year: 912.5 tons (25% of total volume)
User charge for collection per house = Rs. 100
Now, we can use the equations to calculate the various costs:
Cost of Collection
Cost of Collection

$C_{collection} = 100 \times 100 \times 365 = Rs. 3650000$

***Cost of Transportation***

$C_{transportation} = 2 \times 100 \times 365 = Rs. 73000$

***Cost of Disposal***

$C_{disposal} = 50 \times 3650 = Rs. 182500$

***Revenue from Recycled Waste Materials***

$R_{revenue} = 5000 \times 912.5 = Rs. 4562500$

## 4. Results and Analysis

A proposed mathematical model is analysed by assuming some values to calculate cost of waste collection and revenue generated in a year, results obtained are given below

***Total cost of waste collection for one year***

$C_{total} = 3650000 + 73000 + 182500 = Rs. 3905500$

***Installation cost of the system***
The cost of per smart garbage bin = Rs. 15000
Total cost of 100 smart garbage bins = Rs. 1500000
One EV truck cost = Rs. 1500000
Cost of Wi-Fi and IOT system = Rs.100000
Running cost = Rs. 100000
$Total\ installation\ cost = C_{ic} = Rs. 3200000$

***Total net cost***
$Total\ Net\ Cost = C_{netcost} = 3905500 + 3200000 = Rs. 7105500$

***Total revenue generated from the proposed model for one year***
$T_{revenue} = 4562500 - 3905500 = Rs. 657000$

$$Payback\ time = t = \frac{C_{ic}}{T_{revenue}} = \frac{3200000}{657000} = 4.9\ years$$

This simplified analysis demonstrates how the various cost components contribute to the total cost of the waste collection system over the course of one year. Keep in mind that this example uses simplified values and assumptions for illustrative purposes. In a real-world scenario, more accurate data and variables would be used to conduct a comprehensive cost analysis. The payback time is approximate 5 years.

## 5. Conclusion

This study has proposed a comprehensive cost-benefit calculation and analysis framework for waste collection systems in India, particularly in densely populated urban areas. Addressing the pressing challenges of waste management, the research aimed to provide efficient and cost-effective solutions to ensure environmental cleanliness, health, and sustainability. The focus was on mitigating the substantial costs associated with waste collection and transportation, which significantly impact the waste management budget. The study introduced a management tool capable of estimating and monitoring waste collection costs under various collection schemes. By utilizing diverse input data such as waste quantity, composition, collection points, vehicles, routes, and crew, the tool facilitated cost calculations per vehicle, collection point, or collected tonnage. This analytical approach offers waste management entities a valuable tool for benchmarking and variance analysis, enhancing decision-making and optimizing collection strategies. Through a case study in Jaipur, India, the research highlighted challenges within the municipal waste management system, particularly in commercial and residential sectors. Existing collection system shortcomings, including organizational deficiencies, inefficient methods, and resource limitations, were identified. Employing an economic costing procedure, the study proposed a more efficient collection system with substantial potential for reducing collection service expenditures while maintaining or improving quality. The proposed cost-benefit analysis framework empowers waste management authorities to make informed decisions aligned with budgets and objectives, fostering sustainable waste management practices. Ultimately, this research underscores the significance of multifaceted approaches to waste management. By implementing efficient collection systems and promoting behavioral shifts, cities and municipalities can progress towards cleaner environments, diminished health risks, and enhanced overall quality of life for residents.

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