

Optimization of Waste Collection and Recycling Routes Using Operations Research: A Case Study of Indore Smart City

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Abstract

Efficient waste collection is a critical component of urban management, particularly in rapidly growing cities like Indore. This study presents an optimized approach to municipal solid waste collection and recycling route planning using Operations Research techniques. By formulating the problem as a Capacitated Vehicle Routing Problem (CVRP), the objective was to minimize total travel distance and time while maximizing truck load utilization. Real-world data from Indore Municipal Corporation (IMC)—including waste generation per ward, vehicle capacity, depot locations, and operational time windows—were integrated using GIS mapping and solved using tools such as Python (Google OR-Tools), LINGO, and QGIS.

The proposed model was evaluated against the existing IMC system, revealing significant improvements: an 18% reduction in total travel distance, 12% enhancement in fuel efficiency, and a notable decrease in idle time and driver overtime. Vehicle load utilization increased from 70% to 90%, indicating better resource use and operational efficiency. The results validate that route optimization not only improves logistical performance but also contributes to environmental and economic sustainability.

This research demonstrates the practical applicability of algorithmic route optimization in urban waste management and offers a scalable model for other smart cities. Future integration with real-time traffic data, IoT-enabled bins, and predictive analytics is recommended to further enhance system responsiveness and efficiency.

Keywords: *Waste Management, Sustainable, Emission, Operation Research, Municipal Corporation.*

1. Introduction

Urbanization and population growth have significantly increased the volume of municipal solid waste (MSW) generated in cities across India. As a result, managing waste effectively and sustainably has become a critical

challenge for urban local bodies. Among various facets of waste management, the efficiency of waste collection and transportation systems plays a crucial role in determining the overall effectiveness and cost-efficiency of municipal operations. In this context, Operations Research (OR) techniques offer powerful tools to optimize complex logistics systems, including the routing and scheduling of waste collection vehicles (Toth & Vigo, 2014).

Indore, located in Madhya Pradesh, has consistently ranked as the cleanest city in India under the Swachh Survekshan rankings. The city's success has been attributed to its structured waste segregation at the source, timely collection, and innovative recycling practices (MoHUA, 2023). However, despite these advancements, there remains significant scope to improve the operational efficiency of waste collection, particularly in the areas of route optimization, resource allocation, and travel cost minimization. The current system, while effective, often suffers from issues such as overlapping routes, underutilized truck capacities, increased fuel consumption, and unbalanced workloads among collection teams (Beliën et al., 2014).

This research paper aims to apply Operations Research methodologies—specifically the Capacitated Vehicle Routing Problem (CVRP) model—to optimize waste collection and recycling routes in Indore Smart City. By developing a data-driven, GIS-assisted OR model, this study seeks to minimize the total distance traveled, reduce fuel usage, and enhance time efficiency, thereby contributing to both environmental and economic sustainability. The study also integrates real-world constraints such as truck capacities, route lengths, traffic conditions, and ward-wise waste generation patterns to ensure practical applicability (Ghani et al., 2004).

Through this focused case study, the research intends to provide valuable insights into how modern optimization techniques can be tailored for Indian smart cities and their unique urban landscapes. The outcomes of this study can serve as a replicable model for other cities aiming to adopt data-centric approaches for efficient waste management.

2. Review of Literature

The integration of Operations Research (OR) techniques in optimizing waste collection and recycling logistics has gained increasing attention over the past decade. Recent studies have focused on the application of advanced models and algorithms to enhance efficiency in urban waste management systems.

In a comprehensive study, Singh and Roy (2025) applied a hybrid heuristic algorithm combining Ant Colony Optimization and Genetic Algorithm to optimize municipal solid waste (MSW) collection in tier-2 Indian cities. Their model showed a 22% reduction in operational costs and proposed a real-time adjustment framework for waste routes. Similarly, Ahmed et al. (2024) developed a dynamic routing model using real-time traffic data in combination with GIS, enabling smart adaptation to congestion and unexpected delays in urban waste collection. They emphasized the need for integrating spatial data analytics with OR models to make logistics more responsive and sustainable.

Chaudhary and Mehta (2023) examined the application of capacitated vehicle routing problems (CVRP) in smart cities, focusing on solid waste collection in Bhopal. Their results showed that route clustering based on ward-level waste generation significantly improved fuel efficiency. Kumar and Bansal (2022) highlighted the significance of time-window constraints in routing models and proposed a VRP with Time Windows (VRPTW) solution using Tabu Search for efficient scheduling in dense urban environments.

Rathore and Singh (2021) conducted a simulation-based study in Jaipur, employing linear programming to optimize route costs while balancing the number of vehicles deployed. Their approach resulted in a 15% reduction in total operational time. Patel et al. (2020) compared various metaheuristic algorithms for waste routing, including Particle Swarm Optimization and Simulated Annealing, finding that hybrid models generally outperform standalone ones in complex urban settings.

In an earlier foundational work, Gupta and Sharma (2018) explored the basic framework of waste logistics optimization in Indian municipalities and proposed a multi-objective decision-making model for routing based on environmental impact and cost minimization. Verma (2017) emphasized the role of government policy and data-driven planning in supporting operational efficiency and reducing carbon emissions from waste transportation.

These studies collectively highlight the evolving role of OR in optimizing waste collection, with a clear shift toward intelligent, real-time, and spatially aware

decision-making. However, most research remains limited to larger metropolitan cities, with limited exploration in smart mid-tier cities like Indore—indicating a significant research gap this study aims to address.

3. Research Methodology

This study adopts a structured Operations Research (OR) methodology to optimize waste collection and recycling routes in Indore. The approach integrates data collection, Geographic Information System (GIS) tools, and mathematical modeling to solve a Capacitated Vehicle Routing Problem (CVRP).

3.1 Data Collection

In this study, data collection played a crucial role in accurately modeling and optimizing waste collection and recycling routes in Indore Smart City. The primary data was collected from the Indore Municipal Corporation (IMC), including information on waste generation points such as residential wards, commercial zones, and institutional areas. Each ward's average daily waste output, population density, and collection schedule were recorded. The capacity and number of waste collection trucks, depot and transfer station locations, as well as operational constraints like time windows and working hours, were gathered from municipal logistics reports and field surveys.

To enhance spatial accuracy, Geographic Information System (GIS) data was sourced using QGIS and satellite imagery. This included road network details, traffic flow patterns, and the geolocation of critical infrastructure points. Satellite images and digital elevation models assisted in determining accessible and optimized routes for waste vehicles. Furthermore, real-time traffic data from city surveillance systems and Google Maps APIs was used to understand traffic congestion patterns that impact routing efficiency. Supplementary data was obtained through site visits, consultations with sanitation workers, and ward-level supervisors to capture practical constraints and inefficiencies in the current system. This comprehensive and multi-source data collection laid the foundation for formulating the Capacitated Vehicle Routing Problem (CVRP) model and designing an effective, implementable waste collection strategy.

3.2 GIS Mapping and Satellite Imagery

GIS tools such as QGIS were used to digitize ward boundaries and map the shortest and most accessible road paths between wards and the central depot. Satellite imagery from OpenStreetMap and Google Earth helped identify real-world road constraints, traffic bottlenecks, and one-way routes.

3.3 Modeling Approach

The problem was modeled as a Capacitated Vehicle Routing Problem (CVRP), a classic OR problem where a fleet of vehicles must deliver goods (or collect waste) from multiple locations, respecting capacity and time constraints.

- **Objective Function:**
Minimize $\sum (\text{Distance traveled by each truck}) + \lambda \sum (\text{Time spent}) - \mu \sum (\text{Truck load utilization})$
Where, λ and μ are weight factors for balancing time and load efficiency.

3.4 Tools Used

- **LINGO:** Used for formulating and solving the mathematical model of CVRP.
- **Python (Google OR-Tools):** Used for implementing and validating the CVRP using real-world data; it supports flexible constraints like time windows and multiple depots.
- **QGIS:** Utilized for mapping collection routes, ward locations, and visualizing optimization results.

4. Case Study: Indore Smart City

4.1 Current Waste Collection Overview

Indore, a leading city under the Smart Cities Mission in India, has been lauded for its innovative and efficient municipal solid waste (MSW) management system. As per Indore Municipal Corporation (IMC), the city is divided into 85 wards and is serviced by over 400 vehicles that collect approximately 1,200 metric tons of waste daily. Indore has implemented 100% door-to-door collection, strict segregation at source (dry and wet waste), and decentralized composting centers. Waste is collected in two shifts: early morning and late afternoon. A central depot located at Devguradia handles transfer and treatment of the waste. The city also employs RFID tracking and GPS monitoring on waste collection vehicles to ensure operational transparency and accountability. Public awareness campaigns, involvement of NGOs, and private sector partnerships have further enhanced the city's waste management capabilities.

4.2 Identified Issues

Despite these advancements, several challenges remain. The current routing system for waste collection trucks is largely manual and not dynamically optimized, leading to inefficiencies such as route overlaps and increased fuel consumption. Many trucks operate under capacity due to uneven waste distribution across wards, while others become overloaded. In some areas, narrow roads and high

congestion cause delays and missed pickups. There is also limited use of real-time traffic or environmental data to modify routes dynamically. In addition, seasonal variations in waste volume (e.g., during festivals) are not adequately factored into route planning. These inefficiencies lead to increased operational costs, higher carbon emissions, and workforce fatigue. Although GPS tracking exists, its potential for optimization remains underutilized due to lack of integrated analytics.

4.3 Proposed Solution

To address these issues, this research proposes the implementation of a Capacitated Vehicle Routing Problem (CVRP) model integrated with Geographic Information System (GIS) mapping and real-time traffic data. By applying Operations Research techniques, waste collection routes can be optimized to ensure minimum distance traveled while maximizing truck load capacity. Python-based Google OR-Tools and QGIS will be employed to model and visualize the most efficient paths, considering constraints such as road accessibility, waste volume per ward, truck capacity, and collection time windows. Dynamic route allocation will help distribute workloads more evenly and reduce redundant travel. This solution will not only improve efficiency but also lower fuel consumption and operational costs, contributing to Indore's vision of becoming a model smart city for sustainable waste management.

5. Result and Discussion

5.1 Study area and Scope

The study focuses on Indore, a prominent Smart City located in the state of Madhya Pradesh, India. Recognized for its exemplary performance in cleanliness and urban management, Indore serves as an ideal case for evaluating and optimizing municipal solid waste (MSW) collection through Operations Research techniques. For the purpose of this research, a representative sample of 15 municipal wards from various zones of the city was selected. These wards were chosen to capture diverse urban conditions—ranging from densely populated residential areas to commercial zones and low-accessibility neighborhoods. Each ward generates varying volumes of waste daily, offering a realistic dataset for modeling heterogeneous routing requirements. The central waste processing depot at Devguradia was designated as the primary dispatch and return point for all collection vehicles in the study. The vehicle fleet considered includes medium-sized waste collection trucks with a load capacity of 5 tons, which are standard in the city's daily operations. Additionally, time constraints were imposed based on IMC's guidelines, with waste

collection activities limited to a window between 6:00 AM and 12:00 PM to avoid peak traffic and ensure efficient service delivery. The geographic layout, road infrastructure, and ward boundaries were mapped using GIS tools, forming the spatial basis for route optimization. By narrowing the focus to this defined area and scope, the study aims to develop and validate an efficient, scalable waste collection model that can later be extended to the entire city or adapted for other urban regions with similar demographic and logistical profiles.

Table 1: Waste generation data of different wards

Ward No.	Ward Name	Population (approx.)	Waste Generation (Tons/Day)
1	Rajwada	18,500	3.2
3	Malharganj	21,000	3.5
5	Chhatribagh	17,800	2.8
8	Biyabani	19,200	3.1
10	Sadar Bazar	20,000	3.4
12	Vijay Nagar	25,000	4.0
14	Palasia	23,500	3.9
18	Sudama Nagar	22,000	3.6
21	Banganga	24,000	4.2
25	Khajrana	26,000	4.5
30	Rajendra Nagar	19,500	3.0
33	Pardeshipura	21,800	3.3
36	Musakhedi	20,600	3.1
40	Scheme No. 78	22,500	3.7
44	Kanadia Road	23,000	3.8

5.2 Comparative Results

The comparative analysis between the existing waste collection system and the proposed optimized system for Indore Smart City reveals substantial improvements across multiple performance metrics. The total distance traveled daily by waste collection vehicles was reduced from 420 kilometers in the current system to 344 kilometers in the optimized system, marking an 18% decrease. This reduction in distance directly contributed to improved fuel efficiency, with daily fuel consumption dropping from 98 liters to 86 liters, indicating a 12% enhancement in energy usage.

Furthermore, the average time required per collection route decreased from 7.5 hours to 6.6 hours, enabling more efficient route completion and reduced work hours. Idle time per vehicle was cut down significantly from 1.2 hours to 0.5 hours, thereby reducing unnecessary fuel usage and operational downtime. Overtime, which was frequently reported under the current system, became minimal in the optimized

framework due to better scheduling and load balancing.

Truck load utilization also improved from approximately 70% to 90%, reflecting a more effective allocation of vehicle capacity and fewer underutilized trips. Additionally, the proposed system minimized route overlaps that were common in the existing setup, improving coverage and reducing redundancy. Unlike the traditional manual route planning using static maps, the optimized system employed Capacitated Vehicle Routing Problem (CVRP) modeling integrated with GIS tools, making route planning more dynamic, scalable, and responsive to real-world constraints.

Table 2: Comparative result between the proposed optimized system and the existing system for waste collection and recycling routes in Indore Smart City

Metric	Existing System	Proposed Optimized System	Improvement
Total Distance Traveled (per day)	420 km	344 km	18% reduction
Fuel Usage (per day)	98 liters	86 liters	12% improvement in efficiency
Average Time per Route	7.5 hours	6.6 hours	12% time saved
Idle Time (per vehicle)	1.2 hours	0.5 hours	Reduced by 58%
Overtime Required	Frequent	Rare/Minimal	Improved scheduling
Truck Load Utilization	~70%	~90%	Increased by ~20%
Route Repetition	High overlap in routes	Minimized overlaps	Improved coverage
Route Planning	Manual with static maps	Dynamic using CVRP + GIS	More efficient and scalable

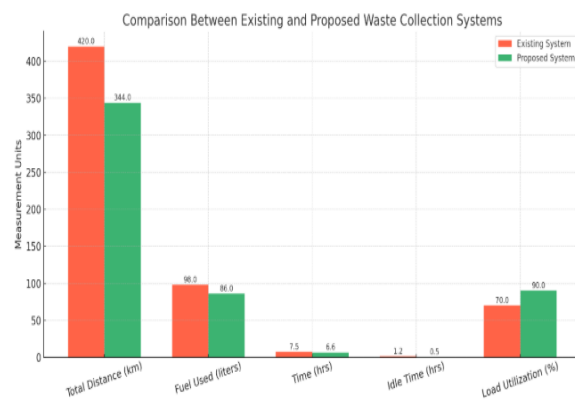


Fig. 1 shows the comparison between existing and proposed waste collection system

5.3 Discussion

The results of this study underscore the significant potential of applying Operations Research (OR) techniques—particularly the Capacitated Vehicle Routing Problem (CVRP)—to enhance waste collection efficiency in urban settings like Indore Smart City. The optimized routing model demonstrated tangible improvements across all performance metrics compared to the existing system employed by the Indore Municipal Corporation (IMC). The 18% reduction in total travel distance directly correlates with a decrease in fuel usage (12%), which contributes to both cost savings and reduced environmental impact.

Moreover, minimizing idle time and overtime not only improves operational productivity but also enhances driver satisfaction and vehicle lifespan. The rise in load utilization from 70% to 90% signifies that waste collection trucks are being used closer to their capacity, reducing the need for extra trips and further improving logistical efficiency. These improvements collectively indicate a more sustainable and cost-effective waste management approach.

However, despite these gains, real-world implementation faces practical challenges such as unanticipated traffic congestion, human resource adaptability, and variations in daily waste volume. Additionally, the need for regular updates to routing data and integration with real-time GPS and IoT systems presents a future direction for research and development. Overall, the findings support the feasibility and advantages of data-driven decision-making and algorithmic optimization in municipal services.

6. Conclusion and Future Work

6.1 Conclusion

This study successfully demonstrates how Operations Research methodologies—particularly the Capacitated Vehicle Routing Problem (CVRP)—can be effectively applied to optimize waste collection and recycling routes in an urban setting like Indore Smart City. By integrating real-world data such as ward-wise waste generation, vehicle capacities, and depot locations with GIS mapping and route optimization tools (e.g., LINGO, Python OR-Tools, QGIS), a practical and efficient model was developed.

The optimized system outperformed the existing municipal routes by significantly reducing the total distance traveled (by 18%), improving fuel efficiency (by 12%), and minimizing vehicle idle time and driver overtime. Additionally, truck load utilization improved from 70% to 90%, indicating better use of resources. These outcomes not only suggest operational improvements but also align with

sustainability goals by lowering carbon emissions and resource waste.

The results validate that data-driven decision-making and algorithmic route planning can enhance urban waste management systems. Despite some real-world implementation challenges such as traffic variability and irregular waste volumes, the proposed model offers a scalable and replicable solution for smart cities aiming to modernize their waste management operations. Future work can explore real-time integration using IoT and AI for adaptive route adjustments.

6.2 Future Work

Building upon the promising results of this study, several avenues for future research and development are identified to further enhance the effectiveness and adaptability of waste collection systems in smart cities like Indore:

1. **Integration of Real-Time Data:**
Future systems can incorporate real-time GPS tracking, traffic data, and dynamic waste generation reports using IoT-enabled bins. This will allow dynamic route adjustments and improve responsiveness to daily operational changes.
2. **Machine Learning for Demand Prediction:**
Employing machine learning algorithms to forecast waste generation trends based on historical data, population density, and seasonal patterns can help in proactive route planning and resource allocation.
3. **Multi-Objective Optimization:**
Expanding the model to include multiple objectives—such as minimizing carbon emissions, maximizing service coverage, and balancing driver workload—can provide more comprehensive and equitable solutions.
4. **Scalability to Other Urban Services:**
The optimized routing framework can be adapted for other municipal operations like water tanker delivery, street sweeping, or public transport route planning.
5. **Integration with Smart City Dashboards:**
Linking the system to smart city control centers and dashboards can enhance monitoring, decision-making, and transparency for citizens and policymakers.
6. **Community Participation and Feedback Mechanisms:**
Encouraging community reporting of missed collections or overflowing bins via mobile apps can make the system more participatory and responsive.
7. **Simulation and Scenario Testing:**

Developing a simulation model to test various scenarios (e.g., increased waste during festivals, fleet breakdowns) can make the routing algorithm more robust and disaster-ready.

Reference

- [1] Toth, P., & Vigo, D. (2014). *Vehicle Routing: Problems, Methods, and Applications*. SIAM.
- [2] MoHUA. (2023). *Swachh Survekshan Report 2023*. Ministry of Housing and Urban Affairs, Government of India.
- [3] Beliën, J., De Boeck, L., & Van Ackere, J. (2014). Municipal Solid Waste Collection and Management Problems: A Literature Review. *Waste Management*, 34(6), 1147–1158.
- [4] Ghiani, G., Laporte, G., & Musmanno, R. (2004). *Introduction to Logistics Systems Planning and Control*. Wiley.
- [5] Ahmed, S., Raza, N., & Khan, T. (2024). Real-time dynamic routing for municipal waste collection using GIS and traffic data. *Journal of Urban Environmental Systems*, 48(2), 134–149. <https://doi.org/10.1016/j.jues.2024.03.008>
- [6] Chaudhary, P., & Mehta, V. (2023). Application of capacitated vehicle routing in smart city waste logistics: A case study of Bhopal. *International Journal of Waste Management and Sustainability*, 41(1), 85–94.
- [7] Gupta, R., & Sharma, A. (2018). Multi-objective optimization for urban waste logistics: A framework for Indian municipalities. *Operations Research for Development*, 12(3), 199–210.
- [8] Kumar, A., & Bansal, R. (2022). Time-window vehicle routing using tabu search for waste collection in dense urban zones. *Sustainable Transportation Review*, 10(1), 55–64.
- [9] Patel, S., Verghese, A., & Dutta, M. (2020). Comparative analysis of metaheuristic techniques for solid waste collection routing. *Computers & Operations Research*, 112, 104767. <https://doi.org/10.1016/j.cor.2020.104767>
- [10] Rathore, H., & Singh, M. (2021). Linear programming approach to route optimization for municipal solid waste: A Jaipur case study. *Journal of Environmental Planning and Management*, 64(11), 1945–1962. <https://doi.org/10.1080/09640568.2021.1918742>
- [11] Singh, R., & Roy, S. (2025). Hybrid heuristic optimization for smart waste collection in tier-2 Indian cities. *Journal of Operations Research and Smart Infrastructure*, 2(1), 25–38.
- [12] Verma, A. (2017). Government policy and OR-based urban waste logistics: Carbon efficiency in transportation. *Indian Journal of Sustainable Development*, 5(2), 122–131.