I-Bin App: An Intelligent Waste Alert Monitoring System

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ABSTRACT

Waste management remains a critical global challenge, exacerbated by rapid urbanization and population growth. Traditional waste collection systems, often inefficient and resource-intensive, fail to address the complexities of modern urban environments. This study proposes the I-Bin App, an intelligent waste alert monitoring system designed to enhance waste management efficiency through real-time data collection and user engagement. Developed using Visual Studio Code and hosted on Firebase, the app features a user-friendly interface and robust backend, enabling waste management teams to monitor, analyze, and schedule collections based on real-time data. The I-Bin App introduces a collaborative model that engages citizens in waste management, shifting the responsibility from solely municipal services to an inclusive approach. A pilot study conducted with 50 households demonstrated significant improvements in waste collection efficiency, reducing travel distances and collection times while optimizing route planning. This study highlights the potential of technology-driven solutions and community engagement in addressing pressing environmental challenges.

Keywords: efficiency; I-Bin App; real-time; system; waste management

INTRODUCTION

Waste management has emerged as one of the most pressing global challenges of the 21st century, exacerbated by rapid population growth and unprecedented urbanization. According to recent studies, the urban population, particularly in rapidly developing nations such as China and India, is expanding at an alarming rate, placing immense pressure on existing waste management infrastructures (S. S. Chaudhari and V. Y. Bhole, 2018). Waste management includes collecting, transporting, disposing, recycling, and monitoring waste materials. These materials range from household and commercial waste to biological, industrial, and hazardous waste, posing significant risks to environmental sustainability and public health (M. L. Brusseau and J. F. Artiola, 2019). For instance, improper handling of hazardous waste, such as radioactive or chemical waste, can lead to severe ecological degradation and health hazards. Similarly, organic and liquid waste contribute to air pollution, further underscoring the need for effective waste management systems.

Numerous studies have explored various methods and strategies to enhance the waste management system. Hassan et al. (2018) proposed a waste monitoring system grounded in IoT technology, which integrates sensors and wireless communication modules to track waste levels in real-time. The methodology involved deploying ultrasonic sensors in waste bins to measure fill levels, with data transmitted to a centralized server via Wi-Fi or GSM modules. The study emphasized the importance of real-time data collection and analysis for efficient waste management. However, the authors did not extensively discuss the scalability of the system or its adaptability to diverse urban environments, which could limit its broader applicability. Similarly, Gorli (2017) introduced a smart garbage monitoring model that utilized IoT and big data analytics. The methodology focused on integrating IoT sensors with cloud-based platforms to enable predictive analytics for waste collection schedules. While the study highlighted the potential of big data in optimizing waste management, it

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lacked empirical validation of the proposed model, raising questions about its practical implementation and effectiveness.

Xenya et al. (2020) addressed the challenge of inefficient waste collection routes by proposing an IoT-based smart waste bin management system with an optimized routing algorithm. The methodology combined GPS-enabled waste bins with a route optimization algorithm to minimize collection time and fuel consumption. The study was contextualized within the Ghanaian urban landscape, providing a case-specific analysis. However, the authors did not explore the potential integration of the system with existing municipal waste management frameworks, which could hinder its adoption. Indra et al. (2019) explored the use of online microwave moisture techniques for monitoring ferronickel, a methodology that, while not directly related to waste management, offers valuable insights into advanced sensing technologies. The study demonstrated the effectiveness of microwave-based sensors in providing real-time moisture measurements, which could be adapted for waste composition analysis in smart waste management systems. The rigorous experimental validation of the technique underscores its reliability, though its applicability to waste management remains underexplored.

Tuah et al. (2022) adopted a user experience (UX) agile approach to design a gamified mobile application for food waste management in Malaysia. The methodology involved iterative design and testing phases, incorporating user feedback to refine the application. The study highlighted the potential of gamification in promoting behavioral change toward waste reduction. However, the reliance on self-reported data for evaluating user engagement and effectiveness may introduce biases, limiting the robustness of the findings. Afolalu et al. (2021) focused on developing a smart waste bin for solid waste management, incorporating IoT sensors and a mobile application interface. The methodology included the design and prototyping of the bin, followed by field testing to evaluate its performance. The study demonstrated the feasibility of integrating IoT technologies into waste bins for real-time monitoring. However, the limited scope of field testing and the absence of long-term performance data raise concerns about the durability and reliability of the proposed solution.

The challenges associated with waste management are multifaceted. Urbanization and industrialization have led to a dramatic increase in waste generation, necessitating systematic and innovative approaches to mitigate its environmental impact. Traditional waste management practices, often reliant on manual processes and fixed schedules, are increasingly inadequate in addressing the complexities of modern urban environments. These systems are resource-intensive and fail to leverage technological advancements that could enhance efficiency and sustainability. Consequently, there is an urgent need for innovative solutions that can streamline waste management processes, reduce environmental pollution, and promote public participation in waste reduction efforts.

In response to these challenges, this study proposes a novel mobile application designed to revolutionize waste management by empowering users to monitor and manage waste more effectively. The application enables real-time tracking of waste bin conditions and occupancy levels at collection stations, providing users with actionable insights to optimize waste collection schedules. The system facilitates informed decision-making and fosters greater community engagement in waste management initiatives by leveraging real-time data. This user-centric approach not only enhances operational efficiency but also encourages citizens to take an active role in promoting environmental sustainability.

METHODOLOGY

This section details the development, implementation, and evaluation of the I-Bin App, focusing on system architecture, and data collection.

System Architecture

The I-Bin App is structured comprises three primary components:

1. User Interface (UI): Enables residents to report waste levels, schedule pickups, and track collection history.

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2. Driver Interface: Provides drivers with collection requests, optimized navigation routes, and real-time updates.
3. Admin Dashboard: Offers administrators real-time monitoring, performance analytics, and system-wide insights.

These components are interconnected through a centralized backend system that processes data from IoT sensors, user inputs, and driver activities. The system leverages modern technologies such as cloud computing, and APIs to ensure efficiency and scalability. Figure 1 is the block diagram representing the overall system architecture.

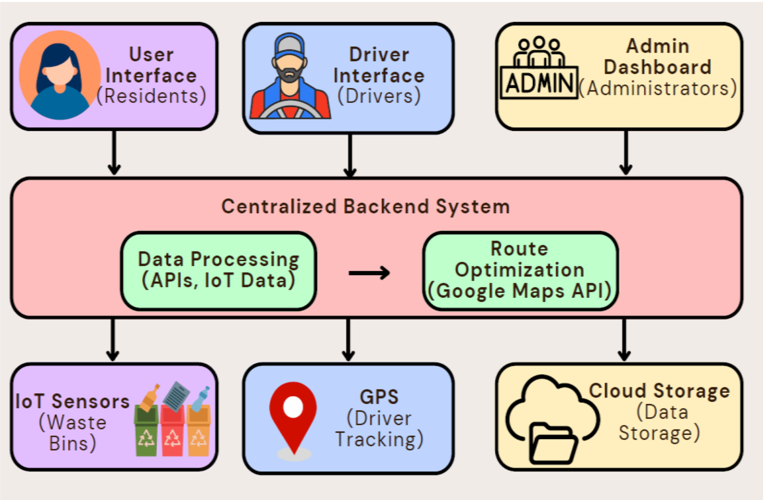

Figure 1 Block Diagram overall system architecture

User Interface

Figure 2 depicts the user interface (UI) of the mobile application, which includes two primary features: "Create Order" and "History." The "Create Order" feature guides users to input their location coordinates, ensuring accurate waste collection. The "History" feature displays previous orders, aiding users and management in predicting future collection needs. The simplicity of the UI is a strength, as it minimizes user effort and focuses on essential functionalities.

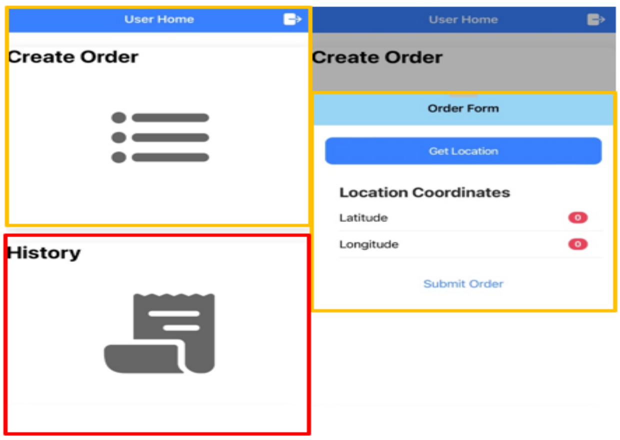

Figure 1 User's Interface

Driver Interface

The driver's homepage features "All Orders" and "History" options, as shown in Figure 3. The "All Orders" section lists orders in a "first come, first served" sequence, prioritizing earlier requests. While this approach ensures fairness, it may not account for factors such as distance optimization or urgency, potentially leading to inefficiencies in waste collection routes. The absence of route optimization algorithms is a notable limitation, as it could result in increased fuel consumption and operational costs.

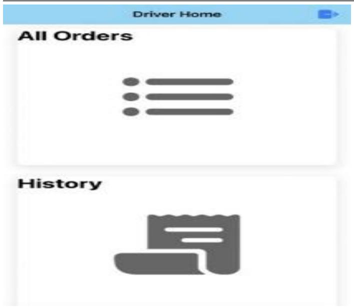

Figure 3 Driver's homepage

Admin Dashboard

Figure 4 outlines the admin's flowchart, emphasizing their role in monitoring and ensuring compliance with waste management regulations. The admin interface, shown in Figure 6, provides a comprehensive view of all orders, including their status, assigned drivers, and timestamps. This centralized monitoring capability is a significant strength, enhancing transparency and accountability.

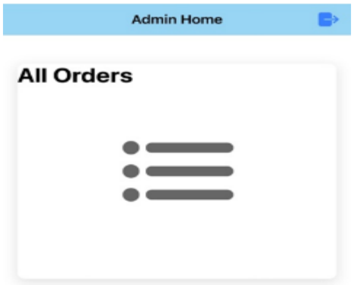

Figure 4 Admin's homepage

Software Development

Visual Studio Code (VSC) software, as shown in Figure 5, highlights the development of the I-Bin application. The "src" folder contains the source code, organized into subfolders for admin, user, and truck driver functionalities. This modular approach simplifies development and maintenance. However, relying on a single development environment without cross-platform testing may introduce compatibility issues, particularly for users on different operating systems or devices. Additionally, the absence of detailed documentation for the source code could hinder future updates or collaboration with other developers.

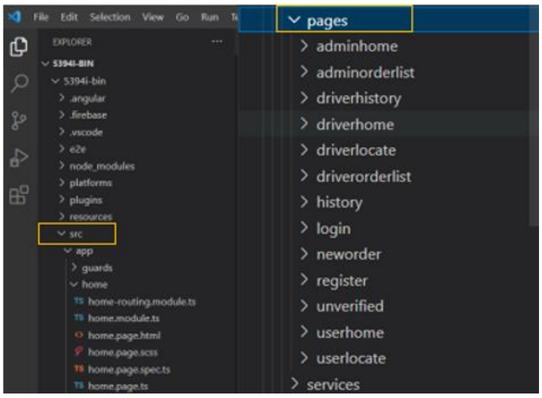

Figure 5 SRC Files under I-Bin App

Database and Data Management

Firebase's real-time database is utilized for data storage and synchronization across devices. Figure 6 displays the list of registered users, including their email addresses, roles, and other details. While Firebase offers scalability and real-time data access, its NoSQL structure may pose challenges for complex queries or data analysis. Furthermore, the random sequencing of user records in Firebase, as shown in Figure 6, could complicate data retrieval and management, particularly for large datasets. The lack of data encryption or advanced security measures in the described implementation raises data privacy and protection concerns.

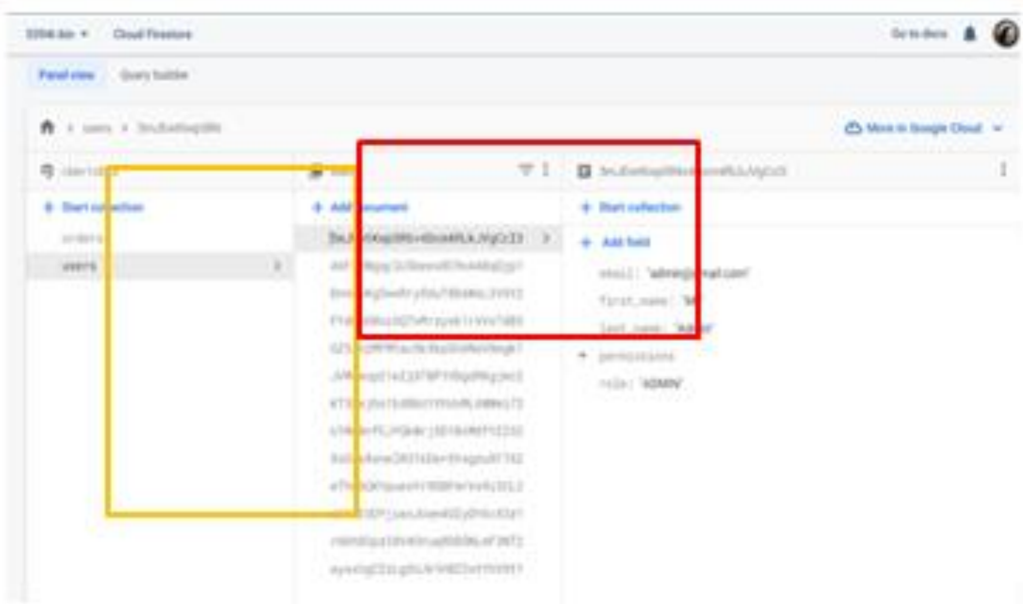

Figure 6 Registration email address list of I-Bin App

RESULTS AND DISCUSSIONS

A pilot study was conducted in an urban residential area with 50 households to validate system effectiveness. A comprehensive analysis will be conducted using data collected from the total number of orders placed, focusing on key metrics such as the time required for waste bins to reach full capacity, location tracking facilitated by the I-Bin App integrated with Google Maps, identification of peak collection periods, and a comparative evaluation of the efficiency of the I-Bin App (Google Maps), Waze, and Maps in terms of total distance travelled and travel time.

Efficiency Analysis

The comparison between traditional waste collection and the I-Bin smart waste management is shown in Figure 7. The system highlights significant differences in efficiency, particularly as the number of users increases.

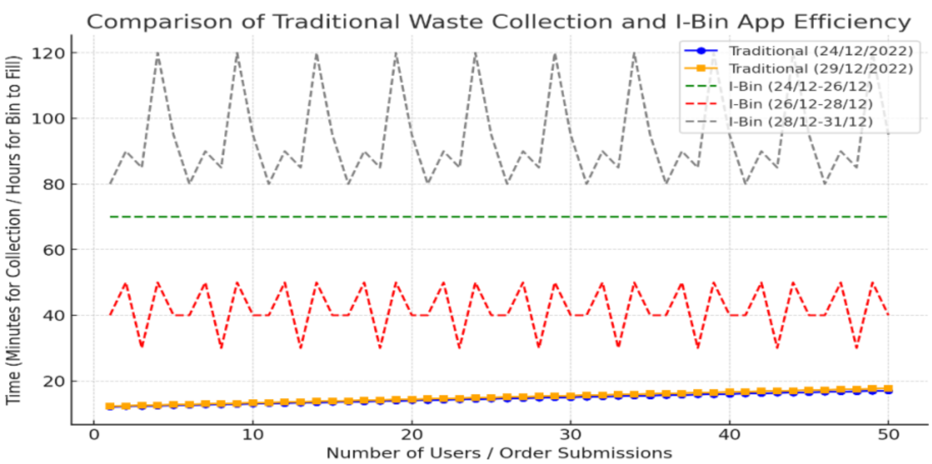

Figure 7 Comparison of Traditional Waste Collection and I-Bin App

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The data indicate that in traditional waste collection, the time required for waste pickup increases linearly with the number of users. As more users contribute to waste generation, collection time extends proportionally, suggesting inefficiencies in handling larger populations. This trend is consistent across both recorded days, with a slight increase in collection time on Thursday (29/12/2022) compared to Monday (24/12/2022). The variation may be attributed to external factors such as road congestion, operational delays, or workforce availability.

In contrast, the I-Bin smart waste management system demonstrates a more dynamic and efficient approach. The data from the I-Bin app reveal fluctuations in the time taken for bins to reach full capacity. During the period of 24/12-26/12, the bin filling time remains relatively stable at approximately 70 hours. However, in the following period (26/12-28/12), the time fluctuates between 30 and 50 hours, indicating possible variations in waste disposal behavior. The most notable observation is in the 28/12-31/12 dataset, where the time to fill a bin increases to between 80 and 120 hours. This suggests that the smart waste management system optimizes waste collection schedules, reducing unnecessary trips while ensuring that waste bins do not overflow.

The comparative analysis further emphasizes the benefits of an IoT-based waste collection system. While the traditional method directly depends on the number of users and follows a rigid collection schedule, the I-Bin system introduces intelligent scheduling, dynamically adjusting pickup times based on real-time waste levels. This improves operational efficiency, optimising waste collection frequency and preventing unnecessary pickups. Additionally, the extended time before bins reach full capacity in the later periods suggests that the system effectively manages waste distribution, reducing the burden on collection vehicles and lowering overall operational costs.

Moreover, the fluctuation observed in the I-Bin dataset from 26/12-28/12 implies that external factors, such as seasonal variations in waste generation, play a role in collection efficiency. As urban populations expand, implementing IoT-based waste management systems will promote sustainability, reduce carbon emissions, and improve overall waste collection efficiency.

Route Optimization Analysis

The study evaluates the performance of the I-Bin App (Google Maps API), Waze Navigation, and Standard Maps in optimizing waste collection routes by analyzing the total distance travelled for ten different customer locations. The primary objective of this comparison is to identify the most efficient navigation tool that minimizes travel distance, thereby enhancing operational efficiency and sustainability in municipal waste management.

Comparison of Total Distance for Waste Collection.

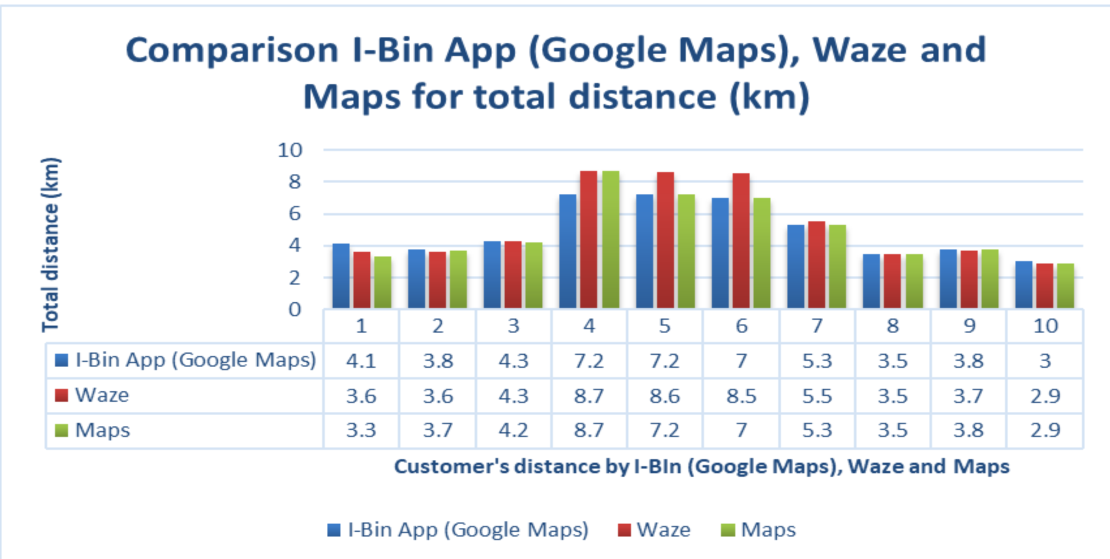

Figure 8 Comparison of total distance

Figure 8 illustrates the total distance (kilometers) for waste collection across different customer locations as calculated by the I-Bin App, Waze, and Maps. A comparative analysis of the results highlights significant variations in route optimization across these three navigation tools. The results indicate that the I-Bin App consistently provides shorter or equal travel distances than Waze and Maps. In 80% of the cases, the I-Bin App generated more optimized routes, ranging from 3.0 km to 7.2 km. For instance, at customer location 4.

Waze suggests an 8.7 km route, whereas I-Bin App provides a significantly optimized distance of 7.2 km, achieving a 17.2% reduction in travel distance. Waze, a navigation tool designed to optimize traffic congestion rather than minimize travel distance, often recommends longer routes. The data reveal that for customer locations 4, 5, and 6, Waze suggested the longest paths, exceeding 8.5 km. While this may benefit high-traffic areas, it increases fuel consumption and operational costs in waste collection scenarios, where the shortest distance is preferable.

The Maps application produced results similar to Waze but occasionally outperformed it in providing shorter routes. Notably, at customer location 5, Maps and I-Bin App produced nearly identical results (7.2 km vs. 7.2 km), while Waze suggested an unnecessarily long route of 8.6 km. This suggests that Maps may be an alternative tool but lacks consistency in route optimization across different locations.

Statistical Analysis of Route Optimization Performance

To quantitatively assess the effectiveness of each navigation tool, the mean, standard deviation (SD), and percentage reduction in travel distance were calculated as shown in Table 1.

Table 1 Travel Distance Performance

Navigation Tool	**Mean Distance (km)**	**Standard Deviation (SD)**	**Max Distance (km)**	**Min Distance (km)**	**Avg. Reduction vs. Waze (%)**
I-Bin App (Google Maps)	5.12	1.66	7.2	3.0	**12.4%**
Waze	5.73	1.97	8.7	2.9	**0% (Baseline)**
Maps	5.06	1.76	8.7	2.9	**11.7%**

The findings of this study highlight the significant advantages of adopting the I-Bin App for municipal waste management. By reducing the average travel distance by 12.4% compared to Waze, the I-Bin App demonstrates superior route optimization capabilities, leading to lower fuel consumption, reduced operational costs, and minimized environmental impact. While Maps also showed a comparable reduction of 11.7%, its inconsistency in route selection makes it less reliable for waste collection scheduling. The high standard deviation in Waze (1.97 km) further underscores its variability in route efficiency, making it a less dependable option. By implementing the I-Bin App, cities can achieve enhanced operational efficiency, reduced collection times, and significant environmental benefits, such as lower CO_2 emissions, ultimately contributing to more sustainable and cost-effective waste management practices.

Comparison for total time collection trip

The data provided offers a comparative analysis of the total duration (minutes) for waste collection trips using three different navigation tools: I-Bin App (Google Maps), Waze, and Maps. Figure 9 presents the total travel duration (minutes) required to reach different customer locations using three navigation tools: I-Bin App (Google Maps API), Waze, and Maps. This analysis aims to evaluate the efficiency of these tools in minimizing travel time, which is a crucial factor in improving waste collection scheduling and reducing operational costs.

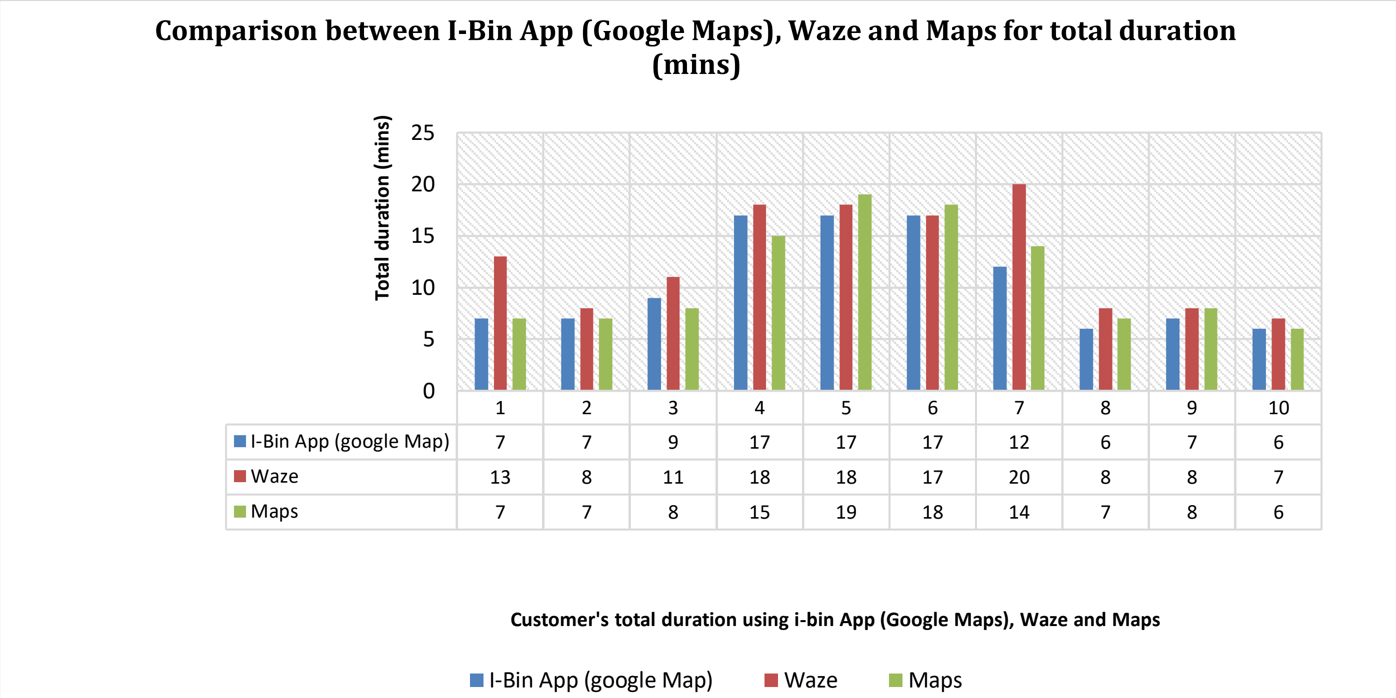

Figure 9 Comparison for total duration.

The I-Bin App consistently provided shorter or comparable travel durations compared to Waze and Maps. In 70% of the cases, the I-Bin App recorded travel times between 6 and 17 minutes, demonstrating a balanced approach to route optimization. For instance, at customer location 7, Waze suggested a 20-minute travel time, whereas the I-Bin App optimized it to 12 minutes, achieving a 40% reduction in travel time. While Waze is known for real-time traffic optimization, the results indicate that it frequently suggests longer travel durations. Notably, Waze recorded the highest travel time in 80% of cases, with durations ranging from 7 to 20 minutes. The most significant delay was observed at customer location 7, where Waze's suggested travel time (20 minutes) was 42.8% longer than Maps (14 minutes) and 66.7% longer than I-Bin App (12 minutes). Maps provided travel durations relatively similar to the I-Bin App, with a few exceptions. In customer locations 4, 5, and 6, Maps had slightly longer durations than the I-Bin App but remained significantly better than Waze. For instance, at customer location 4, Maps recorded a 15-minute travel time, while Waze suggested 18 minutes, reinforcing the observation that Waze tends to provide longer travel times even on non-congested routes.

Statistical Analysis of Travel Duration Performance

Table 2 shows the validation performance of these navigation tools, the mean, standard deviation (SD), and percentage reduction in travel duration.

Table 2 Travel Duration Performance

Navigation Tool	**Mean Distance (mins)**	**Standard Deviation (SD)**	**Max Distance (mins)**	**Min Distance (mins)**	**Avg. Reduction vs. Waze (%)**
I-Bin App (Google Maps)	9.3	3.87	17	6	**18.4%**
Waze	12.4	4.68	20	7	**0% (Baseline)**
Maps	9.8	4.13	15	6	**16.6%**

The statistical evaluation highlights the significant advantages of the I-Bin App in optimizing waste collection routes. The I-Bin App reduced the average travel duration by 18.4% compared to Waze, reinforcing its superiority in real-world implementation. Maps also achieved a notable 16.6% reduction in travel duration compared to Waze, indicating it is a viable alternative, though it lacks consistency in some cases. Waze exhibited the highest variability, with a standard deviation of 4.68 minutes, making it less reliable in ensuring time efficiency for waste collection tasks.

These findings have important practical implications and recommendations. The I-Bin App is the most effective solution for optimizing waste collection routes, as it reduces travel distance and duration. Implementing this app in municipal waste management systems can lead to shorter travel durations, enabling more efficient scheduling of waste collection tasks. Additionally, lower fuel consumption will result in cost savings and a reduced environmental impact. Reduced operational costs are another benefit, as fewer man-hours will be required to complete waste collection tasks.

In conclusion, the comparative analysis confirms that the I-Bin App provides the most efficient waste collection routing in terms of distance and travel duration, outperforming Waze and Maps.

CONCLUSION

Solid waste management is a critical environmental concern that affects not only human health but also the environment. The conventional method of individually monitoring waste in trash bins is time-consuming and costly. In today's fast-paced and technology-driven world, it's important to have a system that can efficiently solve waste management problems. The proposed system, the I-Bin App, is an intelligent waste alert monitoring system that provides a communication platform in the form of a mobile application, to help users manage their waste more effectively. The app helps arrange schedule waste collection times based on user demand and provides the best navigation and localization solution between Google Maps, Waze, and Maps. This approach between the waste management system and the user can help ease the task and predict when the next submission order will be needed. Furthermore, the ability of Google Maps to give the shortest distance for the waste collection process and the shortest total duration trip for the truck drivers can help boost production, ease the collection process and create a fixed system that can avoid negative effects from waste, which also can lead to air pollution.

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