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Optimizing Waste Routes with Cheapest Insertion and A-Star

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ABSTRACT

Efficient waste management is a major challenge. This research develops a web-mobile application, "SampahGo," to optimize collection routes using the Cheapest Insertion Heuristic (CIH) for route sequencing and A-Star for pathfinding. The application, built with Flutter and Node.js, was tested using a dataset of 14 waste banks in Yogyakarta. The main finding shows that the algorithm implementation achieved significant optimization, reducing the route distance by 31.4% compared to the initial route (from 14.59 km to 10.01 km). Functional testing confirmed all system components operate successfully. This research contributes to a practical and validated system that improves operational efficiency, reduces costs, and supports a more structured waste management system in urban areas.

Keywords: *Cheapest Insertion Heuristic, Collection Route, A-Star, Sampahgo, Web Mobile*

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INTRODUCTION

The increasing amount of household waste in Indonesia has become a complex environmental issue in line with population growth and rising consumption patterns. According to data from the Ministry of Environment and Forestry (KLHK), Indonesia generates more than 175,000 tons of waste per day. Unfortunately, public waste management practices remain suboptimal, particularly in waste segregation at the source. Although the volume of waste produced is massive, waste management practices in many regions are still inadequate, especially in waste sorting (Malik et al., 2024; Fargiana et al., 2022). Most waste is collected at temporary storage sites (TPS) before being transported to final disposal sites. However, management at these temporary sites is often inefficient, leading to waste accumulation, unsanitary conditions, and environmental pollution, especially when these sites are located near residential areas (Eka Wijayanti et al., 2020). For instance, in the city of Yogyakarta, waste management at temporary storage sites remains inefficient, resulting in waste buildup and declining public health standards. This highlights the urgent need for a more structured, efficient, and organized waste management system.

One promising solution to this challenge is the development of web and mobile applications that integrate real-time waste location mapping and automatically schedule transportation to optimize the collection process. By utilizing algorithms such as the Cheapest Insertion Heuristic (CIH), the application can determine the most efficient waste transportation routes, minimize travel time, and reduce environmental impact (Herrera-Granda et al., 2024; Oeitema et al., 2024). The CIH algorithm is well-suited to solving this type of problem, as it provides an effective solution to the Vehicle Routing Problem (VRP), which aims to minimize the total travel distance of waste collecting vehicles (Punse et al., 2024). Implementing the CIH algorithm can significantly improve operational efficiency by ensuring that waste collection vehicles follow the shortest and most cost-effective routes (Pires et al., 2025).

Although previous research has demonstrated the effectiveness of heuristic algorithms like CIH (Fargiana et al., 2022) or IoT-based systems (Priyadarshi et al., 2023). separately, a gap remains in the practical integration of these algorithms into a functional, user-friendly web-mobile application platform specifically designed for the context of waste management operators in Indonesian cities like Yogyakarta. Many studies focus on pure algorithmic validation (Eka Wijayanti et al., 2020), without presenting an implementable end-to-end system architecture.

Therefore, this research focuses on developing the "SampahGo" application to bridge this gap. The application is designed to address urgent challenges in waste management. It is developed using the Flutter framework for mobile interface implementation, enabling it to operate seamlessly on both web and mobile platforms. It also integrates OpenStreetMap for accurate and freely accessible mapping of waste collection points (Pratitis et al., 2024). Previous studies have demonstrated that dynamic routing systems and IoT-based real-time monitoring can enhance the effectiveness and responsiveness of urban waste management systems(Priyadarshi et al., 2023; Jerbi et al., 2025). With this system in place, the waste transportation process is expected to become more structured, efficient, and responsive, particularly in cities such as Yogyakarta that continue to face waste accumulation and inefficient collection systems.

METHOD

This research was conducted using a systematic framework, beginning with the identification of route inefficiency issues, followed by a literature study on VRP algorithms and mobile technology, data collection, system architecture design, implementation, and functional testing. This system was designed using client-server architecture. The user interface (frontend), which is a mobile application developed with the Flutter framework, provides an interface for entering data and displaying results. The backend, built with Node.js and Express, handles data processing, runs optimization algorithms, and communicates with the database.

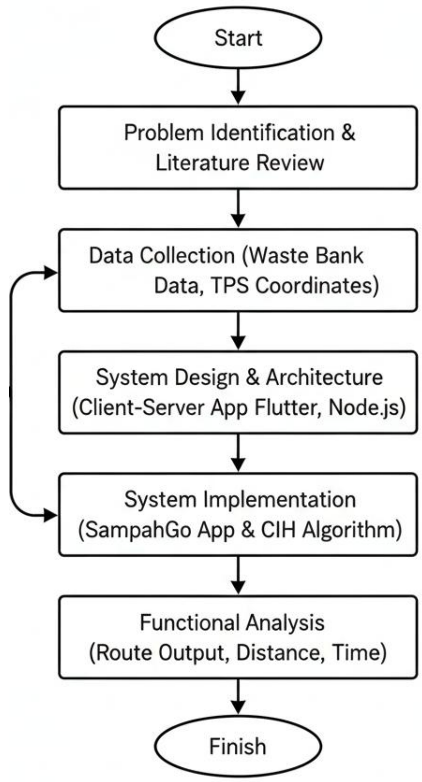

Figure 1. *Research Methodology*

Figure 1 shows this research methodology begins with problem identification and a literature review to establish the research foundation. The next stage is data collection, specifically involving waste bank data and TPS (Temporary Disposal Site) coordinates. Once the data is gathered, the process moves to system design and architecture, where a *client-server* application is designed using Flutter for the *frontend* and Node.js for the *backend*. This design is then implemented by building the "SampahGo" application and implementing the CIH Algorithm, with a potential feedback loop back to data collection if needed. Finally, the research concludes with a functional analysis of the completed system, focusing on evaluating the route output, distance, and time.

Web Mobile Application Development Life Cycle

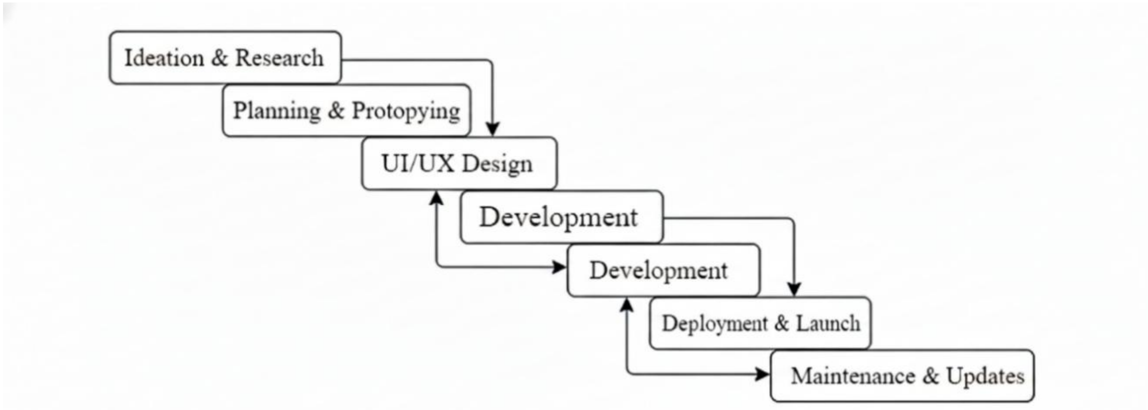

Figure 2. Stage of Web-Mobile Application Development Life Cycle

In developing our application, we implement the Web-Mobile Application Development Life Cycle (WAMADLC) framework. WAMADLC is a systematic framework for planning, designing, developing, and managing the entire lifecycle of web and mobile applications. The WAMADLC process includes various stages to ensure effective, efficient, and customized application development that meets the specific needs of the waste route optimization solution. This approach aligns with the principles of the Life Cycle of Mobile Application Development (MADLC), which emphasizes key stages such as needs analysis, design, implementation, testing, and maintenance (Murtia et al., 2025). These stages are crucial in realizing an optimal and ready-to-use SampahGo application.

Cheapest Insertion Heuristic Algorithm

The route optimization process is at the core of this application and is implemented using the CIH algorithm with the following workflow:

a. **Initialization:** The algorithm begins by constructing a basic initial sub-route, which connects the depot to the nearest TPS, forming the route Depot → TPS → Depot.
b. **Selection:** From the list of TPS not included in the route, the algorithm systematically selects one TPS to insert.
c. **Insertion:** The key step of the CIH algorithm is to identify the most cost-effective, or optimal, insertion position. The algorithm calculates the cost of inserting a selected Temporary Storage Point (TPS), denoted ask, into each existing route segment between nodes i and j. The insertion cost is determined using the following formula:

$$c(i,k,j) = d(i,k) + d(k,j) - d(i,j). \quad (1)$$

The algorithm then selects the position that results in the smallest increase in total route distance. This decision is made by finding the minimum insertion cost among all possible segments in the current route, expressed as:

$$c^*(k) = \min_{(i,j) \in \text{Rute}} \{d(i,k) + d(k,j) - d(i,j)\} \tag{2}$$

d. **Iteration:** This selection and insertion process is repeated continuously until all specified TPSs have been successfully inserted into the route.

A-Star Algorithm

The A-Star algorithm is an efficient method for finding the shortest path in a graph by utilizing a heuristic function to guide the search for the lowest-cost path from the start point to the destination. The algorithm evaluates each node n using the function:

$$f(n) = g(n) + h(n). \tag{3}$$

where $g(n)$ is the actual cost is from the start point to n, and $h(n)$ is the estimated heuristic cost from n to the destination. The heuristic function $h(n)$ is crucial as it allows the algorithm to ignore inefficient paths and minimize the search space. One way to calculate $h(n)$ is using the Heuristic Euclidean Distance (HED) with the formula:

$$d(a,b) = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2}. \tag{4}$$

Using this heuristic approach, A-Star is guaranteed to find the shortest path solution if one exists, making it a highly recommended method for route determination problems(Sumantri et al., 2023).

Data Collection and Sample

The data collection method in this research used two approaches: a literature study and operational secondary data collection.

a. **Literature Study:** Conducted to collect, read, and analyze valid and accountable materials from various scientific journals and conference proceedings. The literature search focused on publications discussing the application of the Cheapest Insertion Heuristic (CIH) algorithm for solving the Vehicle Routing Problem (VRP) and the A-star (A*) algorithm for shortest pathfinding. This section forms the theoretical foundation for algorithm selection.
b. **Operational Secondary Data (Sample):** This data, used as the simulation input, was obtained by accessing public data available on the official website of the Yogyakarta City Waste Bank. The research population is the entire dataset of registered Waste Bank or TPS location points within the Yogyakarta City area. The research sample consists of data from 14 Waste Banks (presented in Table 1) which include clear name, address, and coordinate (latitude and longitude) information. This sample data is used as input nodes for the route calculation and testing process within the "SampahGo" application.

Table 1: Yogyakarta City Waste Bank

Name of Waste Bank	Kemantren	Latitude	Longitude
Arum kemuning	Danurejan	-7.791590	110.372540
Asri	Umbulharjo	-7.804360	110.395720
Bank Sampah Nggirli	Mergangsan	-7.810200	110.371900
Bangkit Sejahtera	Jetis	-7.785831	110.366939
Bank S43	Mantrijeron	-7.818460	110.362090
Bank Sampah 347	Gondokusuman	-7.777090	110.375810
Bali Indah	Umbulharjo	-7.798611	110.390281
Arum Sari	Kotagede	-7.811800	110.401300
Asri Migunani	Umbulharjo	-7.798611	110.390281
Awet Resik	Gondomanan	-7.799730	110.365310
Ayo Pitulas 17	Gedongtengen	-7.793750	110.358890
Ayu	Umbulharjo	-7.794000	110.395000
Azalea	Mantrijeron	-7.813130	110.364230
Bahagia	Gondokusuman	-7.782800	110.392900

Table 1 displays data from the Yogyakarta City Waste Bank, which served as the primary input for the simulation in this study. The core information utilized by the CIH algorithm consists of geographic coordinates specifically, the latitude and longitude of each Waste Bank. These coordinates are crucial for calculating the distance matrix between each service point and the depot, which forms the basis for route optimization.

Population and Sample

The population for this study comprises the entire dataset of location points for registered and operational Waste Banks or Temporary Disposal Sites (TPS) within the Yogyakarta City area. The research sample (or Subject) utilized is operational secondary data sourced from the official website of the Yogyakarta City Waste Bank. This sample consists of data from 14 Waste Banks, which include clear location and coordinate (latitude and longitude) information, as presented in Table 1. This sample data is used as input nodes for the route calculation and testing process within the "SampahGo" application.

Testing Method (Validity and Reliability)

To validate functionality and ensure system reliability, this research used the black box testing method. This approach was chosen to verify that each system component from user authentication, waste point input, route calculation and visualization operate according to the designed specifications. Test scenarios were prepared to cover all major application workflows, as detailed in Table 2. Success was defined as the system's ability to accept valid input, process it correctly (applying CIH and A-Star algorithms), and produce logical and accurate output (route visualization, distance, and time estimation) without errors. This testing directly measures the functional reliability of the application in performing its designed tasks.

Model Architecture

System architecture design is a fundamental framework for organizing components and defining their interactions. For this route optimization app, the architecture is designed to support functional (route efficiency) and non-functional (scalability, responsiveness) requirements, ensuring modules work synergistically to provide optimal waste route solutions.

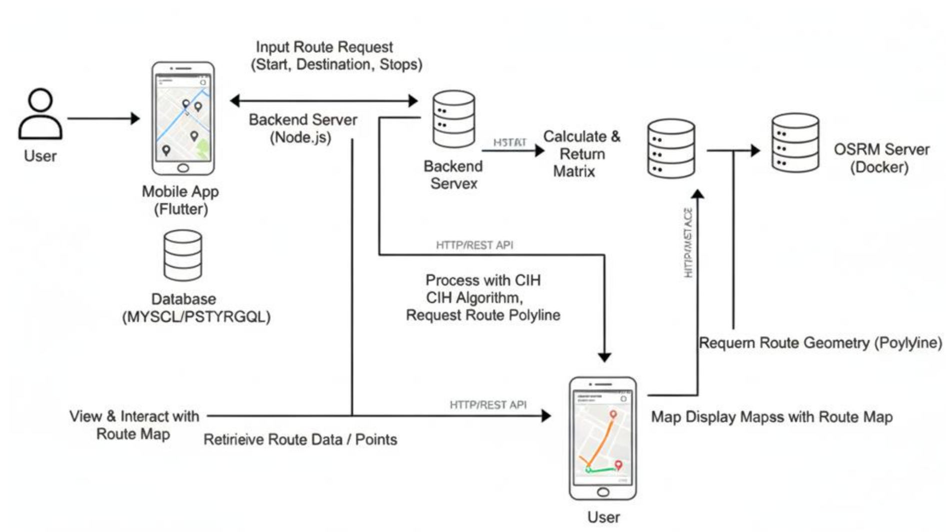

Figure 3. Model Architecture Design

Figure 3 presents the architectural design model that serves as the foundation for developing this waste route optimization application. This architecture is designed to ensure efficient data flow, a clear separation of responsibilities among components, and overall system scalability. The model integrates various technologies and services, ranging from the user interface on mobile devices to complex external routing services. The main goal of this architecture is to effectively manage and process location data, calculate optimal routes using the Cheapest Insertion Heuristic (CIH) algorithm supported by OSRM (Open-Source Routing Machine), and present them to users in an intuitive manner.

FINDING AND DISCUSSION

RESEARCH RESULT

Interface Implementation (Data Visualization)

Data visualization and user interaction are handled through the mobile application interface developed with Flutter.

1. **Login**

   The login page, depicted in Figure 4, is designed for users to access the application by entering their email and password. A 'Login' button is provided for users to proceed with the authentication process. After successfully logging in, users can easily access the main features of the application to determine waste transportation routes.

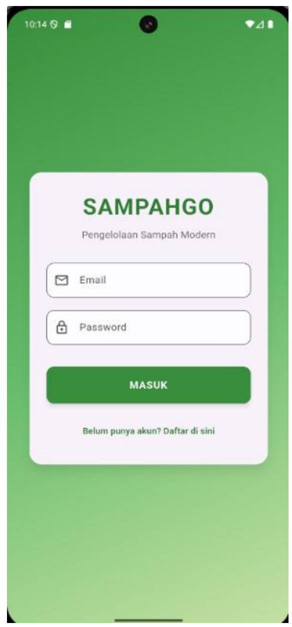

Figure 4. Login

   Figure 4 shows the login page, which functions as an authentication gateway for users to access the system.

2. **Dashboard**

   The dashboard page, as shown in Figure 5, is designed to provide users with a simple yet functional display. On the dashboard, users can view statistics such as waste volume, number of waste collection points, and available vehicles. Furthermore, it offers settings to select waste points for transportation, allows users to view the type of vehicle to be used for waste collection, and displays detailed route information along with map navigation. Additionally, the dashboard facilitates notifications, alerting users to important updates or changes regarding their waste collection operations.

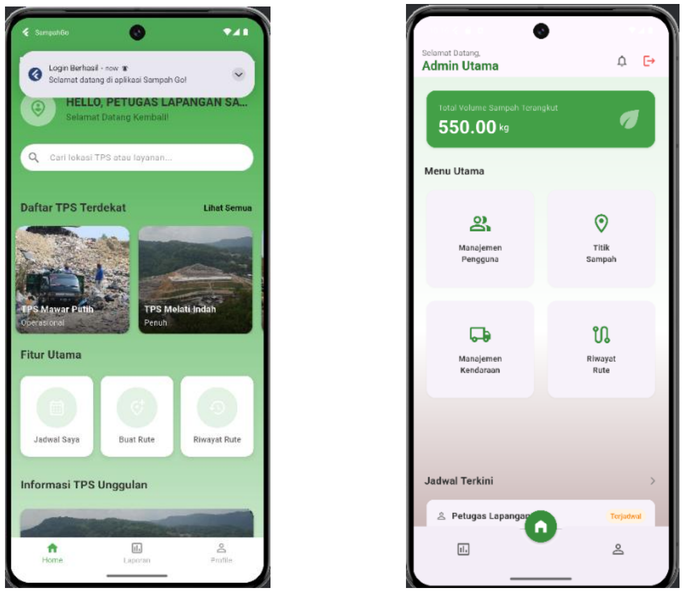

Figure 5. Dashboard

Figure 5 displays the main dashboard. This page presents concise data visualization, such as total waste volume, and provides main navigation to features like user management, vehicle management, and route history.

3. Route

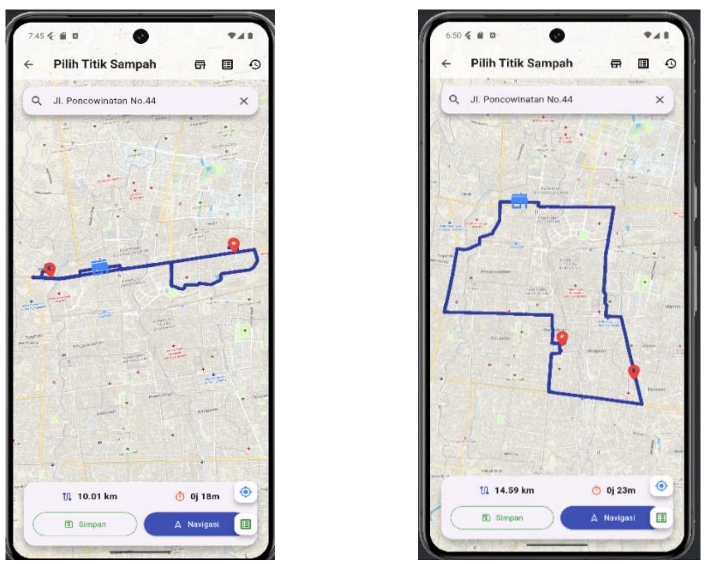

Figure 6. Route

Figure 6 is the primary data visualization of the calculation results. This page displays the generated route on an OpenStreetMap map, complete with the total estimated distance and travel time.

Main Results Route Optimization (Focus on Data)

The main result of this research is the optimal route calculated by the system. Figure 6 (left) shows an example route with a total distance of 14.59 km and an estimated time of 23 minutes. After the CIH and A-Star algorithms were applied, the system generated a new optimized route, as seen in Figure 6 (right).

The focus on data shows that this new route is significantly more efficient, with a total distance of 10.01 km and an estimated time of 18 minutes. This represents a route distance reduction of approximately 31.4% for the same set of waste points, which is the primary quantitative result from the developed system.

Functional Testing Results

To validate the system's functionality, black-box testing was conducted. The test results are summarized in Table 2.

Table 2: Black Box Testing Results

Unit	System Testing	System Reaction	Test Result
Login Page	Enter valid email and password, then click the "Login" button.	The system verifies the credentials and directs the user to the main page.	Successful
Waste Point Input	Add a new location along with its coordinates.	The waste point is successfully saved and displayed on the map and on the table.	Successful
Route Calculation	Click the "Calculate Route" button on the route page after selecting vehicles and points.	The system calculates the optimal route using CIH and displays the visiting order on the map.	Successful
Route Visualization	View the route results on the map after the calculation is complete.	The system displays route lines and visiting points interactively on OpenStreetMap.	Successful
Save Route	Save the calculated route results to the database.	The route data and its details are successfully saved to the route table and route details table in the database.	Successful

Notification	Simulate a scheduled collection time or a change in route status.	The system successfully sends a real-time notification to the user's device or application	Successful

Table 2 The black-box testing results show that all designed key functionalities, including the core "Route Calculation" function applying the CIH and A-Star algorithms, were "Successful". The system proved reliable in performing all its intended functions for waste route optimization and management.

DISCUSSION

This section discusses the interpretation of the findings from the "SampahGo" application development, compares them with existing literature, and outlines the research limitations and implications for future research.

Interpretation of Findings

This research successfully proved that the combination of the *Cheapest Insertion Heuristic* (CIH) and A-Star algorithms can be effectively implemented in a web-mobile application (SampahGo) to optimize waste collection routes. The successful *black box* testing results show that all system functions from user authentication, waste point input, to route visualization on OpenStreetMap operate according to the architectural design.

The key finding is that the system is capable of consistently generating logical routes with accurate distance and estimated time calculations, resulting in a 31.4% reduction in travel distance. This directly addresses the research problem regarding route inefficiency identified in the introduction. The use of CIH proved effective in determining the TPS visit order (the VRP problem), while A-Star supports the determination of the shortest path between points in the road network.

Relationship to Literature

These research findings reinforce previous studies that highlight the advantages of the CIH algorithm in solving the Vehicle Routing Problem (VRP). This result is in line with (Fargiana et al., 2022) and (Oeitama et al., 2024), who also found CIH to be an efficient heuristic method for route optimization.

More critically, this research provides a distinct contribution from previous studies. Unlike the research by (Eka Wijayanti et al., 2020), which focused purely on algorithmic modification for the Yogyakarta context, this study demonstrates the successful integration of CIH with the A-Star algorithm (for real-world road network pathfinding) into a client-server platform (Flutter and Node.js). This is a step forward from mere theoretical validation to a functional, implementable proof-of-concept.

This implementation aligns with the trend of utilizing IoT technology and dynamic systems in urban waste management, as emphasized by (Priyadarshi et al., 2023) and (Jerbi et al., 2025), However, while those studies focus on real-time data collection, the novelty of "SampahGo" lies in providing a solid architectural foundation for static route optimization, which can later be extended to integrate such dynamic data.

Research Limitations

This research has several limitations, primarily the use of static data that does not account for real-time variables such as traffic, waste volume, or fleet capacity. Furthermore, the CIH algorithm used is a heuristic method that finds a "good enough" (near-optimal) solution, rather than the mathematically shortest optimum. Another limitation is that testing was restricted to black box functionality (functional validation), without extensive field trials with workers or a comparative analysis of operational performance before and after implementation (operational validation).

Research Implications

Despite its limitations, this research has practical and theoretical implications. Practically, the "SampahGo" application can be adopted by sanitation departments in Yogyakarta to improve operational efficiency, reduce fuel costs, and save time. Theoretically, this research provides a framework for future studies, such as integrating real-time data (traffic or IoT sensors) for dynamic routing or comparing the CIH algorithm with other metaheuristic methods.

CONCLUSION

This research successfully developed "SampahGo," a functional web-mobile application that optimizes waste collection routes using the Cheapest Insertion Heuristic (CIH) and A-Star algorithms. Built with a client-server architecture using Flutter and Node.js, the system has passed functional black-box testing. The quantitative test results show that the implementation of the CIH and A-Star algorithms significantly enhances operational efficiency by generating a route distance reduction of 31.4%, minimizing travel distance and time.

Supported by a functional interface including an interactive dashboard, notification system, and clear OpenStreetMap visualization, the application proves to enhance usability and field performance. Overall, "SampahGo" provides a practical and effective solution for optimizing urban waste management routes, potentially reducing operational costs and supporting the realization of cleaner, more sustainable cities.

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