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# Design of a Multi-Tenant Waste Management System with Volume Estimation and Vehicle Trip Optimazation

Intan Nur Sifa[1]*, Aulia Hamdi[2], Purnia Setiawati[3], Aulia Suryaning Tyas[4], Rizki Cahya Putri[5], Mayza Nurul Khasanatun Nisa[6], Sri Rahayu[7], Lina Nur Afifah[8]

[1,2,3,4,5,6,7,8]Informatics, Faculty of Computer Science, Amikom University of Purwokerto
intannrsfa@gmail.com[1*], hamdi@amikompurwokerto.ac.id[2], setiawatipurnia@gmail.com[3], suryaningg.tyas@gmail.com[4], rizzkicahyaputri127@gmail.com[5], mayzanurul55@gmail.com[6], srirahayu.23sa11a117@gmail.com[7], linanurafifah14@gmail.com[8]

**Abstract**

Waste management at the village level still faces a number of challenges, such as unstructured waste volume recording, suboptimal collection scheduling, and a lack of transparency in cost management. This study aims to design a multi-user waste management system equipped with a volume estimation model and vehicle route optimization. The approach applied includes a literature review to analyze system requirements, followed by design using flowcharts, Data Flow Diagrams (DFDs), and Entity-Relationship Diagrams (ERDs). The research findings indicate that the developed system successfully integrates the management of waste source data, transportation processes, and cost calculations in a structured manner. The volume estimation model is used to estimate the amount of waste in the field, while route optimization determines the number of vehicle trips based on their carrying capacity. Additionally, the multi-tenant concept allows this system to be used by various regions simultaneously while ensuring data separation. Therefore, this system is expected to improve operational efficiency, management transparency, and the quality of waste transportation services.

***Keywords***: *information system; waste management; multi-tenant; volume estimation; route optimization*

## 1. Introduction

Waste management in rural areas remains a critical issue, particularly regarding transportation, monitoring of waste volume, and the administration of environmental fees. According to data from the Ministry of Environment and Forestry's (KLHK) National Waste Management Information System (SIPSN) in 2024, the volume of waste generated in Indonesia reached approximately 34.0 million tons per year, although this figure represents a decrease from 43.2 million tons the previous year. This decrease reflects progress in waste management efforts, such as improved collection and sorting at the source. Nevertheless, this figure remains high, making waste management in Indonesia a significant and ongoing challenge. Furthermore, the national waste composition indicates that household waste—particularly food scraps—is the largest contributor, followed by plastic waste, which accounts for approximately 19.48% of total national waste. This high proportion of plastic waste signifies high plastic consumption by the public, which has not yet been matched by adequate management and recycling systems [1].

Currently, waste management still relies heavily on manual methods, such as fee collection by sanitation workers and collection schedules that are not yet optimally organized. Inaccurate data on waste volume also hinders the determination of efficient collection needs. The limitations of this manual approach result in increased operational costs, inefficient collection schedules, and a lack of transparency in service delivery. Therefore, the development of a more integrated and structured waste management system is urgently needed [2].

Leveraging digital transformation through information for improving efficiency, transparency, and accountability in waste management. These systems facilitate optimal data integration, enabling management processes to operate in a more measurable and systematic manner [3]. However, currently available systems generally do not support simple on-site waste volume calculations or vehicle route optimization during the transportation phase [4]. Furthermore, many systems have not yet been optimized for a multi-tenant model that enables joint management by multiple villages on a single platform [5].

To that end, this study aims to design a multi-tenant waste management system equipped with a volume estimation model and vehicle route optimization, in order to improve operational efficiency and enable more structured data management. In this study, the system is designed using a multi-tenant architecture, which allows a single system to be used by multiple villages while maintaining the isolation of each village's data.

Given this background, this study focuses on the design of a waste management and environmental fee system using an approach that estimates volume and calculates vehicle trips within the Nusa Busana module of the NUSAEKA platform.

# 2. Literature Review

## 2.1. Information Systems

An information system refers to a collection of data that has been processed into useful information, in the form of specific facts that support the decision-making process. The scope of this field encompasses not only technical aspects but also the design, implementation, and analysis of the interrelationships between people, data, and system technology [5].

## 2.2. Waste Management

Waste is defined as refuse generated from production processes, both in the industrial sector and in households (domestic). Its management is regulated by Law No. 18 of 2008 on Waste Management, which emphasizes the importance of transitioning from conventional management practices to an approach based on waste reduction and treatment. Waste is a problem that must be addressed by the community, as it constitutes a form of environmental pollution caused by human activities (external factors) that initially generate foreign substances. Problems that frequently occur in waste management at the village level are usually due to the lack of waste volume records, irregular collection schedules, limited vehicles, and mismatch between fees an operational costs [6]. Therefore, a system capable of managing the entire process in a structured manner is required.

## 2.3. Multi-Tenant

Multi-tenant architecture is a design that facilitates the sharing of infrastructure among various vendor or tenants, thereby improving cost-effectiveness, maintenance efficiency, and scalability [7]. In a multi-tenant system, data separation is a critical element. A common approach is to include a tenant_id attribute in each table, so that data can be identified according to the relevant tenant. In this study, the multi-tenant concept is utilized so that the waste management system can be accessed and used simultaneously by a number of villages.

## 2.4. Waste Volume Estimation

Waste volume estimation is an approach to estimating the amount of waste based on physical conditions in the field without using measuring instruments such as scales. This approach is often applied in environments with limited facilities, through calculations based on the amount of waste generated or container capacity [8]. This estimation process considers factors such as the number of trash bags, container size, and the experience of field staff. This method allows for practical volume calculations without direct measurement [9]. Although its accuracy is lower, this method remains effective for supporting waste transportation planning and management at the operational level.

## 2.5. Vehicle Trips

Vehicle trips refer to the number of trips made during the waste collection process and serve as a key indicator of operational efficiency, as they are related to waste volume and vehicle capacity. Trip frequency is calculated based on the ratio of waste volume to vehicle capacity, which is generally rounded up to ensure all waste is transported. Additionally, trip frequency is influenced by the transportation system and the amount of waste generated [10]. With accurate route planning, vehicle utilization can be optimized, thereby reducing the number of trips and operational costs [11].

## 2.6. Entity-Relationship Diagram (ERD)

An Entity-Relationship Diagram (ERD) is a graphical notation used in the database design process to connect data elements. An ERD serves as a tool for designing database and provides an overview of how the database being designed will function. An ERD consists of three main elements, entities, attributes, and relationship [12].

## 2.7. Data Flow Diagram (DFD)

A Data Flow Diagram (DFD) is a graphical tool used to depict the flow of data within an information system. Specifically in system design, Data Flow Diagrams are used to visualize how data moves between various processes within the system. This approach supports the modeling of system functions by illustrating the processing, storage, and transmission of data between processes or system components [13].

# 3. Research Methodology

This research involves the development of a system design focused on creating a multi-tenant waste management system that integrates volume estimation methods and vehicle route calculation. The research methodology flowchart used in this study is shown in fig. 1, which systematically outlines the research stages from needs analysis to system design.

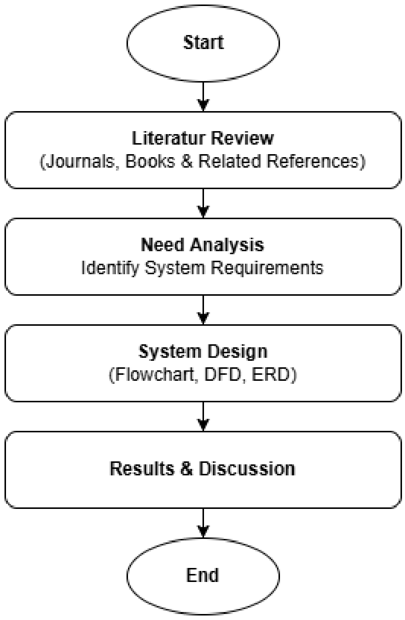


**Fig. 1:** Research Methodology Flowchart

### 3.1. Data Collection Method

In this study, data collection was conducted through a literature review. The literature review encompassed an examination of various sources, such as scientific journals, books, and related references on information systems, waste management, multi-tenant architecture, waste volume estimates, and vehicle routes. The collected data served as the primary foundation for system design.

### 3.2. System Design Methodology

#### 3.2.1. Need Analysis

During the requirements analysis phase, system requirements were identified based on the results of a literature review. The system is designed to manage data regarding waste sources, service areas, and collection schedules, including the recording of estimated waste volumes and the calculation of vehicle trip frequencies. In addition, the system facilitates the management of both collective and individual costs, as well as the monitoring of staff activities during the collection process.

#### 3.2.2. System Design

The system design phase aims to describe the workflow and framework of the system to be developed. During the phase, flowcharts are used to map process flows, Data Flow Diagram (DFD) to illustrate data movement, and Entity-Relationship Diagram (ERD) to define the database structure and relationships between entities. This study is limited to the system design stage, including flowchart, DFD, ERD, volume estimation, and vehicle trip calculation design, without implementing and testing the system directly.

## 4. Results and Discussion

### 4.1. System Overview

This system is a multi-user waste management platform designed to coordinate waste collection activities and environmental fees at the village level. It integrates three key stakeholders, village officials responsible for data management and scheduling. Waste management

staff who handle transportation, record activities, and estimate volumes, and residents or organizations-as waste generators-who receive services and pay fees. These three parties are interconnected within a single platform that facilitates structured waste management.

### 4.2. System Flowchart

#### 4.2.1 Admin Flowchart

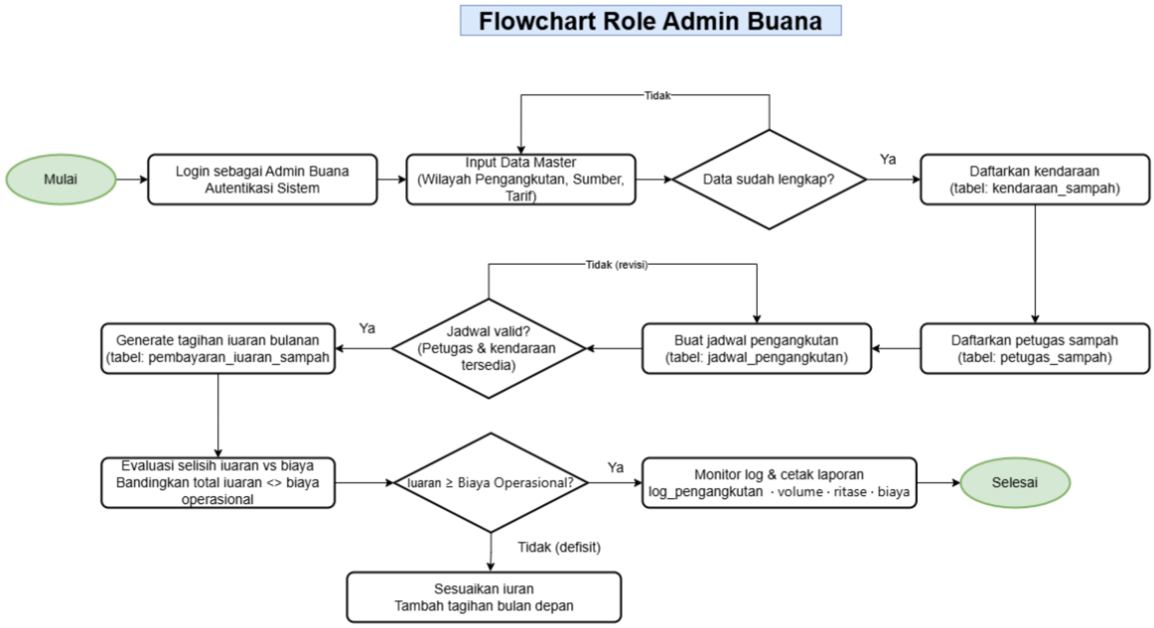


**Fig. 2:** Admin Flowchart

The flowchart in fig. 2 illustrates the administrator's workflow in managing the system, which includes entering master data, scheduling transportation, and evaluating fees and operational costs.

### 4.2.2 Staff Flowchart

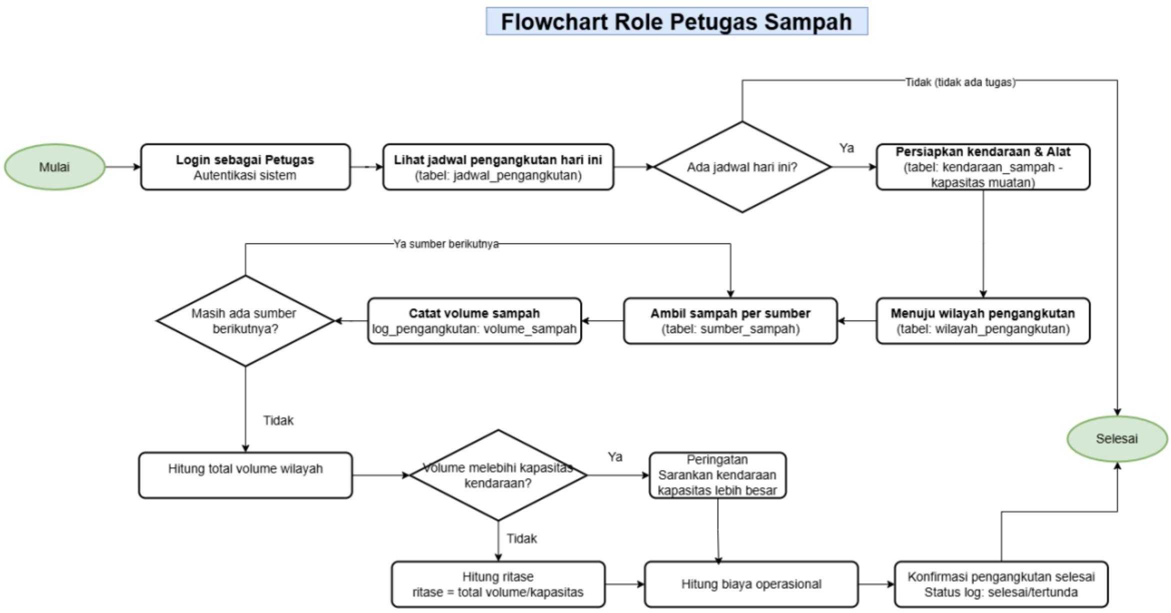


**Fig. 3:** Staff Flowchart

The flowchart in Fig. 3 illustrates the workflow of waste collection staff throughout the waste collection process, from checking the schedule, carrying out the collection, recording the volume of waste, to calculating the number of trips and operational costs.

### 4.2.3 Resident Flowchart

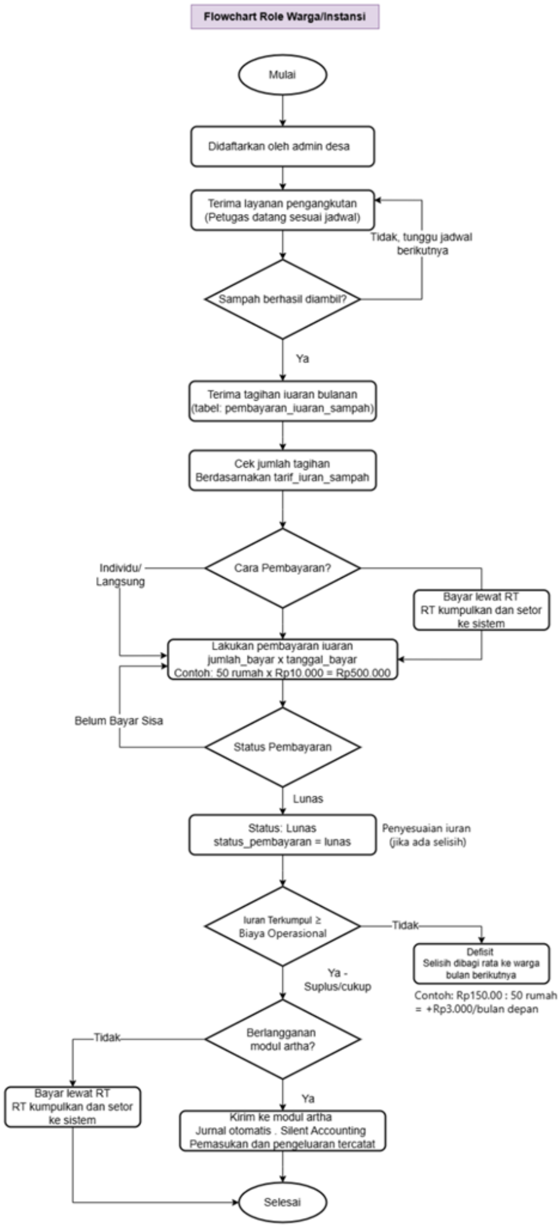


**Fig. 4:** Resident Flowchart

The flowchart in Fig. 4 illustrates the interaction process between residents or agencies within the system, which includes the provision of transportation services and the payment of fees, whether collectively or individually.

### 4.3. Data Flow Diagram

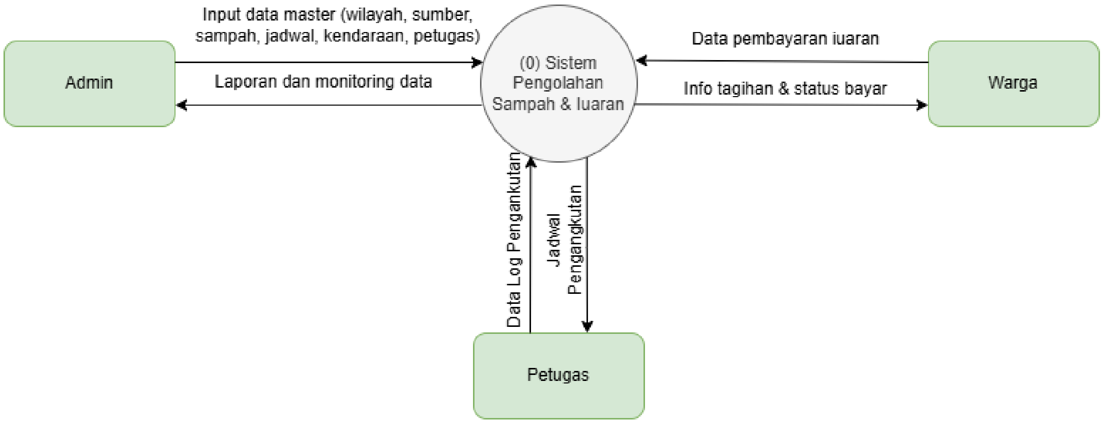


**Fig. 5:** Level 0 DFD

Fig. 5, which shows the Level 0 DFD, provides an overview of the waste management and fee collection system, in which administrators, staff, and residents are involved in the exchange of data, including master data, transportation data, and fee payments.

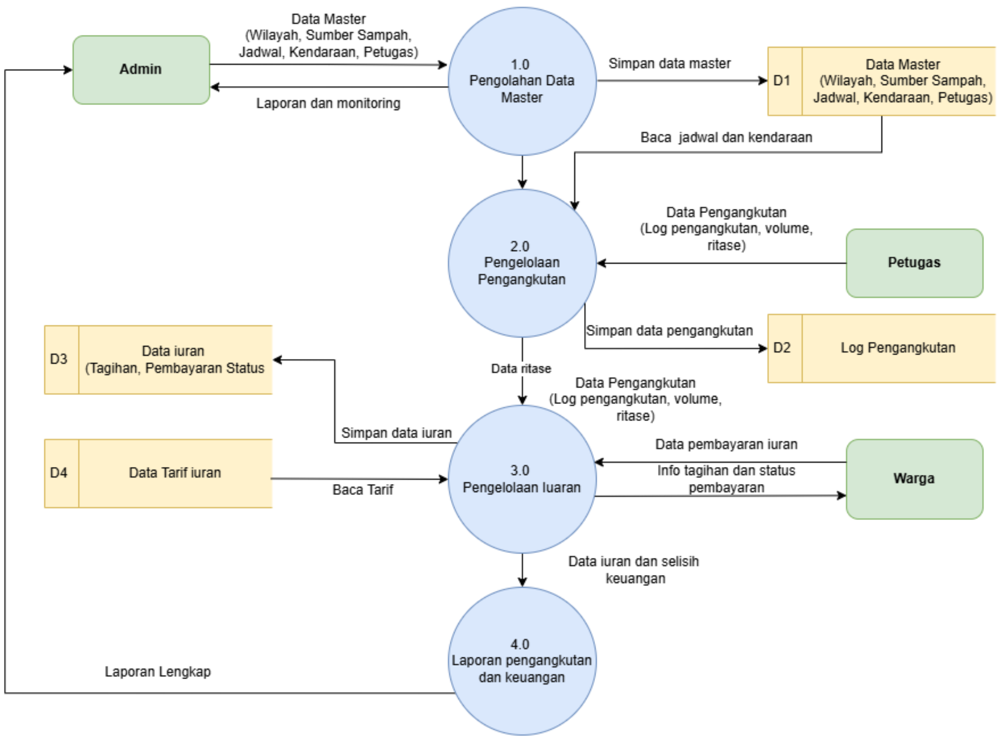


**Fig. 6:** Level 1 DFD

Fig. 6, which illustrates the Level 1 DFD, outlines the process flow within the system, including master data processing by administrators, recording of transportation by staff, management of fee payments by residents, and the generation of reports as the system's final output.

### 4.4. Entity-Relationship Diagram

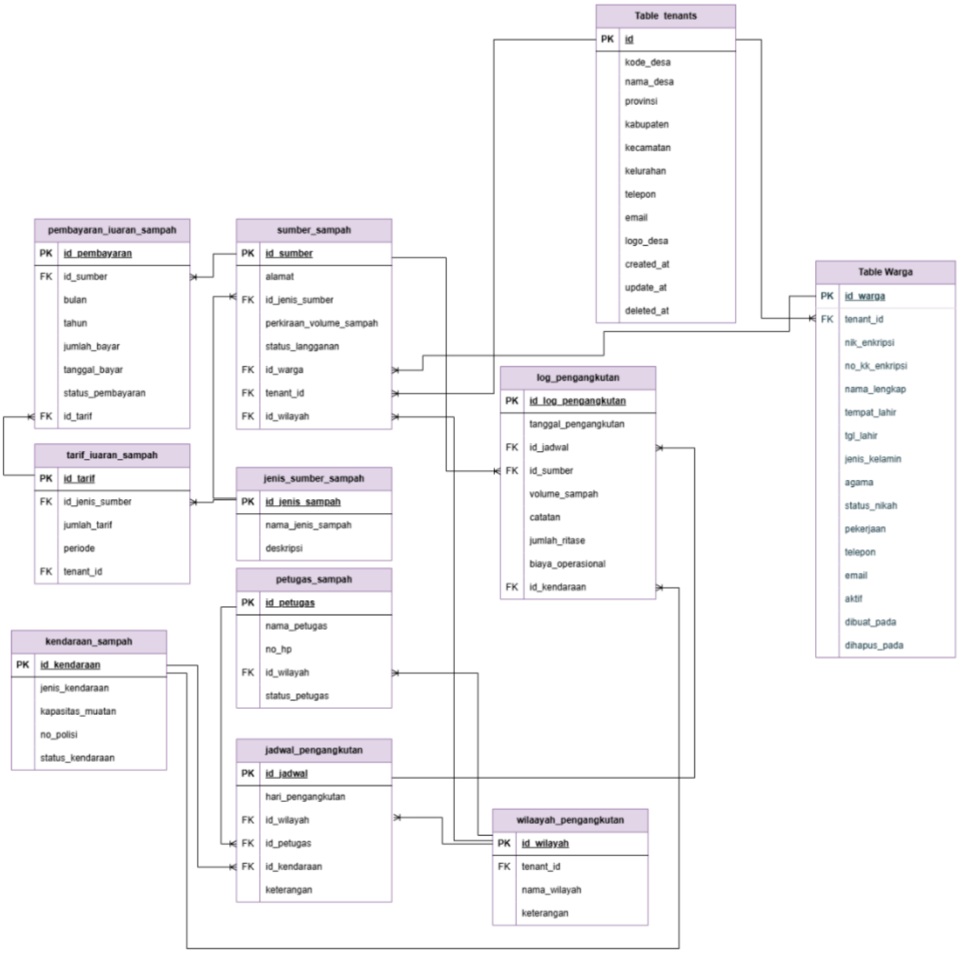


**Fig**. **7:** Entity Relationship Diagram

The Entity-Relationship Diagram (ERD) in Fig.  illustrates the database structure for the waste management and fee collection system, which includes various key entities such as waste_source, transport_log, waste_fee_payment, waste_fee_rate, and other supporting entities. The relationships between these entities reflect the interconnections between waste source data, the transportation process, and fee management. Transportation-related data is documented in the transportation_log entity, while fee calculations are based on stored rates. Additionally, this system implements a multi-tenant approach through the tenants entity to facilitate data management according to relevant regions or agencies.

### 4.5. Volume Estimation Model

Volume estimation models are used to estimate waste volume without measuring instruments, based on field conditions such as the number of bags, container capacity, and the experience of staff. This method was chosen for its practicality and suitability for day-to-day operations, although its accuracy is lower than that of direct measurements. These estimates serve as the basis for calculating collection routes and operational costs.

### 4.6. Route Optimization

Route optimization aims to determine the number of vehicle trips required for waste volume with vehicle capacity. According to Purba and Ramadhan (2024), the ratio of waste collection vehicle capacity to waste production affects the number of collection trips.

$$Ritase = \frac{\text{Total Waste Volume}}{\text{Vehicle capacity}} \quad (1)$$

The number of trips is rounded up to ensure that all waste is collected. The system also issues a warning if the volume exceeds the vehicle's capacity. For example, a waste volume of 250 kg with a capacity of 100 kg will result in 3 trips.

### 4.7. Multi-Tenant

This system is built on a multi-tenant architecture, allowing multiple villages to use the same platform. Data is separated between villages using the 'tenant_id' attribute, ensuring the security and independence of each user's data. This approach enhances the efficiency of centralized system management and simplifies the addition of other modules, such as a financial module, without affecting other tenants data.

## 5. Conclusion

The design results show that a multi-tenant waste management system is capable of handling data management, waste volume estimation, and vehicle route calculations with a more robust structure. In addition, this system also facilitates more efficient fee management and operational monitoring.

It is recommended that further research focus on developing the system through the implementation and testing phases, including the addition of route optimization features and digital payment integration, to make the system more optimal and practical.

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