Wastewatch: Architecture and Design of Vehicle Monitoring and MRF-Integrated Waste Collection for Cenro Alaminos City

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DOI: https://doi.org/10.47772/IJRISS.2026.100601031

Received: 21 June 2026; Accepted: 26 June 2026; Published: 11 July 2026

ABSTRACT

Effective waste collection monitoring remains a significant challenge for the City Environment and Natural Resources Office (CENRO) of Alaminos City due to existing operational processes that rely on manual monitoring, the absence of real-time vehicle tracking capabilities, coordination delays in collection activities, and the need for a more structured complaint reporting mechanism. Consequently, these concerns present opportunities for improvement in delivering timely and organized waste management services. Although various technology-driven waste management solutions have been explored in different contexts worldwide, localized systems specifically designed for LGU-level operations in the Philippine context remain limited. To address this gap, the researchers propose WasteWatch, a web and mobile-based system designed to support vehicle monitoring and MRF-integrated waste collection management. The Agile Prototyping Model was utilized by the researchers to guide the system development process through continuous refinement based on user feedback. WasteWatch was structured using a Three-Tier Architecture composed of the presentation, application, and data tiers. Relevant information and system requirements were gathered through interviews, observation, document analysis, and purposive sampling of 85 respondents from CENRO personnel, garbage truck drivers, MRF representatives, landfill representatives, IT experts, and residents of Alaminos City. The proposed system integrates several critical functions: GPS-based vehicle monitoring, complaint reporting, MRF hauling coordination, digital landfill recording, and centralized administrative oversight. Its usability and acceptability will be assessed through stakeholder feedback to determine how well the system supports the needs of its intended users. Overall, WasteWatch aims to provide CENRO Alaminos City with a more organized, responsive, and technology-driven approach to waste management operations, replacing informal coordination methods with structured digital processes.

Keywords – Waste Management, Vehicle monitoring, Responsive, GPS-based

INTRODUCTION

Waste collection plays an important role in maintaining a clean, safe, and healthy community. As municipal solid waste generation continues to increase, there is a growing need for organized, responsive, and sustainable waste management systems [9, 10]. This need is also consistent with the Philippine policy framework, which assigns local government units an important role in planning and implementing solid waste management programs. In Alaminos City, the City Environment and Natural Resources Office (CENRO) is responsible for managing waste collection operations. However, its current process faces several challenges, including manual monitoring, delayed coordination, the absence of real-time garbage truck tracking, and the lack of a centralized complaint reporting mechanism. Because of these concerns, a technology-based system is needed to support more organized, responsive, and efficient waste management operations [1, 3].

WasteWatch was designed as a web and mobile-based system to address these challenges. It combines GPS-based truck monitoring, MRF hauling coordination, complaint reporting, digital landfill recording, and an administrative dashboard into one platform [6]. It will use Global Positioning System (GPS) technology to support location-based monitoring, a web dashboard for CENRO administrators and landfill personnel, mobile access for drivers, MRF personnel, and residents, and a database for storing and managing system records. Previous studies have emphasized that real-time monitoring, digital data collection, and smart waste management technologies can support more efficient and responsive waste collection operations [4].

The study had four objectives: (1) To identify the existing waste collection and monitoring processes implementation by the City Environment and Natural Resources Office. (2) To identify the challenges encountered by CENRO personnel in the existing waste collection and monitoring system. (3) To design and develop features to be integrated in the proposed web and mobile-based System. (4) To evaluate the acceptability of the developed system based on a software quality tool. These goals guided WasteWatch's development and ensured it addressed the actual needs of its users.

This paper presents WasteWatch's architecture and design as a response to the challenges at CENRO Alaminos City. It covers the development approach, core technologies, and three-tier architecture consisting of web and mobile clients, an application server, and a database layer. The paper also explains how the system addresses problems in manual monitoring, coordination delays, complaint reporting, MRF hauling requests, and landfill documentation.

METHODOLOGY

The study is situated at the City Environment and Natural Resources Office (CENRO) of Alaminos City, Pangasinan, which serves as the primary locale of the project. This office was selected by the researchers on the basis of direct institutional responsibility over the city's waste collection operations, making it the most appropriate setting for identifying the actual needs, existing processes, and operational challenges that the proposed system seeks to address. At present, the office manages a workforce of 109 employees and operates a fleet of seven garbage trucks dedicated to citywide waste collection services. Moreover, despite this operational capacity, the office continues to encounter persistent difficulties in its day-to-day functions, including reliance on manual monitoring procedures, delayed coordination among field personnel, dependence on informal messaging platforms for operational updates, and insufficient real-time visibility over garbage truck movements and activities. These prevailing conditions establish CENRO Alaminos City as a fitting and well-justified setting for the development and proposed implementation of WasteWatch [2, 5].

Purposive sampling was employed by the researchers as the primary technique for selecting respondents who were directly involved in waste collection, route monitoring, landfill operations, and community reporting. This approach was considered appropriate because the study required information from individuals who possessed relevant knowledge and direct experience with the current waste management process.

Table 1. Respondents of the Study

Respondent	Number of Respondents
Sanitary Engineer of CENRO	2
Truck Drivers	9
Landfill Representative	3
MRF Representative	24
Resident	45
IT Expert	2
Total Respondents	85

To gather the necessary data, the proponents created a structured interview guide containing relevant questions pertaining to garbage collection procedures, daily route schedules, operational challenges, and existing monitoring practices. Interviews were conducted with selected CENRO personnel and other concerned stakeholders to obtain firsthand information that would directly inform the design and development of the system. Alongside this, observation was employed to examine actual collection procedures and route scheduling as they occur in practice, while document analysis was carried out through a review of existing forms, records, and operational documents currently used in the office to determine the required inputs for the system. A structured questionnaire was likewise prepared to gather evaluative feedback from the intended users and IT experts concerning the acceptability, usability, technical feasibility, and overall effectiveness of WasteWatch.

System Evaluation

To establish a clear basis for future evaluation, the proponents identified performance indicators that can be measured once the system is deployed in CENRO operations. Since WasteWatch is designed with built-in data collection mechanisms—including GPS tracking, hauling transaction records, duty logs, and complaint submissions—the system is structurally equipped to generate the quantitative data needed for performance assessment.

Waste volume analysis measures which barangays generate the most waste based on hauling transaction records and tonnage data. MRF fill rate tracks how quickly the material recovery facility reaches capacity per barangay, indicating areas with higher waste generation. Collection frequency evaluates the number of back-and-forth trips required per barangay to complete waste collection, reflecting the efficiency of the current routing assignments. Distance traveled measures the total kilometers covered by garbage trucks during each collection cycle through GPS tracking data. Complaint response time tracks the duration from when a resident submits a concern to when it is resolved. User acceptability will be measured through a survey based on the quality characteristics of ISO/IEC 25010:2023 [11]. Data accuracy compares the rate of recording errors between the current manual process and the proposed digital system. Respondents will rate each system feature using the five-point Likert scale presented in Table 2, where 5 indicates strongly agree and 1 indicates strongly disagree.

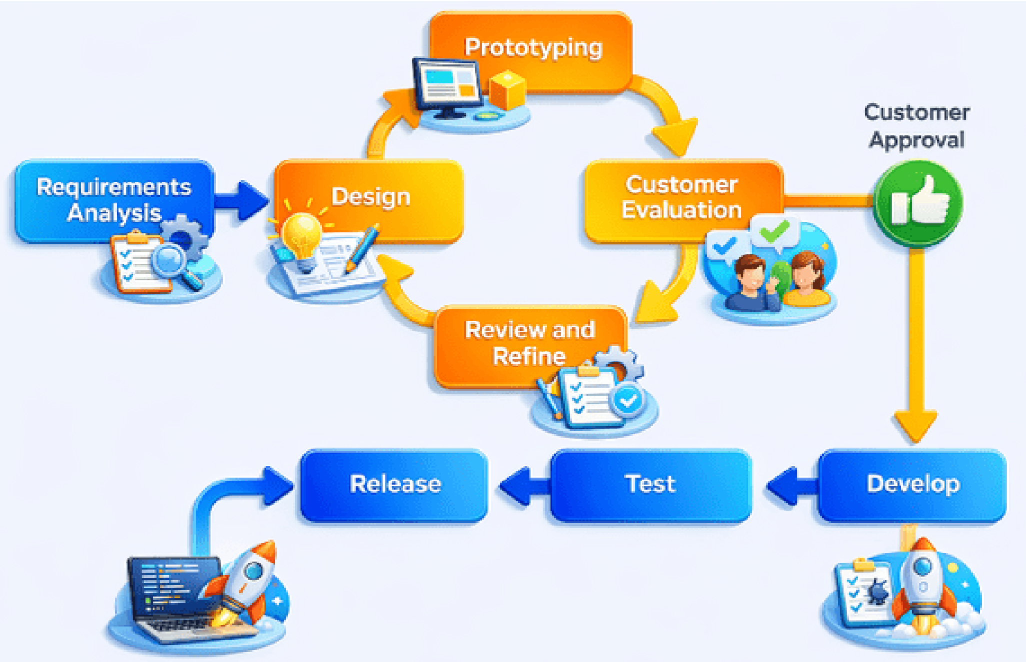
Table 2. Scale of Measurement

Scale	Statistical Limit	Rating	Description
5	4.21–5.00	Strongly Agree	The system feature is highly effective, intuitive, and exceeds requirements.
4	3.41–4.20	Agree	The system feature is functional, efficient, and meets requirements.
3	2.61–3.40	Neutral	The system feature is acceptable but has room for improvement.
2	1.81–2.60	Disagree	The system feature is functional but inefficient or difficult to use.
1	1.00–1.80	Strongly Disagree	The system is non-functional or does not meet needs.

System Development Life Cycle

WasteWatch was developed using the Agile Prototyping Model. This model was chosen because it supports iterative, user-centered development [8]—an early version of the system is built, tested by users, and refined based on their feedback. Unlike waterfall approaches that follow a fixed sequence, Agile Prototyping allows continuous revision, which suited WasteWatch's multiple modules and diverse user roles. This flexibility helped the team align the design with actual operational needs identified during data gathering. Figure 1 shows the model as applied in this study.

Figure 1- Agile Prototyping Model

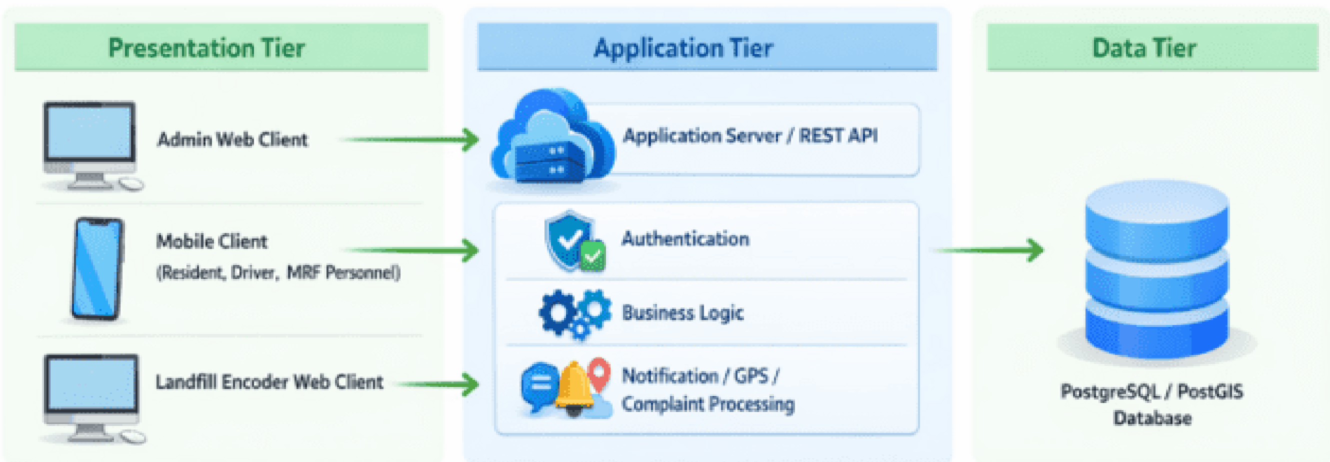


The model follows a structured sequence of phases beginning with the identification of initial system requirements, during which the proponents gathered relevant data through interviews, observation, and document analysis to define both the functional and non-functional specifications of the proposed system. This was followed by the design phase, wherein the system architecture, database structure, interface layout, and process workflows were planned and organized. An initial prototype was subsequently developed and presented to intended users for evaluation, after which feedback was analyzed and used as the basis for revising the system. The refined prototype then proceeded to full development, testing, and final maintenance. Through this iterative process, the Agile Prototyping Model provided a systematic and responsive framework for guiding the design and development of WasteWatch.

System Architecture and Design

WasteWatch uses a Three-Tier Architecture with three layers: Presentation, Application, and Data [7]. This structure separates responsibilities while keeping all components connected as a unified platform. Figure 2 shows the system architecture.

Figure 2- System Architecture Model of WasteWatch



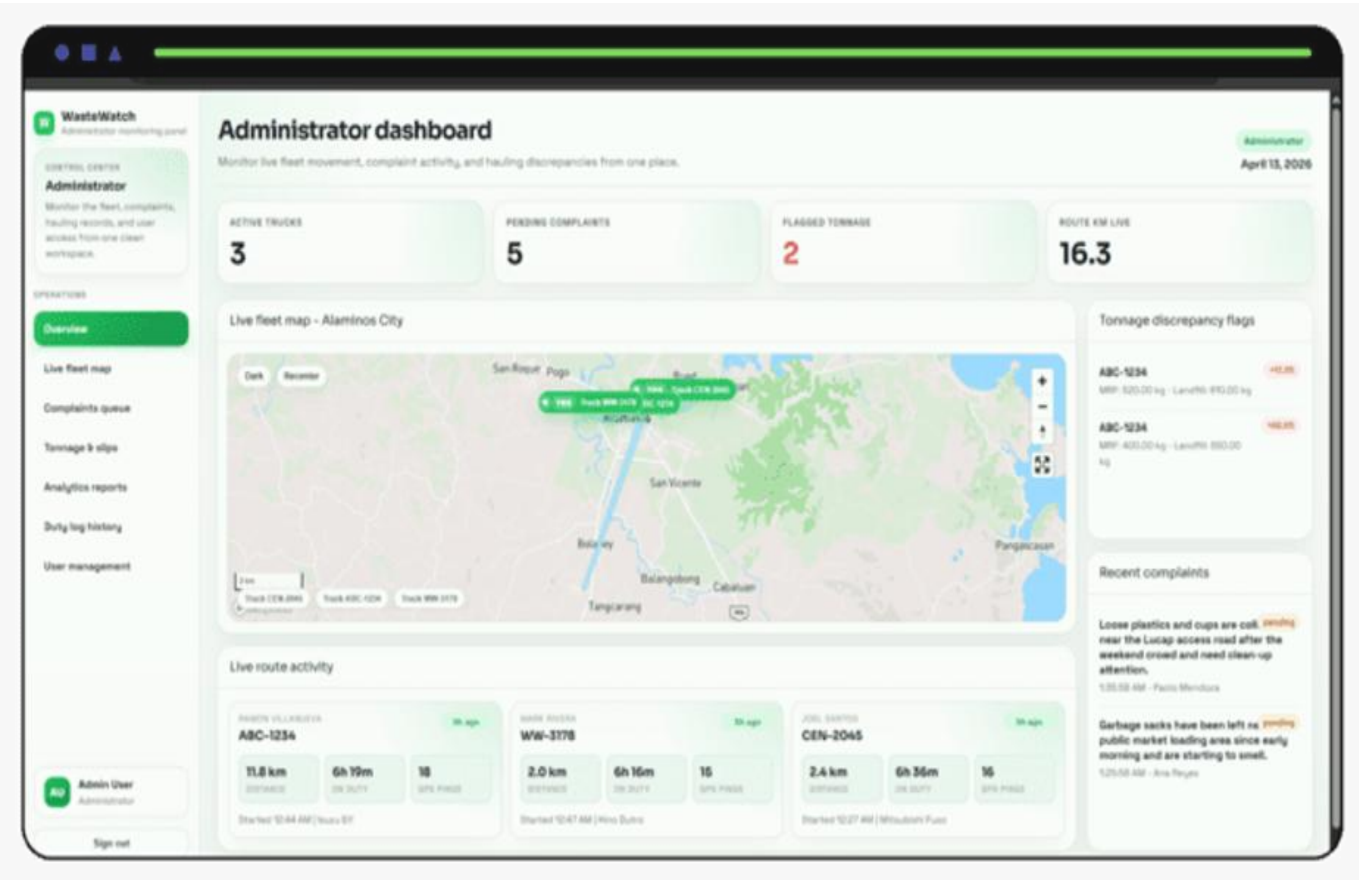
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

The Presentation Tier consists of the user-facing interfaces accessible through both web and mobile platforms, including the dashboards for administrators and landfill encoders, as well as the mobile screens designated for residents, garbage truck drivers, and MRF personnel. The Application Tier functions as the processing layer of the system through a REST API, which handles incoming requests, validates user access, applies system logic, and coordinates communication between the interface and the database. The Data Tier utilizes a PostgreSQL database with the PostGIS extension to store and manage all system records, following patterns established in GPS-based waste tracking systems, including user accounts, complaints, GPS tracking data, duty logs, hauling transactions, and waste slips. In operation, user actions initiated through the presentation layer are processed by the application layer, and the corresponding data is retrieved from or saved to the data layer before results are returned to the user.

Prototype Overview

Prior to full system development, an initial prototype of WasteWatch was constructed to validate the proposed system design and evaluate its functional adequacy through early user feedback. The mobile prototype incorporates shared authentication screens and role-specific interfaces developed for residents, garbage truck drivers, and MRF personnel, while the web prototype encompasses the administrator dashboard and the landfill encoder interface. The succeeding figures present selected screens from both prototypes, illustrating the layout, navigation structure, and core functionalities of the proposed system.

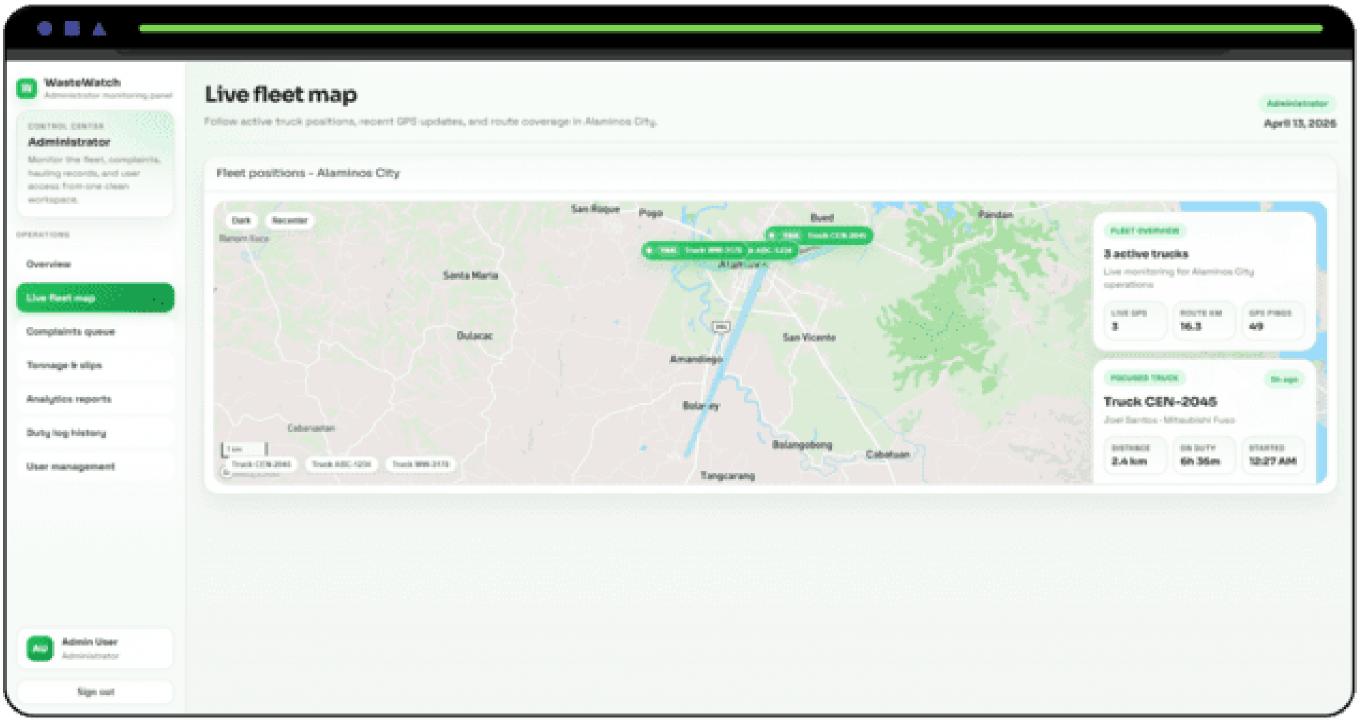
Figure 3- Administrator Dashboard



The administrator dashboard displays a summary of active fleet status, pending complaints, hauling requests, and operational data, giving administrators a centralized view of ongoing waste collection activities.

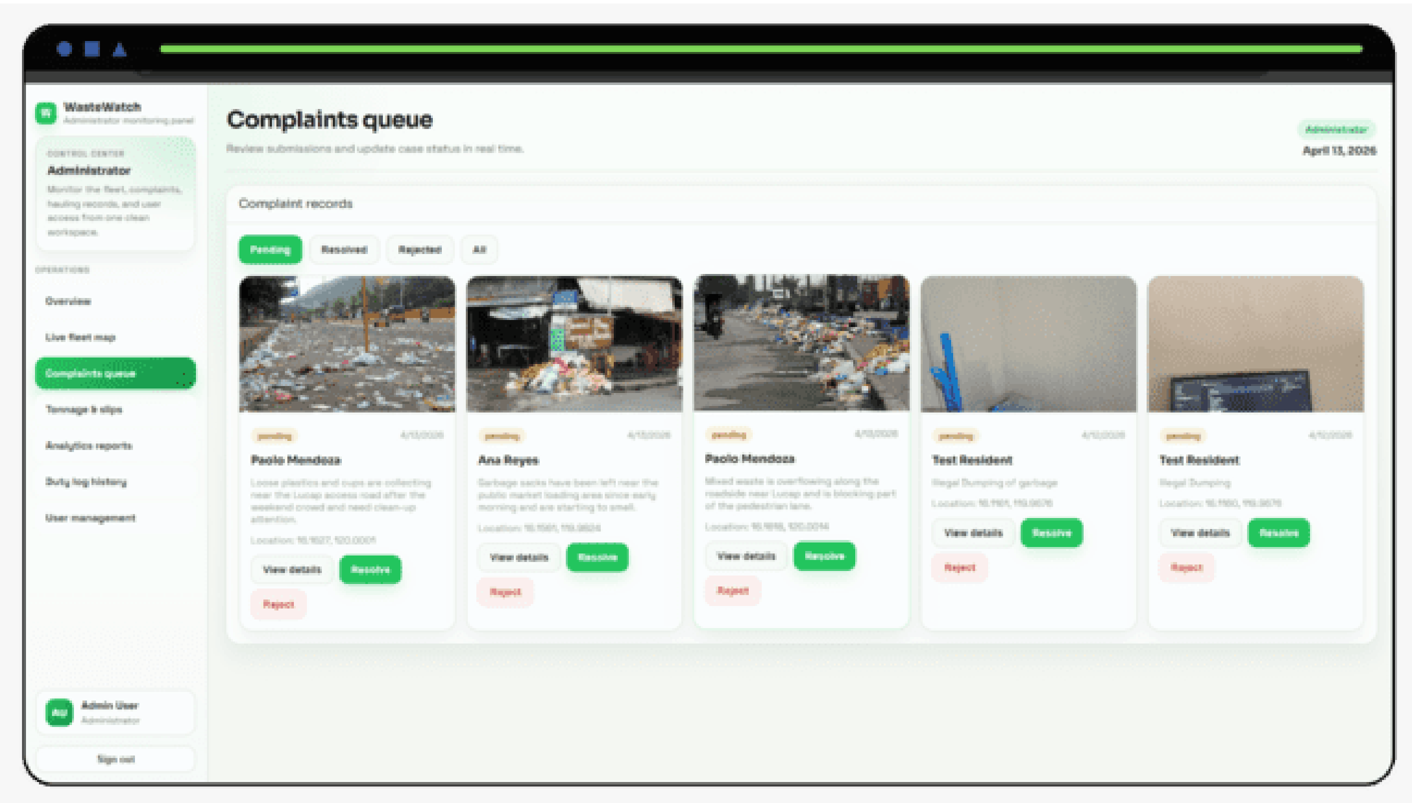
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

Figure 4- Live Fleet Map



The live fleet map shows the real-time location of garbage trucks on an interactive map, allowing administrators and other authorized users to monitor vehicle movement during active duties.

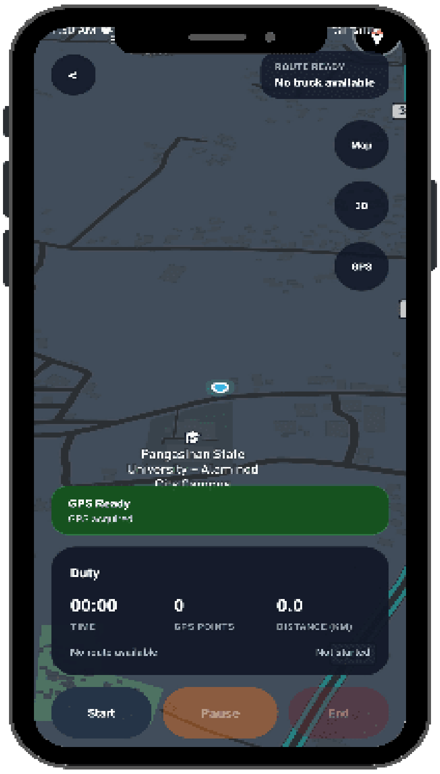
Figure 5- Complaints Queue



ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

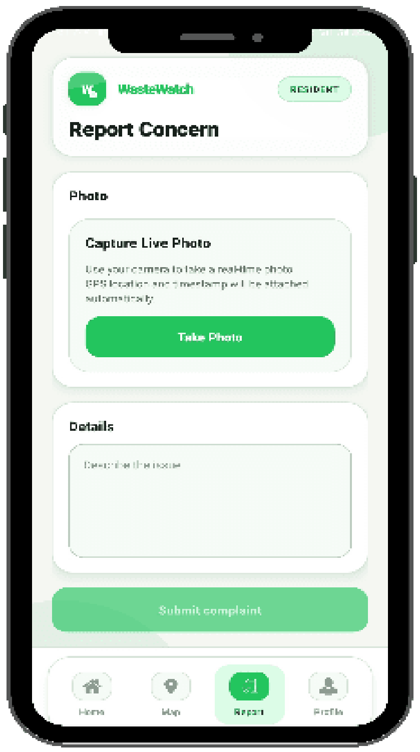
The complaints queue presents a list of resident-submitted waste concerns with their current status, enabling administrators to review, act on, and resolve each report in an organized manner. Each complaint includes a photo, GPS location, and timestamp to support faster verification and resolution.

Figure 6- Driver Map Screen



The driver map provides a full-screen view of the assigned collection route, displaying the driver's real-time GPS position and a breadcrumb trail of the path taken during the active duty.

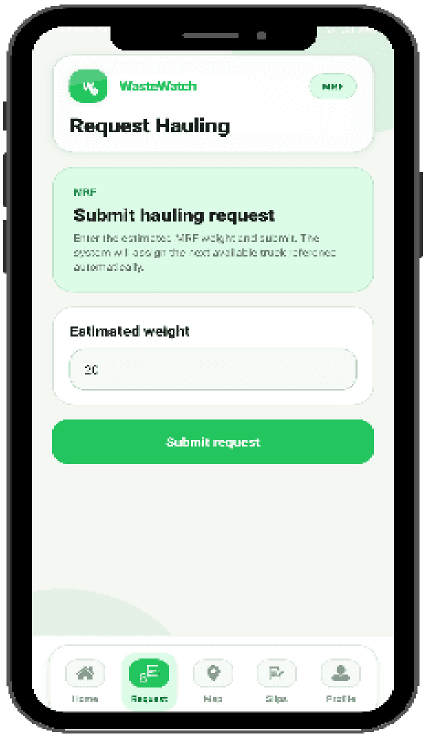
Figure 7- Resident Report Concern Screen



ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

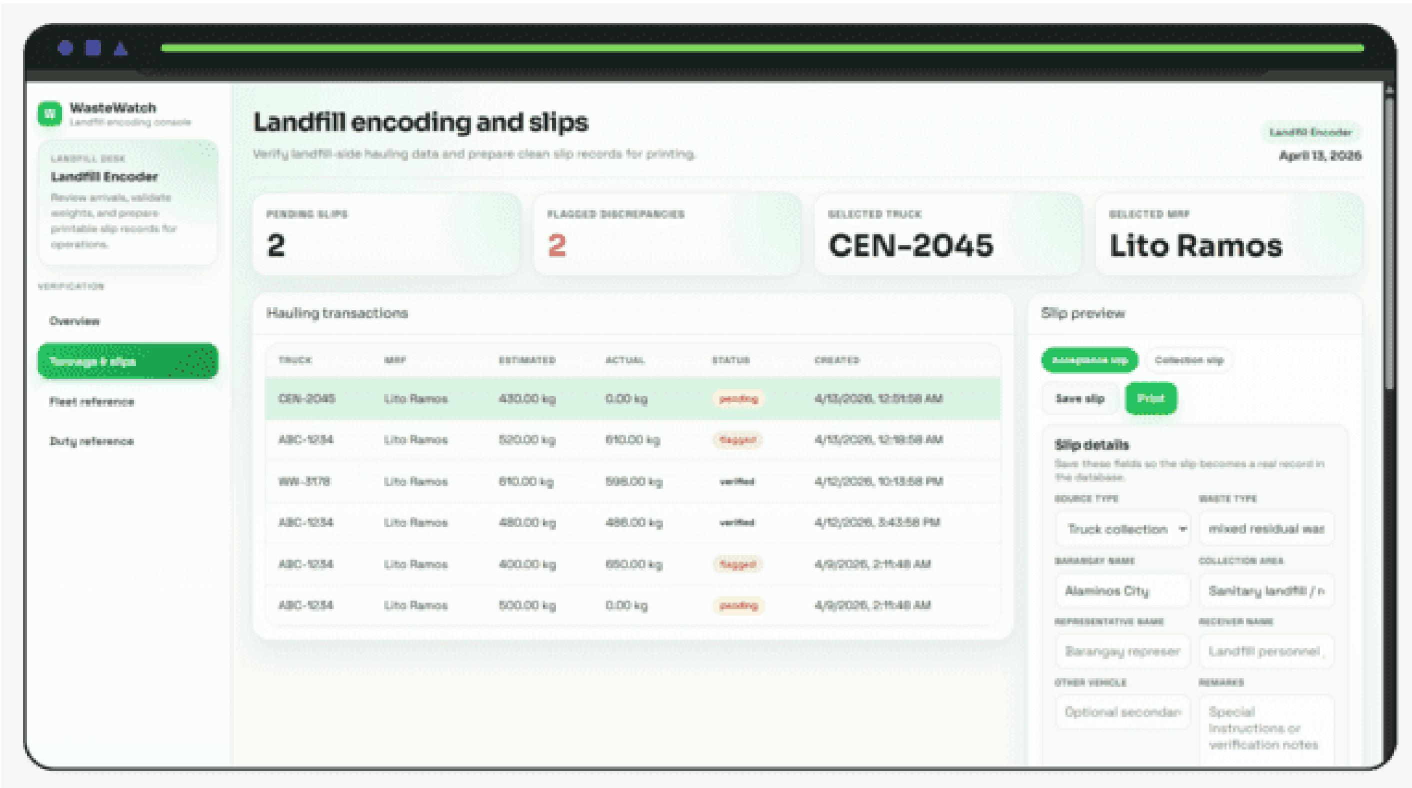
The report concern screen enables residents to submit a waste-related complaint by providing a description, photo, and location, which is then forwarded to the administrator for action.

Figure 8- MRF Hauling Request Screen



The hauling request screen allows MRF personnel to formally submit a collection request with the estimated waste weight, replacing the previous practice of coordinating through informal messaging.

Figure 9- Landfill Encoding and Slips Page



The landfill encoding page provides landfill encoders with a workspace for reviewing incoming hauling records, verifying transaction details, and generating official waste slips digitally.

System Security and Privacy Design

Given that WasteWatch is designed as a web and mobile-based platform that processes sensitive information—including user credentials, geospatial tracking data from garbage trucks, and complaint reports submitted by residents—the protection of personal data and the assurance of secure system operations constitute critical considerations in its architectural design. To address these concerns, the system incorporates a comprehensive set of security controls across authentication, data storage, and network communication layers.

For authentication, the system uses JSON Web Token (JWT) to manage user sessions without storing session data on the server [12]. Access tokens expire after 30 minutes, while refresh tokens last 7 days and are replaced each time they are used, limiting the window for unauthorized access. User passwords are encrypted using Bcrypt before being stored in the database, making them resistant to brute-force attacks. Role-based access control (RBAC) ensures that each user type—resident, driver, MRF personnel, landfill encoder, or administrator—can only access features and data appropriate to their role [13].

All communication between the mobile app, web dashboard, and server is transmitted over HTTPS to prevent data interception. The server applies rate limiting on sensitive operations such as login attempts and file uploads to prevent abuse. Database queries use parameterized statements to prevent SQL injection, and security headers are set on the server to protect against common web vulnerabilities. GPS data from drivers is collected only during active duty sessions and is not used for personal tracking. Each GPS record is tied to a specific duty session, so location data is only gathered during assigned collection routes. Complaint records are visible only to the person who submitted them and to authorized administrators, and complaint photos are stored in a separate cloud service accessed through temporary links that expire.

For field workers in areas with poor internet, the app temporarily stores duty logs and GPS data locally using SQLite, which syncs to the main database once connectivity is restored. User passwords are never saved on the device. In compliance with the Philippine Data Privacy Act of 2012 (Republic Act No. 10173), personal data is collected only for legitimate purposes and is protected through encryption when stored and during transmission [14].

CONCLUSION

With the proposed architecture and features, WasteWatch addresses the current challenges at CENRO Alaminos City by providing real-time GPS tracking of garbage trucks during active collection duties, allowing administrators to monitor fleet movement and verify route coverage. The system also enables centralized complaint reporting that allows residents to submit waste-related concerns with photos and location data, which administrators can review and resolve in an organized manner. For MRF operations, the system provides formal hauling coordination that allows MRF personnel to submit collection requests with estimated waste weights, replacing informal messaging practices. The digital landfill recording feature gives encoders a workspace for reviewing hauling records, verifying transactions, and generating waste slips. The administrative dashboard provides CENRO administrators with a centralized view of operational data, including fleet status, pending complaints, and hauling requests.

Additionally, the system supports offline data synchronization that allows field workers to collect GPS and duty data in areas with poor internet connectivity, syncing to the server once connectivity is restored. Role-based security ensures that each user type—resident, driver, MRF personnel, encoder, or administrator—can only access features appropriate to their function.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

However, this study is limited to the architectural design and prototype development of WasteWatch. Actual implementation, user acceptance testing, and performance evaluation were not conducted within the scope of this paper. The system has not yet been deployed in CENRO's operational environment, and therefore, real-world performance data have not been measured. The mobile application is currently designed for Android devices only, and iOS support has not yet been developed. For future work, the proponents recommend the full implementation and deployment of WasteWatch within CENRO Alaminos City. Once deployed, the performance indicators identified in the system evaluation—such as waste volume analysis, MRF fill rate, collection frequency, distance traveled, complaint response time, and user acceptability—can be measured to determine whether the system is effective in improving waste management operations.

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