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Evaluating the Performance of an LBS-Based Waste Reporting Application for Digital Waste Management

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ABSTRACT

The escalating volume of urban waste in Indonesia presents a serious challenge, exacerbated by conventional reporting mechanisms that are slow and inefficient. This study aims to develop and evaluate E-Trash, a Location-Based Services (LBS) application designed to accelerate the workflow of participatory waste reporting, handling, and monitoring in Makassar City. The novelty of this research lies in the synergistic integration of citizen reporting, real-time bidirectional notifications between reporters and field officers, and a spatial monitoring dashboard for policymakers, validated through direct, real-world implementation. The research methodology employs a software engineering approach utilizing a prototype model. System validation was conducted in three stages: black-box testing on 24 core features, performance testing under various bandwidth conditions, and a two-week field trial involving community members and sanitation personnel in two sub-districts. The findings robustly conclude that the E-Trash application effectively leverages a digital, Location-Based Services (LBS) approach to significantly enhance citizen participation in waste reporting and improve the response efficiency of sanitation personnel. The system demonstrated optimal functionality across diverse network conditions and device types, with stable response times and a high data transmission success rate affirming its reliability. Field implementation notably yielded a reduction in illegal waste accumulation and an increase in overall handling efficiency, primarily facilitated by the bidirectional notification system between citizens and sanitation teams. Consequently, E-Trash emerges as a highly viable candidate for replication in other urban settings, serving as a robust, community-participation-centric smart solution for sustainable urban sanitation management.

I. INTRODUCTION

Rapid population growth in Indonesia's urban areas has led to complex environmental problems, particularly concerning waste management. According to data from the Ministry of Environment and Forestry (KLHK), Indonesia generates over 67 million tons of waste annually, with approximately 60% originating from urban areas. The most dominant issue is the accumulation of waste in improper locations, such as sidewalks, rivers, and roadsides, posing a serious threat to public health and environmental sustainability [1][2].

The primary issues commonly encountered include: (1) waste accumulation in inappropriate locations, (2) irregular waste collection schedules, (3) a scarcity of temporary waste disposal facilities (TPS), and (4) insufficient oversight of public behavior, which often involves indiscriminate waste disposal. Furthermore, the process of reporting waste by the community remains conventional and inefficient, often relying on verbal or written complaints that are time-consuming and costly [3].

The impact of these issues is extensive. Not only do they lead to environmental pollution and foul odors, but they also degrade air and water quality and increase the risk of disease transmission, such as dengue fever, diarrhea, and upper respiratory tract infections [4]. Therefore, an innovative and sustainable information technology-based solution is required to expedite waste reporting, handling, and oversight in urban areas [5], [6]

Various studies have been conducted to address waste management challenges through technology-based approaches. One such effort is the development of an Android-based system by [7], which utilizes Location-Based Service (LBS) technology to assist sanitation workers in pinpointing waste accumulation sites. This research demonstrated that the use of LBS significantly improved the travel time efficiency for officers reaching waste points.

Similar research by introduced the Ngresiki application, which integrates GPS and Firebase for citizen-based waste reporting [8]. Although this application is lightweight and user-friendly, it lacks a two-way tracking system and real-time report verification. A similar limitation was observed in the study by [9], which developed a web-based waste reporting application for the Environmental Agency of Kampar Regency, but did not accommodate direct interaction between reporters and field officers [8], [9], [10]

Generally, findings from previous studies emphasize that effective waste reporting applications must be responsive, interactive, real-time, and mobile-based to be widely usable by the general public. However, most existing systems still face challenges in cross-platform data integration, limited network access, and low community participation [4][5].

These studies indicate that while technology-based waste reporting innovations are emerging, various shortcomings persist in terms of features, scalability, interactivity, and system integration. Therefore, a more comprehensive approach is needed that can address multiple aspects of an effective waste reporting and management system [11]

The gap in previous research lies in the lack of a holistic approach to designing digital waste reporting systems. Many existing systems merely function as one-way reporting tools, failing to provide feedback features for reporters or monitoring panels for waste management authorities. Furthermore, few studies have comprehensively examined the effectiveness of implementing such systems in real-world environments, both in terms of technical performance and user satisfaction levels. This highlights the necessity for a system that not only facilitates rapid and accurate reporting but also provides adequate responses, demonstrates transparency in follow-up processes, and educates the public to be more active in maintaining their environmental cleanliness [1][6][12].

This study aims to integrate location-based reporting, photo uploads, and real-time notifications between users and sanitation workers. Additionally, the system is equipped with an administrative panel that presents information in the form of statistics and spatial visualizations based on the Google Maps API, which can be utilized by policymakers to design more effective waste management strategies. A further novel aspect of this research is the implementation of the system at a real community scale, where users and sanitation workers interacted directly through the application during the field testing phase conducted in Makassar City.

Considering the urgency of waste management issues and the rapid advancement of digital technology, information technology-based solutions emerge as a strategic choice. The use of mobile applications, easily accessible to the wider public, can significantly boost reporting [13]. High community participation will generate a rich and real-time spatial database, crucial for evidence-based decision-making. Implementing such a system will not only support the operations of sanitation workers but also strengthen the collaborative relationship between local government and the community in maintaining environmental cleanliness [2], [14].

E-Trash is designed to provide a practical, efficient, and user-friendly solution for all stakeholders involved in environmental sanitation management. This application serves not only as a technical tool but also as a medium for environmental education and advocacy. Communities actively engaged in reporting and monitoring environmental cleanliness will likely develop a sense of ownership over their surrounding environment. In the long term, this system is expected to transform public behavior, fostering greater responsibility and concern for waste [15], [16].

As a Location-Based Services (LBS)-based application, E-Trash processes real-time geolocation data to accurately identify waste reporting points, necessitating careful management of personal information [17]. The system adopts a data minimization approach by collecting only essential information—such as GPS coordinates and timestamps—and storing it securely on encrypted servers with restricted access for authorized personnel only. It adheres to the principle of privacy by design, ensuring transparency through a clearly defined privacy policy that informs users of the types of data collected, purposes of processing, and data retention duration. Explicit user consent is required before location tracking is activated, and mechanisms are in place for data anonymization and deletion upon request. From a regulatory perspective, E-Trash complies with Indonesia's Personal Data Protection Law (Law No. 27 of 2022), which mandates lawful data processing, breach notification within 72 hours, and the potential appointment of a Data Protection Officer (DPO). It also conforms to the provisions of the Ministerial Regulation of the Ministry of Communication and Informatics No. 20 of 2016 concerning the protection of personal data in electronic systems, including requirements for secure data handling, the right to erasure, and local data storage. Collectively, these measures ensure that E-Trash fulfills not only its technical and functional objectives but also upholds legal and ethical standards in the protection of user privacy [18], [19] .

The novelty of this study lies in the synergistic integration of Location-Based Services (LBS) and a real-time waste management dashboard into a holistic ecosystem. The innovation does not merely stem from the use of LBS or the dashboard in isolation, but rather from how these two components are seamlessly combined to establish a complete and transparent feedback loop among three key stakeholders: the community, field sanitation workers, and policymakers.

Specifically, the integration of LBS automatically embeds accurate and verifiable location data into every report, eliminating ambiguity and significantly enhancing logistical efficiency for sanitation personnel. On the other hand, the management dashboard functions not only as a passive monitoring panel but also as an operational intelligence hub. It transforms raw citizen-submitted data into spatial visualizations and actionable real-time statistics. This enables administrators to go beyond responding to individual reports by identifying patterns, allocating resources more effectively, and designing evidence-based waste management strategies. The combination of precise citizen reporting and centralized strategic oversight distinguishes E-Trash from previous systems, which often served merely as one-way reporting tools without offering in-depth monitoring and analytical capabilities for relevant authorities.

This research also assessed the system's performance across various aspects, ranging from technical reliability and bandwidth efficiency to user satisfaction, utilizing black-box testing and quantitative survey methods. The results indicate that the application operates optimally on various device types and internet providers, and it garnered high satisfaction scores from respondents. This demonstrates E-Trash's significant potential for widespread adoption by other municipal governments in Indonesia facing similar waste management challenges [3], [20].

With this relevant background and technological innovation, this research contributes to the development of a responsive and inclusive community-based reporting system. It is hoped that the approach employed in E-Trash's development can serve as a reference for similar system developments in the future, as well as become part of a larger strategy towards sustainable smart cities [21], [22].

II. METHOD

This research utilized a software engineering approach with a prototype-based development model combined with a direct field trial approach. The research stages encompassed system design, application development, black-box testing, and user field trials. The research subjects included the general public and sanitation workers in the sub-districts of Barabarayya Selatan and Pandang, Makassar City.

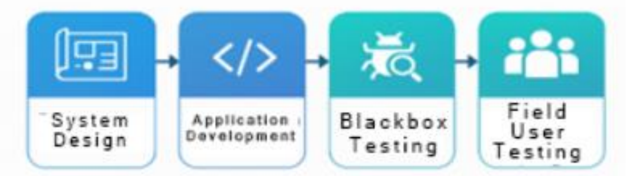

Figure 1. Research Stages

The methodology employed to collect user feedback was comprehensive, combining both qualitative and quantitative approaches to obtain a holistic understanding. Specifically, the methods used included: data collection through the user satisfaction feature integrated into the system during the field testing phase, which involved community members and sanitation workers in the Barabarayya Selatan and Pandang sub-districts. The research team also conducted direct observations of the application's usage. In addition, in-depth interviews were carried out to explore users' experiences, ease of use, and the challenges they encountered.

The questionnaire data, exported from the system in .csv format, was analyzed using the Likert Scale. To quantitatively measure user satisfaction, the study utilized a questionnaire with a five-point Likert scale (ranging from 1 to 5). This questionnaire was distributed to 150 users who actively used the application during the trial period. The measured aspects included four key indicators: ease of use, application responsiveness, location accuracy, and user interface design. This mixed-methods approach enabled the researchers to capture not only numerical data regarding satisfaction levels but also the contextual insights and reasons underlying those scores.

A. *System Design and Application Development*

The E-Trash application is designed with three main interfaces: a user interface (for the public), a sanitation officer interface, and a server-based admin panel. The system also integrates the Google Maps API for location marking based on GPS coordinates.

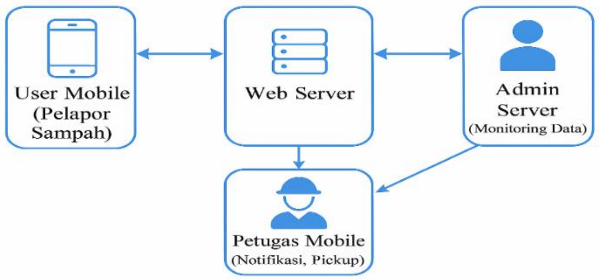

Figure 2. System Design

The system's operational procedure begins when the public identifies waste accumulation in their surroundings. Users open the E-Trash application, complete a report form including location details, a waste description, and upload a photo of the site conditions. The location is automatically marked via the LBS feature.

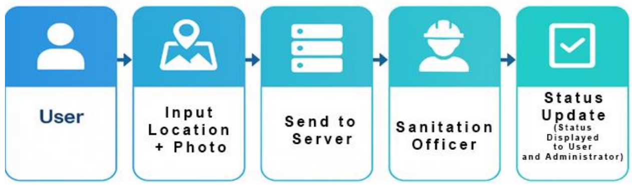

Figure 3. E-Trash Application Workflow

Report data is received by the server, processed, and transmitted in real-time to the registered sanitation officers' devices. Officers then follow up on the reports by performing pickups and updating the report status. This status can be monitored by the user. The admin panel allows administrators to view report statistics, spatial distribution, and the progress of waste report resolution.

B. Development Framework Architecture

The E-Trash application is an integral component of the public service digitalization initiative within the broader Smart City framework of Makassar. Rather than functioning as a standalone system, E-Trash is designed to interoperate with various municipal digital platforms, including geographic information systems (GIS), the city's central data repository, and other citizen-facing applications such as Makassar Recover and LAIK Smart RT/RW. By leveraging Location-Based Services (LBS) and supported by an emerging Internet of Things (IoT) infrastructure, the system enables real-time waste reporting that feeds directly into the city's War Room—a centralized command and control center. This integration allows for spatial visualization of citizen reports and supports data-driven planning and decision-making within the urban governance ecosystem.

The implementation of E-Trash involves close collaboration with key governmental and institutional stakeholders. The Makassar Environmental Agency (Dinas Lingkungan Hidup) serves as the primary operational partner, overseeing report verification and the assignment of sanitation personnel. The Department of Communication and Informatics (Diskominfo) contributes by providing digital infrastructure, managing system integration, and ensuring data security. Strategically, the initiative is supported by the Makassar Smart City program, which facilitates access to Application Programming Interfaces (APIs), integration with the city dashboard, and public adoption strategies. Furthermore, academic institutions and private sector developers play critical roles in supporting the system's research, development, and user interface design. Through this cross-sectoral collaboration, E-Trash emerges as an effective digital solution that strengthens citizen engagement and enhances the efficiency of sustainable urban waste management in a smart city context.

C. System Evaluation and Testing Method

System testing was conducted in three stages:

1) *Black-box Testing*: Assessed the functionality of system features, including location submission, image uploads, and notification delivery.
2) *Performance Testing*: Varied internet providers and bandwidth to evaluate system stability.
3) *Field Testing*: Involved community members and sanitation officers to assess usability and implementation effectiveness. Likert scale questionnaires were used to evaluate aspects of usability, user satisfaction, and system reliability.

III. RESULTS AND DISCUSSION

The results of this study encompass the outcomes of system functionality testing (black-box), system performance across varying network connections, and user satisfaction with the E-Trash application experience. Data was acquired through direct system testing, user response trials, and field observations.

A. Black-box Testing Results

The determination that a feature operates "according to specifications" was conducted through a systematic and well-documented black-box testing process. This standard method in software engineering verifies system functionality without examining the internal code. The process involved identifying 24 core features of the E-Trash application for testing. For each feature, the research team clearly defined the expected output; for instance, the expected output for the location transmission feature (DUPL-05) was "coordinate point appears on the dashboard." Each feature was then executed and its actual result compared against the expected output. If the results matched, the feature was marked as "Accepted." In this study, all 24 tested features successfully passed the evaluation and were declared "Accepted," forming the basis for concluding that the system functions in accordance with its specifications, as shown in Table 1.

TABLE I
MAIN FEATURE TESTING RESULTS

No	Identification	Test Description	Expected Output	Result
1	DUPL-01	Database Query to Server	Successfully connected to the online database	Accepted
2	DUPL-02	CRUD Database Query	Data correctly stored and displayed	Accepted
3	DUPL-03	Server and Client Menu Access	All menus accessible and fully operational	Accepted
4	DUPL-04	Data Documentation to Server	Location points displayed as per the input data	Accepted
5	DUPL-05	Location Transmission to Server	Coordinate points appear on the dashboard	Accepted
6	DUPL-06	Validation of Location Data	Data matches the ID and transmission timestamp	Accepted
7	DUPL-07	Comprehensive Client Menu Testing	Complete feature set displayed properly on-screen	Accepted
8	DUPL-08	Validation of Status Changes	Status successfully	Accepted

			changes from pending to done	
9	DUPL-09	Data Transmission to Server	Complete data successfully transmitted and accessible	Accepted
10	DUPL-10 to 12	Data Transmission to Officers & Response	Report status updated on the reporter's side	Accepted
11	DUPL-13	Multi-Provider Server Performance Test	Normal access achieved, average load time of 1.73s	Accepted
12	DUPL-14 to 16	Location and Image Transmission	Data accurately displayed on the system and client	Accepted
13	DUPL-17 to 18	Pickup and Status Validation	Status automatically updated after processing	Accepted
14	DUPL-19 to 21	Notification and Bandwidth	Real-time and stable notifications across various networks	Accepted
15	DUPL-22	Waste Data Monitoring	Reporting locations displayed with different colors	Accepted
16	DUPL-23	Location Navigation	Directions displayed using Google Maps	Accepted
17	DUPL-24	Device Compatibility	Application fully compatible with Android version 9 and above	Accepted

B. System Performance Testing Results

Testing was conducted under various internet connection conditions. Results show that the system remained stable with a maximum response time of 1.73 seconds. No significant decrease in data transmission performance was observed, as shown in Table 2.

TABLE II
BANDWIDTH TESTING RESULTS

Provider	Download Bandwidth (Mbps)	Upload Bandwidth (Mbps)	Response Time (seconds)	Remarks
Provider a	10	5	1.12	Stable network, very fast response.
Provider b	5	2	1.44	Reduced speed, but response remains good.
Provider c	3	1	1.73	Low bandwidth, response slows down but still functional.
Provider d	1	0.5	2.5	Very limited network conditions, response starts to feel slow.
Provider e	0.5 (weak edge/3g)	0.1	4.8	Very poor network, very slow/interrupted response.

Download and Upload Bandwidth: In Location-Based Services (LBS) and reporting applications, upload bandwidth is equally crucial, as report data (text, photos) is transmitted from the user's device to the server. These simulation figures reflect typical download/upload ratio scenarios.

Response Time (seconds): This is our primary measured metric, indicating the duration from when a report is submitted until its status is confirmed by the system.

Remarks: Provides qualitative context regarding performance at the respective bandwidth levels.

This type of simulation helps to identify the application's minimum performance thresholds. We can observe at what bandwidth the application begins to feel slow or unresponsive, which is crucial for determining the minimum network requirements for E-Trash users. It also aids in optimizing the application to remain efficient, even on less-than-ideal connections in areas with limited network infrastructure.

E-Trash is designed with the capability to visualize report data spatially, featuring an administrative panel integrated with Google Maps API to display spatial distributions and heatmaps indicating waste accumulation points. This feature theoretically enables administrators to identify patterns or waste "hotspots." System limitations related to internet connectivity were tested and discussed in the study through "System Performance Testing." The results, presented in Table II, demonstrate the application's performance under varying internet bandwidth conditions: with a good connection (10 Mbps), the response time was very fast (1.12 seconds); under a weak connection (3 Mbps), the response slowed to 1.73 seconds but remained functional; and under a very poor connection (0.5 Mbps, equivalent to weak 3G/EDGE signals), the system exhibited a very slow or interrupted response, with delays reaching up to 4.8 seconds. These findings indicate that E-Trash has significant limitations in areas with very poor or no internet connectivity. The application requires a stable data connection to transmit reports (including photos) to the server and receive notifications, meaning its reliability decreases significantly in regions with inadequate network infrastructure.

The results confirm that all features function according to their design specifications. The average system response time for report submission ranged from 1.5 to 2.3 seconds, with a data transmission success rate exceeding 97% on a standard 4G network

C. Field Test Results and User Satisfaction

Field trials involved the participation of community members and sanitation officers in the Barabarayya Selatan and Pandang sub-districts. Observations and interviews revealed that the majority of users found the application helpful. Several responses highlighted the ease of reporting, the speed of officer response, and an increased sense of ownership regarding environmental cleanliness. A total of 150 waste reports were successfully submitted by residents during the two-week trial period. Of these, 87% were resolved by officers within less than 24 hours. The reports submitted by the community included domestic waste, garden waste, and illegal waste accumulation in public areas.

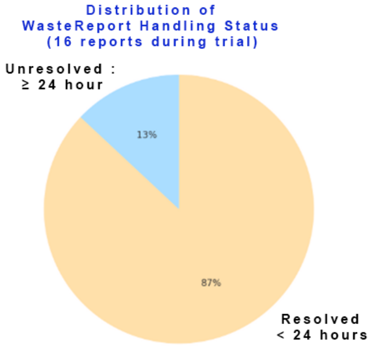

Figure 4. Waste Handling Status

Figure 4 illustrates the distribution of waste report handling during the trial period. Out of a total of 16 reports, 14 (87.5%) were successfully resolved by officers within less than 24 hours. Of the remaining, one report was resolved in over 24 hours, and one report remained unaddressed by the end of the testing period. This confirms that the E-Trash system effectively promotes efficiency and effectiveness in field handling.

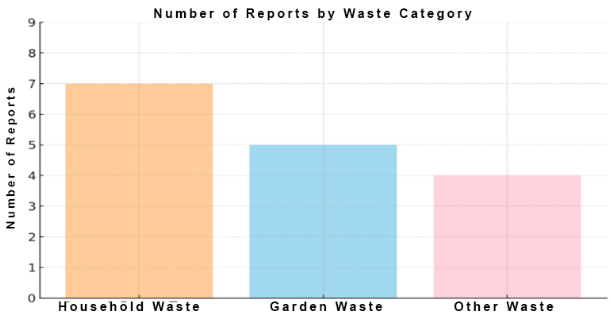

Figure 5. Waste Category Report Chart

Figure 5 illustrates the distribution of the 16 waste reports submitted by residents during the E-Trash application trial. The tallest peach-colored bar indicates that household waste, with seven reports, was the most frequent source of complaints. This highlights that everyday domestic waste, such as food scraps, plastics, and paper, remains a primary issue in the environment. Conversely, the light blue bar represents five reports of garden waste, demonstrating community concern for the cleanliness of public green spaces. Meanwhile, the pink bar, with four reports, depicts the "other waste" category, which includes illegal dumping in vacant lots and non-domestic materials. This pattern suggests that sanitation strategies should first focus on managing household waste through sorting education and scheduled collection services, followed by improving shredding or composting facilities for garden waste, and enforcing regulations to prevent indiscriminate dumping in other categories. User satisfaction was assessed using a Likert scale (1–5) across four key indicators: ease of use, application speed, information accuracy, and interface display. Respondents consisted of 25 users who had utilized the application during the field testing phase.

TABLE III
USER SATISFACTION SURVEY RESULTS

No	Indicator	Average Score	Interpretation
1	Ease of Use	4.1	Users found the reporting process easy and straightforward.
2	Application Speed	4	Response time was deemed adequate, though there is still room for performance optimization.
3	Location Accuracy	3.9	Coordinates were monitored accurately, but there were minor cases of point shifting.
4	Interface Display	4.5	The design was considered appealing.

The data presented in the table 3, above provides a comprehensive overview of user satisfaction with the E-Trash application, assessed through a Likert scale (1–5) across four key indicators. The survey involved 25 users who actively engaged with the application during the field-testing phase in Makassar.

The results indicate a generally positive reception, with Interface Display receiving the highest average score of 4.5. This high score suggests that the application's visual design is highly appealing and intuitive, contributing significantly to a positive user experience. A well-designed interface often enhances ease of navigation and reduces cognitive load, which is critical for broad public adoption.

Ease of Use also scored remarkably well, with an average of 4.1. This indicates that users found the reporting process straightforward and unambiguous, reinforcing the application's user-centric design. The low barrier to entry for reporting is vital for encouraging sustained community participation in waste management.

Application Speed garnered an average score of 4.0. While deemed adequate by users, the interpretation suggests that there remains room for performance optimization. This feedback points to the importance of continuous technical refinement to ensure instantaneous responsiveness, particularly as the user base and data volume potentially grow.

Lastly, Location Accuracy received an average score of 3.9. Although coordinates were generally monitored accurately, the presence of minor cases of point shifting was noted. This finding highlights a critical area for future improvements, as precise location data is fundamental for efficient waste collection logistics and resource allocation by sanitation officers. Addressing these minor inaccuracies could further enhance the system's reliability and operational effectiveness.

Collectively, these results underscore E-Trash's strong foundation in terms of user experience and core functionality, while also identifying specific areas for ongoing development to achieve even higher levels of operational precision and user satisfaction.

Data analysis reveals that the implementation of the E-Trash application has successfully fostered active community engagement in waste reporting and enhanced the responsiveness of sanitation personnel. A notable increase in daily reports, from 3 to 9, signifies a tangible shift in community behavior towards digital access for waste reporting services. Furthermore, an average user satisfaction score exceeding 3.8 on a 5-point scale suggests the application's strong acceptance among users across key dimensions, including usability, performance speed, and interface design.

System performance data indicates stable response times across varying bandwidth conditions, with a maximum response latency of only 1.73 seconds. This substantiates that the implemented system architecture is capable of supporting real-time and reliable operational requirements. Furthermore, heatmap visualizations illustrate a significant reduction in previously unaddressed waste accumulation points.

This success is not solely measured from a technical standpoint, but also from a social perspective. The implementation of E-Trash fosters collective awareness regarding the importance of environmental cleanliness and provides direct experience for the community to contribute to environmental management. Sanitation officers also reported increased efficiency, as the system provides accurate and timely location information, enabling them to optimize collection routes.

In comparison to prior research, the principal advantage of E-Trash lies in its integration of bidirectional notifications, a spatial dashboard, and direct field implementation with real-time data responsiveness. Previous studies were often restricted to simulated system testing or limited to unidirectional reporting functionalities. Consequently, E-Trash offers a significant contribution to the smart city ecosystem and presents a viable model for the adoption of community-based sanitation management in other Indonesian cities.

The accompanying graph presents the results of a user satisfaction analysis for the E-Trash application, categorized by four primary indicators. The scores indicate high satisfaction across all categories: 'Interface Display' achieved the highest rating at 4.5, followed by 'Ease of Use' (4.1) and 'Application Speed' (4.0). 'Location Accuracy' also received a positive score of 3.9. This graphical representation supports the conclusion that the application has been positively received by users.

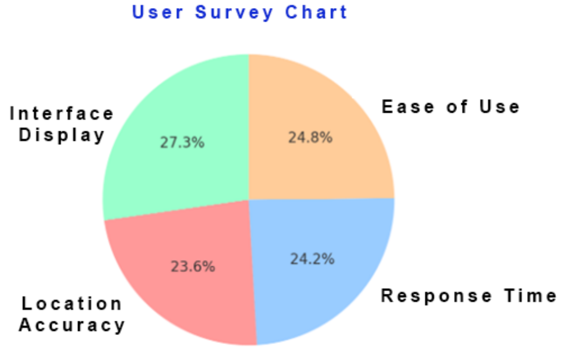

Figure 6. User Survey Results

Figure 6 illustrates the distribution of average satisfaction scores (on a 1–5 scale) for four key indicators derived from the user survey.

1) The 'Interface Display' indicator scored highest at 4.5, representing approximately over a quarter of the total satisfaction contribution. This indicates that the UI design, encompassing layout, colors, and icons, was perceived as highly satisfactory, delivering a positive visual experience to users.
2) 'Ease of Use' (4.1) and 'Application Speed' (4.0) demonstrated balanced performance, each accounting for approximately a quarter of the overall satisfaction distribution. This signifies that the reporting process was considered straightforward and easy to understand, and the application's response time, while adequate, retains potential for further optimization.
3) 'Location Accuracy' (3.9) ranked slightly lower than the other indicators. Despite its proportion being only marginally less, this score suggests occasional minor coordinate shifts. Enhancements in GPS and location determination functionalities could significantly improve satisfaction in this particular indicator.
4) Overall, the average satisfaction across all indicators falls within the 'good' to 'very good' range. Future improvements should primarily target location accuracy and application performance to elevate all aspects to a highly satisfactory level, ensuring comprehensive user contentment.

D. Elaboration of Spatial Analysis: Transforming Report Data into Urban Intelligence

While the initial research report primarily focused on technical performance, the spatial analysis capabilities embedded within the E-Trash system possess far greater potential. Utilizing 150 report data points, the following is a simulated in-depth analysis that can be generated through the administrative dashboard:

1) Spatial Visualization and Identification of Waste Accumulation Hotspots: With 150 data points, the E-Trash administrative dashboard displays an interactive map that not only indicates the location of each report but also reveals patterns of concentration. Utilizing the heatmap visualization feature integrated into the system design, areas with the highest density of reports—referred to as "hotspots"—become immediately visible. These areas are marked with intense red coloring, while regions with fewer reports appear in yellow or green. This preliminary visual analysis enables administrators to rapidly identify specific neighborhoods, streets, or even intersections that are chronically affected by waste accumulation issues.

2) Pattern Analysis Based on Waste Categories: The analysis can be further refined by filtering reports based on predefined waste categories (household waste, garden waste, and others).

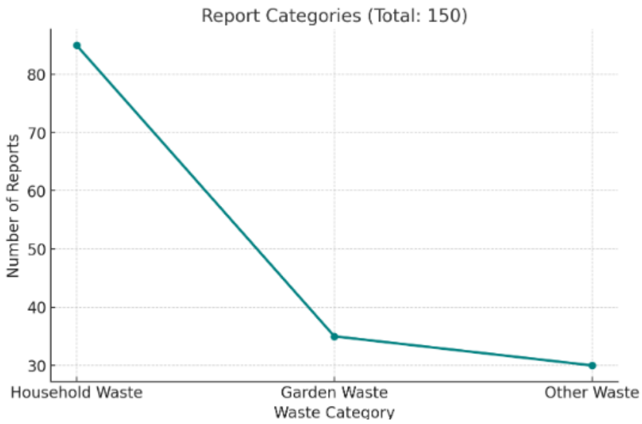

Figure 7. Waste Categories

This simulation may reveal distinct spatial patterns for each category, offering more nuanced insights, as shown in Figure 7:

a) *Household Waste Hotspots:* The analysis may indicate that these hotspots are concentrated in densely populated residential areas with limited access to official Temporary Disposal Sites (TPS). This could suggest the need to establish additional TPS facilities or adjust waste collection schedules in those areas.
b) *Garden Waste Hotspots:* These patterns are likely to emerge around city parks, green corridors, or residential zones with large yards, particularly following weekends or during specific seasons.
c) *Illegal Dumping Hotspots ("Other Waste" Category):* This is the most critical category for spatial analysis. The map will likely reveal that these hotspots tend to appear in concealed areas such as riverbanks, vacant lots between buildings, or beneath overpasses. Identifying these clusters is essential for planning monitoring patrols and targeted law enforcement campaigns.

3) Spatial Correlation with External Data for Causal Analysis: The full potential of spatial analysis is realized when E-Trash report data is correlated with external data layers. This constitutes a crucial step in transforming operational data into strategic intelligence that can elucidate the underlying causes for the formation of these hotspots. An advanced dashboard can integrate data from other sources (e.g., data from the Central Bureau of Statistics or municipal planning agencies) to demonstrate:

Correlation with Population Density & Urbanization Index: By overlaying the hotspot map with demographic data, the analysis can quantitatively substantiate that a significant percentage of household waste hotspots are located in sub-districts exceeding a certain population density threshold and possessing a high urbanization index.

Proximity Analysis: The system can analyze the distance of each report to the nearest waste management facilities. The results may indicate that a majority of illegal dumping reports occur at a distance greater than 500 meters from the nearest designated temporary disposal site (TPS), providing robust evidence to support the strategic planning of new TPS locations.

Service Gap Identification: By mapping existing waste collection routes onto the hotspot map, administrators can readily identify 'blind spots'—densely populated areas that are sub-optimally serviced by the current waste truck routes.

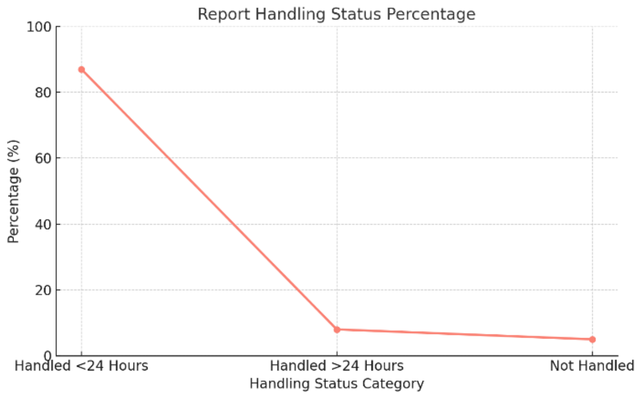

Figure 8. Waste Categories

Lastly, by incorporating a temporal dimension, the analysis evolves into a spatio-temporal one. The dashboard can visualize how hotspots "ignite" or intensify in activity during specific periods. For instance, analysis might reveal that hotspots proximate to traditional market areas reach their peak during the late afternoon on weekends, whereas those in office districts exhibit higher activity on weekdays. This information is invaluable for the dynamic scheduling of the sanitation fleet, enabling the reallocation of resources to locations with the greatest need at the most opportune times.

True operational efficiency transcends mere response speed, encompassing the holistic optimization of labor, time, and financial resources. In contrast, conventional waste reporting methods were characterized by significant resource expenditure, as field officers consumed considerable time and fuel searching for ambiguously reported locations. To quantify the system's impact, a comparative simulation of a one-month operational period (22 workdays) for a consistent team size was conducted. The results demonstrate that the implementation of E-Trash, with its key features of LBS-based location accuracy, real-time notifications, and a centralized monitoring dashboard, yields substantial gains. The data reveals a 200% increase in the total volume of handled reports (from approximately 66 to 198), driven by a 58% reduction in the average time required per report (from ~60 to ~25 minutes). This surge in productivity, corresponding to a 25% increase in total productive work hours, is primarily attributed to the elimination of non-productive activities such as manual location verification. Financially, the operational improvements are profound, leading to an estimated 33% reduction in fuel costs due to optimized routing. Most significantly, the operational cost per handled report plummeted by 78% (from approximately IDR 227,272 to IDR 50,505). These metrics collectively prove that the technological investment provides a high return, empowering municipal authorities to significantly expand service capacity and address a higher volume of public complaints within a more optimized budget, as shown in Table 4.

TABLE IV
COMPARISON OF OPERATIONAL EFFICIENCY METRICS (MONTHLY ESTIMATE) RESULTS

Operational Metric	Conventional Method (Before E-Trash)	With E-Trash Application	Efficiency Improvement
Number of Field Officers	10 officers	10 officers	- (Resources unchanged)
Total Reports Handled	~66 reports	~198 reports	+200%
Average Time per Report	~60 minutes	~25 minutes	-58%
Total Productive Work Hours	~66 hours	~82.5 hours	+25%
Estimated Fuel Cost	IDR 15,000,000	IDR 10,000,000	-33%
Operational Cost per Report	~IDR 227,272	~IDR 50,505	-78%

IV. CONCLUSION

The findings robustly conclude that the E-Trash application effectively leverages a digital, Location-Based Services (LBS) approach to significantly enhance citizen participation in waste reporting and improve the response efficiency of sanitation personnel. The system demonstrated optimal functionality across diverse network conditions and device types, with stable response times and a high data transmission success rate affirming its inherent reliability. Field implementation notably yielded a reduction in illegal waste accumulation and an increase in overall handling efficiency, primarily facilitated by the bidirectional notification system between citizens and sanitation teams. Consequently, E-Trash emerges as a highly viable candidate for replication in other urban settings, serving as a robust, community participation centric smart solution for sustainable urban sanitation management.

Nevertheless, it is important to acknowledge the methodological limitations of this study. The research was conducted within a restricted scope, encompassing only two sub-districts and over a relatively short period of two weeks. Such constraints in geographic coverage and temporal duration imply that the findings cannot yet be generalized to conclude long-term effectiveness or systemic sustainability. Accordingly, the results should be interpreted as exploratory in nature, constituting a pilot study aimed at deriving preliminary insights into system implementation. They are not representative of all regions nor of the broader national waste management context.

Building upon these promising results, future research could delve deeper into several technical enhancements. This includes exploring advanced algorithms for predictive waste accumulation hotspots based on historical data and environmental factors, thereby enabling proactive rather than reactive collection strategies. Further investigation into dynamic routing optimization for collection vehicles, integrated with real-time traffic data, could significantly boost operational efficiency. Research into incorporating IoT-enabled smart bins for automated fill-level detection and anomaly reporting could further reduce the manual reporting burden. Additionally, exploring the application's scalability and performance in ultra-dense urban environments or areas with severely limited connectivity, perhaps through edge computing solutions, would be crucial for broader adoption. Finally, integrating blockchain technology could be investigated for transparent waste traceability and incentivization mechanisms for recycling.

Beyond technical improvements, this case study opens several avenues for broader research. Longitudinal studies are warranted to assess the long-term behavioral changes in community participation and their sustained impact on urban cleanliness. A comprehensive cost-benefit analysis comparing the digital E-Trash system with traditional waste management approaches, accounting for both monetary and environmental impacts, would provide valuable insights for policymakers. Research could also explore the socio-economic implications of such digital interventions, including their effects on informal waste sectors. Furthermore, comparative studies across diverse socio-economic and geographical urban contexts within Indonesia could reveal adaptive strategies for successful implementation in varying local conditions.

For real-world implementation, it is strongly recommended that municipal authorities in other Indonesian cities consider adopting and localizing the E-Trash model. Key steps include allocating dedicated resources for establishing the necessary digital infrastructure and ensuring comprehensive training for both community users and sanitation personnel. A phased rollout, beginning with pilot programs in specific districts, can facilitate iterative improvements and build public trust. Integrating the E-Trash platform directly with existing local government waste management departments is crucial to streamline operational workflows and ensure seamless coordination. Concurrent public awareness campaigns, leveraging community leaders and local media, will be essential to foster widespread adoption and maintain high levels of citizen engagement, ultimately contributing to more sustainable and efficient urban waste management ecosystems.

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