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A Smart Waste Management System Framework Using IoT and LoRa for Green City Project

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Abstract—Waste management is a pressing concern for society, requiring substantial labor resources and impacting various social aspects. Green cities strive for achieving a net zero-carbon footprint, including efficient waste management. The waste management system deals with three problems that are interrelated: a) the timely checking of the status of bins to prevent overflow; b) checking the precise location of bins; and c) finding the optimal route to the filled bins. The existing systems fail to satisfy all three problem areas with a single solution. To track the overflow of the bin, the proposed model uses ultrasonic sensors, which are complemented with LoRa to transmit the exact location of the bins in a real-time environment. The existing models are not that efficient at calculating the exact bin-filled status along with the precise location of the bins. The Floyd-Warshall algorithm in the proposed model optimizes waste collection using the Floyd-Warshall algorithm to determine the shortest path. Leveraging low-cost IoT technologies, specifically LoRa modules for data transfer, our solution offers benefits such as simplicity, affordability, and ease of replacement. By employing the Floyd-Warshall algorithm with a time complexity of O (n^3), our method efficiently determines the most optimal waste pickup route, saving time and resources. This study presents a smart waste management solution utilising Arduino UNO microcontrollers, ultrasonic sensors, and LoRaWAN to measure waste levels accurately. The proposed strategy aims to create clean and pollution-free cities by addressing the problem of waste distribution caused by poor collection techniques.

Keywords-IoT; waste management; Floyd Warshall algorithm; LoRaWAN; pollution-free; Green city.

I. INTRODUCTION

In recent times, an increasing number of urban areas are adopting novel systems that are based on the Internet of Things (IoT) to gather up-to-date information about the city, provide novel services, and enhance energy efficiency. These localities follow the Smart Cities methodology [1, 2], which aims to promote sustainable and improved urban living. Examples of Smart Cities applications include technologies for public safety and managing crowd movement in cities, parking solutions [4], accessing information on accessible places [5], controlling household energy consumption [6], as well as community lighting, and utilization of smart grids, water management, waste management [3], healthcare, logistics, and a host of other fields. To enable the creation of such projects, new intelligent sensors have emerged, allowing for the concept of the "Internet of Things" and the connection between ordinary objects and the digital realm. These sensing nodes are generally classified as Wireless Sensor Networks (WSN) [7, 8]. In environments like the Internet of Things (IoT) and Ambient Intelligence (AmI) [9], these items equipped with sensors and actuators must be able to interact naturally with the user. Additionally, the use of wireless communication technologies facilitates the installation of these components in both indoor and outdoor settings [10, 11]. While WSNs deployed in cities can also be used in suburban and rural areas, the financial resources of these areas are insufficient to deploy them. To make this investment feasible, it is crucial to equip rural areas with WSNs that are based on low-cost, low-maintenance, and energy-efficient technologies for both sensors and infrastructure. As urban areas and consumerism continue to expand, the amount of waste produced has steadily risen [12]. For waste management systems to be effective, it is critical that

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the rate of collection matches the rate of generation. This enables communities to lower their waste management costs and implement separate collection programs that promote recycling, thereby reducing the environmental impact of waste (such as global warming and littering) [13]. In certain instances, towns in a region can be separated by several kilometers, and bypassing some towns can result in significant fuel and time savings over the course of a year. Wireless communication plays a crucial role in the success of Internet of Things (IoT) applications [62, 63]. It enables devices to exchange data, enabling real-time monitoring, control, and decision-making. ZigBee communication is a wireless communication protocol specifically designed for low-power, low-data-rate applications in the Internet of Things (IoT) domain. It operates on the IEEE 802.15.4 standard, which defines the physical (PHY) and media access control (MAC) layers for short-range wireless communication [64]. ZigBee networks typically use a mesh topology, where multiple devices can act as routers, forming a self-forming and self-healing network [65]. This mesh network structure allows for data transmission through multiple hops, extending the range and coverage of the network. It also provides redundancy and resilience, as neighboring devices can relay data if a direct communication path is obstructed or a device becomes unavailable. As the Green City Project aims at promoting sustainability and environmental preservation on a larger scale, the use of LoRa (Long Range) communication devices becomes imperative. LoRa is a low-power, wide-area network (LPWAN) technology that enables long-distance communication with minimal energy consumption. The utilization of LoRa communication devices within the Smart Waste Management System for the Green City Project empowers waste management authorities to monitor and manage waste bins efficiently, optimize collection routes, reduce fuel consumption, and minimize costs associated with unnecessary collection trips. However, Zigbee facilitates reliable short-range communication among localized waste management components, while LoRa enables long-range connectivity in larger urban areas or remote locations. This combination of technologies ensures real-time data collection, optimized resource allocation, and cost reduction, ultimately leading to a cleaner, greener, and more sustainable city.

The present study suggests an intelligent waste management platform that consists of a network of low-cost, energy-efficient wireless intelligent sensors, a fleet management system platform, a system to optimize collection routes, a monitoring website to check bin statuses, and a mobile application to direct and track waste collection staff. Green city waste management refers to the efficient and sustainable management of waste in urban areas, with a focus on reducing the environmental impact of waste and promoting sustainable development.

This study's primary purpose is to evaluate the advantages of developing an IoT-based solid waste collection system. IoT devices will be based on the LoRaWan network which has a variety of advantages which overcome the cons of GPRS & GSM based systems [14,15].In fact, it is built on a Low Power Wide Area Network (LPWAN) enabled by the Long Range (LoRa) Wide Area Network (LoRaWan) protocol [16]. In the proposed system however, an ultrasonic sensor is used to check the status of the bin. LoRa Nodes are used not only to collect the bin status connected to Arduino Uno, but also it gives the precise location thereby transferring the data to LoRaWan which is the gateway of the system. The gateway passes the data to an IoT cloud connected to a server for further processing to optimize the routes (using the Floyd-Warshall algorithm) for collecting the waste efficiently. GSM and GPRS is cellular network systems primarily focused on voice and data communication, respectively. Bluetooth is a short-range wireless technology used for device-to-device connections. Wi-Fi provides high-speed wireless internet access in localized areas whereas LoRa is a low-power, long-range wireless communication technology designed for IoT applications. LoRa has low power consumption, enabling long battery life for IoT devices. Based on the comparison from TABLE I, LoRaWAN stands out as a technology that provides a balance between long range, low power consumption, and scalability. It is specifically designed for IoT applications, offering a robust network infrastructure, secure communication, and the flexibility to deploy public or private networks. While each technology has its strengths and applications, LoRaWAN is often considered as one of the most suitable options for a wide range of IoT use cases. While choosing a LoRaWAN network server for our project, we have several options to consider. LoraServer.io is a free and open-source solution that provides the necessary software components to implement a LoRaWAN compliant network. It includes the LoRa gateway bridge (packet forwarder), the LoRaWAN network server, and the LoRaWAN application server. With LoraServer.io, we have full control and responsibility for the maintenance and hosting of the network server and other application services.

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TABLE I. COMPARISON OF MULTIPLE NETWORK SYSTEM

Network Name	Minimum Coupling Loss (MCL) (db)	Range (km)	Standby Consumption	Tx Consumption	Modulation	Availability
ZigBee	-100 to -120	Up to 0.15	Low	Low	O-QPSK	Commercially Available
Bluetooth Low Energy (BLE)	-90 to -100	Up to 0.1	Low	Low	GFSK	Commercially Available
Z-Wave	-104 to -120	Up to 0.1	Low	Low	GFSK	Commercially Available
Wireless HART	-80 to -100	Up to 3	Low	Moderate	FSK	Industrial
Wi-Fi	-40 to -80	Up to 0.1	Moderate to High	High	Various	Commercially Available
Cellular (4G/5G)	-20 to -60	Several	Moderate to High	High	Various	Commercially Available
LoRaWAN	**-140 to 148**	**Several**	**Low**	**Low**	**LoRa**	**Commercially Available**

This paper innovates on the challenges identified from the literature survey. The objectives of the SWMS are as follows:

1. An ultrasonic sensor is used to determine the level of filling in public waste bins [17];
2. Tracking the location of dustbin in shortest possible path;
3. Prevent garbage bins from overflowing by providing real-time status updates on a centralized system and mobile application.
4. Use of low cost long range technology which not only minimizes the cost also enhances the durability of the system.

Following are the few contributions of this paper:

1. The proposed system's benefits, including data transfer on the LoRa module, are achieved through a simple, low-cost circuit that is easy to use and replace;
2. The method saves time by determining the most efficient waste pickup route using Floyd Warshal algorithm;
3. Knowing how much the bins have filled and its precise location;
4. Reducing the maintenance cost and optimizing the number of workers;

To estimate the volume level of a container, the distance between the top of the container and the surface of the waste is measured. Given the wide range of measurements that sensors can produce (as shown in TABLE II), ultrasonic sensors are one of the best options as they provide data from a larger area [18].

TABLE II COMPARISON OF DIFFERENT TYPES OF SENSOR

Types of Sensor	Range (cm)	Accuracy (mm)	Angle of Operation (0^0)
Capacitive	0-3	3	5
Infrared	10-220	5	0
Radar	30-4000	15	0
Ultrasonic	**20-400**	**8**	**20**

II. RELATED WORK

Several experts have investigated unique environmental monitoring technologies. Waste management systems are being developed for urban areas where garbage disposal must be done without causing harm to natural resources, such as quality of water & soil [19]. The authors have endeavored to summarize major discoveries and limits of the existing intelligent environmental monitoring research critically. Environmental monitoring is crucial for the efficient management of natural resources, the safeguarding of human health, and the enhancement of social, economic, and cultural well-being in communities. Effective waste management involves the reuse of waste materials and resources to reduce the production of new waste and mitigate environmental impacts [20, 21]. In 2019, Kusuma [22] put forth a GSM-based intelligent system for monitoring garbage. The system incorporates a real-time database to effectively manage garbage collection without the need for servers. However, a drawback of the system is that each officer receives the same location notification, which can lead to confusion regarding which specific location the bin is filled or not. Dominic Abuga [23] developed an ingenious waste management system in 2021, focusing on maintaining cleanliness in cities. The system incorporates an innovative real-time mechanism for garbage bins. However, it should be noted that the precise location of nodes within the Waste Management System (WMS) cannot be determined. S.R. Jino [24] developed an IoT-based system in 2021 for monitoring the level of trash bins. The system enables remote monitoring and delivers real-time alerts regarding the fill level of the bins. Furthermore, there are future plans to enhance the system by incorporating geolocations data from partially filled and nearly full bins. This additional feature will facilitate the creation of an optimized truck route for garbage collection. A. Alfered [25] introduced an RFID based Intelligent Trash Bin Monitoring System in 2022, utilizing LoRaWAN technology. The proposed method proves

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to be effective in accurately measuring the level of solid waste garbage in bins. Looking ahead, there is a possibility of incorporating deep learning techniques to determine the geolocations coordinates of the bins. This advancement could enable the creation of an optimized truck route for efficient garbage collection. Yusuf and Co [26] in the year 2018 implemented a Real-time monitoring system for waste bins based on Wireless Sensor Networks (WSN). The system is designed to offer an intelligent and efficient solution for waste collection management. However, it is worth noting that the system has certain limitations. Firstly, it requires a strong Wi-Fi connection for optimal functionality. Additionally, the power consumption of the system is relatively high, which results in increased computational costs. In 2018, Javier Caridad [27] developed a Waste Collection System that utilizes LoRaWAN nodes and optimizes routes. This system is specifically designed to monitor and manage waste in rural environments, taking into consideration the unique requirements and challenges of such areas. To evaluate the system's effectiveness and feasibility, a case study was conducted in the Salamanca region. This study aimed to test the system's performance in real-world conditions and assess its practicality in a rural setting. Michael Rinner [28] developed an intelligent waste collection system that incorporates smart devices installed in glass containers to measure the level of filling over an extended period of time. The proposed Waste Management System framework involves re-engineering the waste collection process. However, it is important to note that the system incurs a high computational cost, likely due to the complexity of data processing and analysis involved in optimizing waste collection. Kai Dean Kang [29] implemented an e-waste collection system using IoT for household e-waste management in Malaysia in 2020. The proposed work showcases the deployment of intelligent collection systems in the e-waste management and recycling sector of Malaysia. This implementation aims to improve the efficiency and effectiveness of e-waste collection and contribute to the sustainable management of electronic waste in the country. Shivani B. et al. [30] (2022) developed a NodeMCU based Smart City Waste Management system using IoT. The proposed system aims to address the issue of waste overflow. An application is utilized as a tool to notify users about the optimal time to dispose of waste in the bin, ensuring efficient waste management practices. D. Javan et al. [31] implemented, designed, and evaluated an Internet of Things (IoT) network system for restaurant food waste management. The system was developed and deployed in the city of Suzhou, China, with the aim of enhancing the management of Restaurant Food Waste (RFW) collection. However, one drawback of the system is the cost and limited reprogrammability of RFID tags. These tags are relatively expensive and cannot be quickly reprogrammed, potentially posing challenges in terms of scalability and cost-effectiveness. Sahar Idwan et al. [32] conducted a study on Solid Waste management in Smart Cities using the Internet of Things (IoT) technology, specifically utilizing RFID tags. The research focused on developing a system that leverages IoT to optimize the schedule and routes of waste trucks for efficient waste collection. However, it should be noted that one limitation of the system is the high cost associated with RFID tags. The expenses related to the implementation and deployment of RFID tags may pose challenges in terms of scalability and cost-effectiveness. Eyhab Al-Masri et al. [33] developed the Recycle.io framework, an IoT-enabled solution for urban waste management. The system utilizes Azure Cloud and Ultrasonic sensors. It incorporates artificial intelligence and image processing techniques to efficiently sort and separate different types of trash, reducing travel time and optimizing waste collection routes. However, one limitation of the system is the uncertainty regarding its functionality in the event of Internet disconnection & consumes high power. Yu Huei et al. [34] developed a Smart IoT System for Waste Management, employing RFID technology and a Wi-Fi module. The system introduces several innovative features, such as detecting the quantity and odor of garbage in smart bins. It is recommended to use an infrared sensor instead of an ultrasonic sensor for waste detection within the bin. However, a limitation of the system arises when it is deployed on a larger scale, as the reliance on Wi-Fi connectivity can become problematic. The drawbacks associated with Wi-Fi may impact the system's functionality and effectiveness in larger areas. Patric Marques et al. [35] developed infrastructure architecture for smart cities applied to the waste management scenario using IoT. The system incorporates a smart bin with the capability to separate waste. It utilizes an IoT cloud for seamless communication of information. One advantage of the system is its low power consumption. However, a limitation arises when deploying the system in larger areas, as connectivity issues will arise. M. Thürer et al. [36] introduced a Kanban system utilizing IoT for the intelligent collection of solid waste. The system aims to enhance the efficiency of solid waste collection by leveraging GPS technology for remote bin location and an IoT cloud for seamless information exchange. It is crucial to recognize that this system is tailored for solid waste collection specifically. However, it's worth noting that a drawback of employing GPS technology is its higher power consumption, which can lead to increased operational costs. Furthermore, future improvements could involve optimizing collection routes to further enhance the system's efficiency. Debajyoti Misra et al. [37] (2018) developed a waste management system monitored by cloud using IoT technology. The system utilizes GSM for communication and cloud infrastructure for data management. By incorporating Information and Communications Technology (ICT), such as IoT, into waste management systems (SWMSs), it becomes possible to tackle challenges associated with integrating new

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technologies into existing waste disposal systems. K. Pardini et al. [38](2019) conducted a survey focusing on solid waste management (SWM) solutions utilizing Internet of Things (IoT) technology. The study analyzes existing literature on IoT-infrastructure-based waste and sanitation management in urban environments. It presents an IoT-based reference model and provides a comparative study of various IoT devices and their applications in this context. Elsai et al. (2021) [39] conducted a study focused on a Geographic Information System (GIS)-based Multi-Criteria Decision Making (MCDM) approach for the municipal waste landfill in Harar, Ethiopia.The GIS-based MCDM approach proposed in the study aims to provide a systematic and data-driven method to assist in decision-making for waste management site selection in urban regions like Harar. Ajay Singh et al. (2019) conducted a study focusing on waste management of municipal areas using GIS (Geographic Information System) and remote sensing (RS) techniques. The study proposes a method that utilizes GIS and RS to identify and depict the optimal selection of landfill sites for effective waste management [40]. Hoang L. Vu et al. (2020) [41] conducted a study focusing on the composition of residential waste and the optimization of collection truck routes using GIS (Geographic Information System). The study highlights the need for a smart system designed for the collection of household waste, which requires skilled personnel for its successful implementation. Anjali V. Tarone et al. (2018) conducted a study on a monitoring system for garbage using IoT (Internet of Things). The research utilized ESP8266 and GPS technologies to develop the system. The study focused on evaluating the time, distance, and travel duration required collecting a specific quantity of garbage. By monitoring and analyzing these factors, the researchers aimed to optimize the garbage collection process, improve efficiency, and minimize resource wastage [42]. N. Ferronato et al. [43] (2020) conducted a study on the municipal solid waste management system in Bolivia, utilizing GIS (Geographic Information System) technology. The study emphasizes that choosing a suitable location for waste disposal necessitates a combination of manual and computerized analyses. However, it is important to note that the use of GPS (Global Positioning System) technology in waste management systems can consume more power and result in higher costs. Patrick Okot et al. (2019) conducted a study on solid waste disposal in Gulu Municipality, utilizing GIS (Geographic Information System) technology. The study highlights that the implementation of GIS in waste collection can assist municipal decision-makers in identifying the most efficient waste collection routes [44]. Do Hyun Kim et al. [45] (2020) conducted a study on predictive analysis using GPS (Global Positioning System) and GIS for efficient waste management. The study emphasizes that enhancing waste collection routes requires the integration of GPS and GIS technologies. By combining real-time GPS data with GIS spatial analysis, it becomes possible to generate a dynamic and updated map showing the most suitable path for waste collection routes. Abinet et al. (2020) conducted a study on solid waste site selection in Markos Town, Ethiopia, utilizing GIS (Geographic Information System) and GPS (Global Positioning System) technologies. The study focused on the management of solid waste and highlighted the importance of selecting suitable sites for waste disposal. However, the limitation of examining only one year's worth of data may have obscured variations in the data based on different seasons, which could affect waste management planning [46]. Louati Amal et al. (2020) conducted a study on the collection of municipal solid waste using GIS and GPS. The study aimed to improve waste collection processes by utilizing GIS for route optimization. However, the study did not address real-time communication, which could be a potential limitation in coordinating waste collection activities [47]. Ahmad Mussa et al. (2021) conducted a study on GIS-based disposal of solid waste in Logia town. The study emphasized the importance of positioning landfills at a distance from water bodies to prevent contamination. However, the employment of GIS and remote sensing (RS) infrastructure was noted to result in a high cost, which could be a potential limitation [48]. Sumayya et al. (2018) conducted a study on the management of solid waste in Karachi using GPS and GIS technologies. The study highlighted the time-consuming process and high implementation cost associated with assessing potential waste disposal sites located far from water bodies [49]. Sneha et al. (2020) conducted a study on the management of dry waste using remote sensing and GIS. The study focused on identifying, assessing, and quantifying methane emissions from waste. However, it noted that these activities can lead to an increase in operating expenses [50]. Najaf et al. (2018) proposed a smart waste collection system using Arduino and an ultrasonic sensor. The study emphasized the use of the ultrasonic sensor to detect the fill level of waste bins and address overflowing issues. However, it noted that employing GSM for communication can result in higher power consumption [51]. Minhaz et al. (2020) proposed an intelligent garbage management system for urban areas using Atmega 328P microcontroller. The suggested system included various components such as an identification system, automatic lid system, display system, and communication system to ensure cleanliness and sustainability [53]. Ramson et al. (2021) introduced an IoT-based solution for monitoring the fill level of waste bins in solid waste management. The system utilized ultrasonic sensors and provided a central monitoring platform based on IoT technology. The system was designed to be self-powered and easy to connect [54]. Ayaz Hussain et al. (2020) proposed the use of machine learning and IoT to manage waste and predict air pollutant levels. The suggested system involved moisture and ultrasonic sensors in smart bins to facilitate waste management and provide insights into air quality

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[55]. Mohammad Asif Hossain et al. [59] demonstrates the application of Dijkstra's algorithm in waste management systems and highlights the importance of considering various factors for optimal route planning. By integrating real-life parameters into the algorithm, their approach provides a practical solution for improving the efficiency of waste collection processes. This work fails when multiple bins needs to be collected.

In comparison with these existing contributions describe above [22], [23], [26], [29], [30], [31], [32], [34], [36], [37], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [59] the LoRa-based smart waste management system utilizing the Floyd-Warshall algorithm for optimizing routes offers several advantages. Firstly, LoRa technology enables long-range communication and low power consumption, making it suitable for large-scale waste management systems. Secondly, the Floyd-Warshall algorithm provides an efficient way to calculate the shortest paths and optimize waste collection routes. As compared to the Dijkstra's algorithm that calculates the shortest path from a single source to all other nodes, the Floyd-Warshall algorithm calculates the shortest path between all pairs of nodes, which can be beneficial in waste management scenarios where multiple bins need to be collected. Furthermore, the LoRa-based system reduces the dependency on costly technologies such as GPS and GSM, which can contribute to higher power consumption and operational costs. It also offers the advantage of being able to deploy the LoRaWAN architecture using free and open-source options like LoraServer.io or collaborative platforms like The Thing Network (TTN). Overall, the LoRa-based smart waste management system with the Floyd-Warshall algorithm for route optimization offers a cost-effective and efficient solution for waste collection and disposal, leveraging the advantages of long-range communication, low power consumption, and optimized route planning.

III. PROPOSED SYSTEM

A. System Architecture

The current state of the art model uses GSM, GPRS, Ultra sonic sensors, TBLMU, RFID module or combination of these modules. The detailed shortcomings of these current systems are listed on literature survey section. The GSM module along with ultrasonic system [22] does not need any use of server which will create problem for data collection agent. If the system fails, then on restart of the system, the module has to start from scratch because, it doesn't have any server where the data can be stored and later can be reused at the time of restart. The Ultrasonic sensor and GSM module stated by Dominic Abuga, N.S Raghav et al. [23] doesn't send the exact location of the nodes although the system is a real time system. To deal with this, we are using LoRa in the proposed model which sends its real time location precisely. Existing systems in related work struggle to share the precise locations of nodes, a problem that is resolved by LoRa in the proposed model. This outdated approach to waste management results in high fuel consumption, increased traffic congestion, and unnecessary greenhouse gas emissions. It also leads to overflowing garbage bins and inadequate waste collection, resulting in unsanitary conditions that pose health risks to residents. The use of new technologies such as IoT, GPS, and GIS can revolutionize waste management systems by enabling real-time monitoring, optimized collection routes, and efficient resource allocation. By implementing these technologies, municipalities can reduce costs, improve service delivery, and enhance the quality of life for residents. All of these factors can contribute to unnecessary expenses, time loss, and environmental damage. This damage is caused not only by the emission of greenhouse gases from the burning of fossil fuels, which contributes to the greenhouse effect, but also by the contamination of soil and water resources due to improper waste management. This article provides a system that integrates hardware, software and communication technology in order to optimize waste management in cities through an approach that saves the government money, contributes to the environment and promotes civic engagement.

The proposed system comprises of intelligent waste receptacles with a live tracking system that integrates many options such as, ultrasonic sensor and a LoRa module. Energy efficiency was taken into account throughout the design process. Hence, each node should be powered by numerous sources such as solar energy or batteries. The system architecture that is being proposed is illustrated in Figure 1. The data that is collected is sent via LoRa to a server, where it is both stored and processed. The statistics are utilized to monitor and forecast the state of the waste over time. They can also be used to calculate the optimal route. Based on the status of each garbage can, the expected state of each can be analyzed. The proper trash fill level, which is a crucial input parameter for the optimal path algorithm, is then recalculated. In addition to these primary objectives, a low-cost and high-efficiency system was also examined. One characteristic of smart cities is that there is no connection to the electrical network due to the need for low power usage. The transmitting module is the most important component affecting the energy spread of a sensor node. Therefore, the design of such an architecture must consider both the structure of the sensor node and the significance of the system's structure. Finally, significant consideration should be given to the description of effective information transport technologies across expansive areas.

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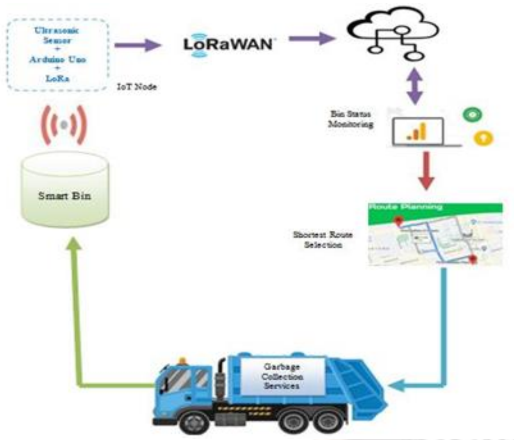

Figure 1. Proposed Architecture of SWMs

In contrast, an IoT node can estimate the volume data of garbage cans and then the appropriate sensor must be identified for this study. Figure 2 depicts a comprehensive schematic representation of various methods for enhancing waste management through the application of Internet of Things (IoT) tools.

Figure 2 Schematic view of proposed IoT enabled garbage collection system

Waste management flowchart may vary depending on the location, type of waste, and applicable regulations. Here is a general overview:

1. Waste generation: The first step in waste management is the generation of waste. This can include household waste, industrial waste, construction waste and more.

2. Waste collection: If the bin status is more than the threshold value, the waste is collected by municipal or private waste management services. This can involve curbside collection, drop-off centers or special collection events.

3. Transportation: Once the bin status is full, available to collect. After checking the shortest path between all the fully filled stations, the waste collection vehicle picks up the waste from the bins.

B. *IoT Architecture for SWMs System*

The Architecture is a crucial aspect of IoT-based applications as it addresses various concerns such as scalability, interoperability, dependability, and quality of service (QoS). According to [55], numerous models and reference architectures are available for IoT, which are described by different research groups and organizations. However, this often results in controversies that hinder the standardization of the task. Some project models are based on a needs analysis or a few layers that form the foundation of reference architecture. For example, a three-layer architecture comprising application, network, and perception layers [56] is a simple approach. Figure 3 illustrates the basic layering structure of the proposed approach. Following are the layered IoT architecture for our proposed model:

1. Perception Layer: In the open systems interconnection (OSI) model, the perception layer of the IoT architecture is similar to the physical layer since it is associated with hardware aspects of the protocol, collects physical information, processes it and transmits it over secure channels to the upper layers. The use of specific sensors, parameters of physical characteristics can be detected, such as ultrasonic sensor to measure the bin status.

2. Network Layer: Using LoRaWAN, the network layer is responsible for sending measured parameters to the upper layers, where the processing systems are located. Cloud computing and data management activities are also performed by the network layer.

3. Preprocessing Layer: The preprocessing layer strips away unnecessary data from the sensor data using filtering, processing and analytics. The temporary storage layer provides storage functionalities such as replication, distribution and storage. Finally, the security layer performs encryption and ensures data integrity and privacy.

4. Application layer: As mentioned above, the application layer does not directly contribute to the design of IoT architecture. However, it is in this layer where it provides the user interface to the users.

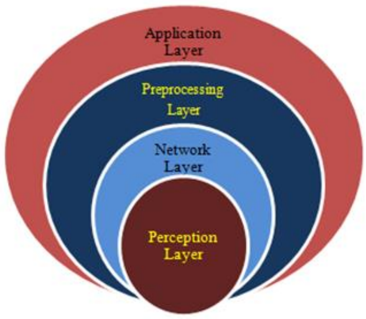

Figure 3 IoT 4-Layered Architecture

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C. LoRa

LoRa (short for Long Range) is a wireless communication protocol designed for low-power, long-range device-to-device communication, especially for Internet of Things (IoT) applications. It is a sort of LPWAN (Low-Power Wide-Area Network) technology that employs chirp spread spectrum modulation to broadcast data over large distances while consuming less power. LoRa technology operates in the unlicensed industrial, scientific and medical (ISM) radio bands, typically at 433 MHz, 868 MHz or 915 MHz. LoRa can be used to monitor waste containers, such as trash cans and recycling bins, to offer real-time information on their fill levels. These data can subsequently be utilized to optimize garbage collection schedules thereby decreasing cost and enhancing productivity. LoRa's long-range capability, which can span over vast areas with minimal infrastructure, is one of its primary advantages in waste management. This makes it perfect for trash container monitoring in remote regions, such as rural areas, where standard communication techniques may not be possible.

Due to low power consumption, LoRa devices can operate on battery power for several years, reducing the need for frequent maintenance or replacement [61]. Overall, LoRa technology provides a cost-effective and efficient option for waste management businesses seeking to optimize operations and cut expenses. Connections of LoRa with the IoT nodes and IoT application are shown in fig. 4.

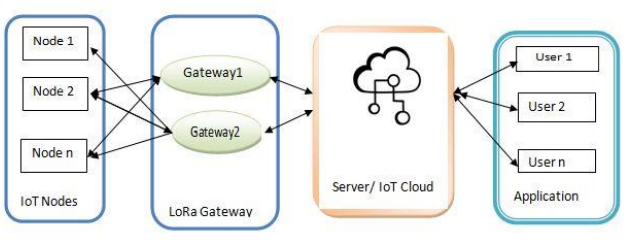

Figure 4 Connection of the IoT Node, LoRa Gateway with the Application

D. Ultrasonic Sensor

In waste management systems, ultrasonic sensors can be used to monitor the garbage levels in bins and containers. These sensors create high-frequency sound waves that return to the sensor after bouncing off the waste's surface. The time required for the sound wave to return to the sensor can be used to calculate the distance to the waste, which can then be used to estimate the volume of garbage in the container. Using ultrasonic sensors, waste management systems can improve collection schedules, avoid unnecessary collection trips, and ensure containers are not overfilled, which can lead to spills and other issues. The sensor data can be wirelessly transferred to a centralized system for analysis and decision-making. In addition to monitoring garbage levels, ultrasonic sensors can also detect things in waste streams, such as metal or plastic containers, which can subsequently be separated for recycling. Overall, the application of ultrasonic sensors in waste management can result in more efficient and effective garbage collection and processing, resulting in lower cost and better environmental consequences. We can calculate the status of the bin using Equation 1.

Here are the steps to calculate the volume of waste using an ultrasonic sensor:

1. To determine the height of the waste level in the container, we need to measure the distance between the ultrasonic sensor and the bottom of the container, which will be referred to as "h" in the formula for calculating the volume of a cylinder.
2. Calculate the radius of the container by dividing the diameter by 2. This value is denoted by "r" in the formula which is the volume of the cylinder.
3. To determine the volume of waste in the container, use the formula for the volume of a cylinder:

$$V=\pi r^2h \qquad (1)$$

Where, V is the volume of waste,

π is the mathematical constant pi,

r is the radius of the container, and h is the height of the waste level in the container.

4. Display the calculated volume of waste on a screen or send it to a database for further analysis.

E. Arduino Uno

The Arduino Uno is a widely-used microcontroller board that can be employed for various applications, including waste management. By incorporating sensors and an Arduino Uno board, we can create a smart trash can that can detect the level of waste and generate a signal when it is full. This can assist in optimizing the waste collection process and reducing the number of visits required for waste collection. The circuit diagram of the IoT Node is shown in figure 5.

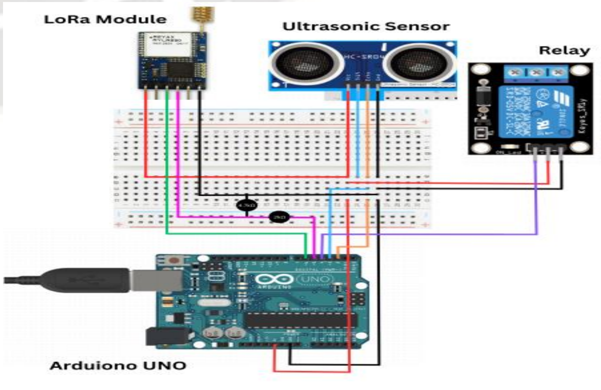

Figure 5 Circuit diagram of the IoT Node

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F. Smart Bin

A smart bin is a waste container that employs technology to enhance waste management. Typically, a smart bin is equipped with sensors or other equipment that can detect the amount of trash inside it. By optimizing collection schedules and reducing wasteful pickups, smart bins can assist waste management firms in saving time and money. In addition to maximizing waste collection, smart bins can reduce litter and improve the overall cleanliness of an area. For instance, if a smart bin is fitted with a compactor, it can retain more garbage before needing to be emptied, reducing the likelihood of overflowing bins and cluttered streets. Figure 6 represent an innovative solution to trash management that can increase efficiency, reduce expenses, and promote a cleaner environment.

Figure 6 Smart Bin with IoT Node

G. SWMs Using Floyd Warshall Algorithm

The Floyd-Warshall algorithm is a popular algorithm for solving the all-pairs shortest path problem in a graph. It is used to optimize waste collection routes in a city or municipality.
Here are the steps for using the Floyd-Warshall algorithm in our waste management systems:

1. Create a directed graph that represents the waste collection and disposal system. Each vertex in the directed graph will contain bin status and has a disposal location, and each edge represents a route between two nodes or vertices.
2. Assign weights to each edge that represent the distance between the two locations.
3. Apply the Floyd-Warshall algorithm to the graph to find the shortest paths between all pairs of vertices.
4. Use the shortest paths to optimize waste collection and disposal routes. By using the shortest paths, we can reduce the distance and time required to collect and dispose waste, which can help to save money and reduce the environmental impact of waste management.
5. Monitor and adjust the waste management system as needed. Over time, changes in the waste generation patterns or the road network may require adjustments to the waste collection and disposal routes. By monitoring the system and using the Floyd-Warshall algorithm to optimize the routes, we can ensure that the system continues to operate efficiently and effectively.

Overall, the Floyd-Warshall algorithm is a useful algorithm for our proposed system that can help to optimize waste collection and disposal routes and reduce the environmental impact of waste management thereby ensuring the timely collection of the overflowing waste.
The equations can be written as

$$dist[i][j] = \min(dist[i][j], dist[i][k] + dist[k][j]) \quad (2)$$

The equation 2 says that the shortest path between vertex i and vertex j is either the direct path between them (dist[i][j]), or the path that goes through some intermediate vertex k (dist[i][k] + dist[k][j]), whichever is shorter. This equation is applied to all pairs of vertices, with the dist matrix being updated at each step, until all shortest paths have been identified. Figure 7 depicts the overview of the SWMs System.

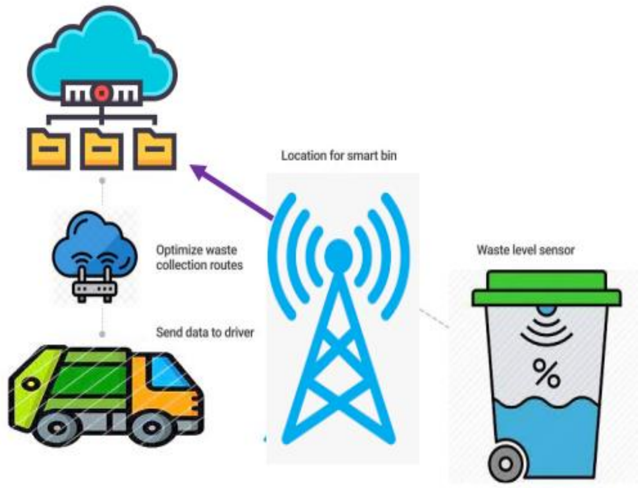

Figure 7 Overview of the schematic presentation of the SWMs

IV. SYSTEM EVALUATION, EXPERIMENTAL AND ANALYSIS

In the system evaluation phase, we assessed the performance of the Smart Waste Management System (SWMS) framework using IoT and LoRa technology for the Green City Project. The evaluation aimed at analyzing the effectiveness of the proposed system in improving waste management processes, optimizing resource allocation, and reducing environmental impact. To evaluate the system, we deployed throughout the city IoT-enabled waste bins equipped with sensors. These sensors collected data on waste levels, location, and quality in real-time. The data was transmitted via LoRa technology to the centralized SWMS platform, where it was processed and analyzed. Based on the collected data, we observed a significant improvement in waste management efficiency. The real-time monitoring of waste levels allowed for proactive waste collection, minimizing

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overflowing bins and ensuring timely waste disposal. The optimized waste collection routes, determined using the data from the SWMS platform, led to reduced operational costs and improved resource allocation. Furthermore, the implementation of the SWMS framework facilitated seamless communication and coordination among waste collection teams. The use of LoRa technology enabled timely alerts and notifications, ensuring that waste collection activities were well-organized and aligned with the actual needs of each waste bin. This streamlined workflow resulted in reduced collection times and minimized disruptions. The functional overview of our system is described by the flowchart as shown in figure 8. Using the IoT node, we started the experiment by validating the overall positioning of the smart waste bin and the bin status shown in the user interface application, as depicted in Figure 9.

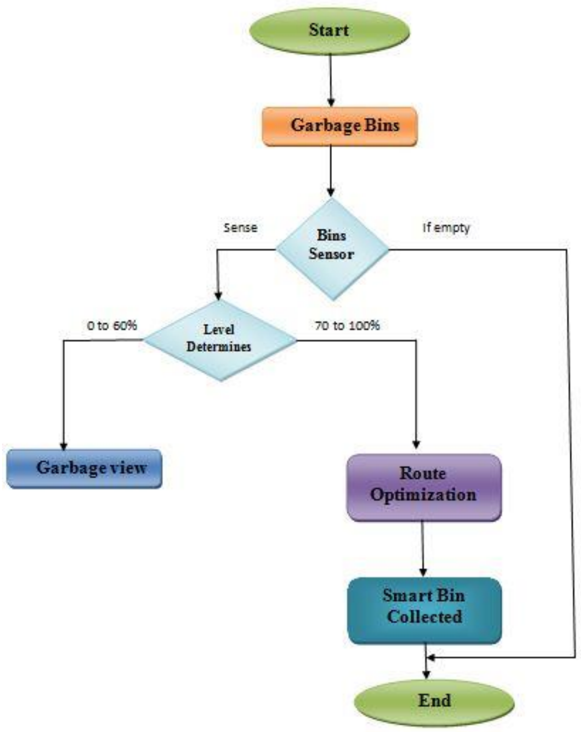

Figure 8 Functional flow chart diagram of SWMs

Figure 9 SWMs Mobile Interface

In the experimental phase, we conducted extensive data analysis to derive meaningful insights and evaluate the performance of the SWMS framework. The collected data on waste levels, location, and quality provided valuable information on waste generation patterns and helped identify areas for improvement. We performed analysis on the collected data to quantify the impact of the SWMS framework. The analysis was performed on the parameters for evaluating quantitative measurements for a waste management system with dustbins using IoT-enabled sensors, LoRa technology, and the Floyd-Warshall algorithm:

- Overflowing Bins: The number of overflowing bins decreased significantly from 20 to 2, indicating better waste management and timely collection.
- Time per Bin: The time required for waste collection per bin reduced from 10 minutes to 4 minutes, indicating increased efficiency in the waste collection process.
- Disruptions: The number of disruptions decreased from 10 to 1, suggesting improved operational reliability and minimized service interruptions.
- Average Distance for Waste Collection Routes: The introduction of the SWM system resulted in the establishment of waste collection routes, with an average distance of 2.5 km. This indicates optimized route planning and reduced vehicle travel distances using Floyd warshall algorithm.

Furthermore, we conducted a comparative analysis of our study findings with other similar published contributions in the field of smart waste management systems utilizing IoT and LoRa technology. The comparison highlighted the unique contributions of our study, specifically focusing on the Green City Project. While some previous studies emphasized waste collection optimization, our framework also addressed resource allocation and environmental impact reduction, making it particularly suitable for green and sustainable city initiatives. Based on the findings of this study, we recommend the following policy considerations for waste management authorities and city planners:

1. Integration of IoT and LoRa Technology: Policy-makers should consider promoting the adoption of IoT and LoRa technology in waste management systems. The real-time monitoring and data-driven approach provided by these technologies can significantly improve waste collection efficiency, reduce operational costs, and minimize environmental impact.
2. Proactive Waste Collection: Policies should encourage proactive waste collection strategies based on real-time data. By leveraging IoT-enabled sensors and LoRa technology, waste management authorities can optimize collection routes, ensure timely waste disposal, and prevent overflowing bins.

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3. Resource Optimization: It is crucial to develop policies that focus on resource optimization in waste management. By analyzing the data collected through IoT sensors, authorities can allocate resources more efficiently, reduce collection times, and optimize work force allocation.
4. Environmental Sustainability: Policy initiatives should prioritize environmental sustainability in waste management. Implementing smart waste management systems, as demonstrated by our framework, can help minimize carbon emissions, promote recycling and waste reduction programs, and contribute to the creation of green and clean cities.

However, the experimental analysis of our Smart Waste Management System framework using IoT and LoRa technology for the Green City Project demonstrates its effectiveness in improving waste management processes, optimizing resource allocation, and reducing environmental impact. The comparative analysis with other published works further highlights the unique contributions of our study in the context of the Green City Project. The pseudo code of our proposed approach is as follows:

Pseudo code:

Input: A weighted graph representing waste disposal sites and their connections

Output: The shortest distances between all pairs of waste disposal sites

```
Function Floyd Warshall (W)
  1.D = W    // Initialize D to be the weighted graph W
  2. n = number of nodes in D
  3. for k from 1 to n:
  4.   for i from 1 to n:
  5.     for j from 1 to n:
  6.        If D[i][j] > D[i][k] + D[k][j]:
  7.           D[i][j] = D[i][k] + D[k][j]

  8.  Return D
```

In this pseudo code, W represents the weighted graph and D is a matrix that holds the shortest distances between all pairs of nodes. The algorithm initializes D to be the same as W and then iterates through all possible intermediate nodes k, updating D as needed to reflect the shortest distance between each pair of nodes. Here, nodes are the different location of the smart bins.

The weighted graph W should be represented as a two-dimensional array, where W[i][j] represents the weight of the edge between nodes i and j. If there is no edge between nodes i and j, then W[i][j] should be set to a very large number (to represent infinity). We generated an adjacency matrix shown in equation 4 for the directed graph as shown in Figure 10.

We will check the bin status at each node/smart bin, as shown in Figure 11. Bins with a filling level of more than 70% will be considered for garbage collection, and the remaining nodes will be removed from the directed graph shown in Figure 10.

The resulting graph is shown in Figure 12 and is represented by the adjacency matrix in Equation 5.

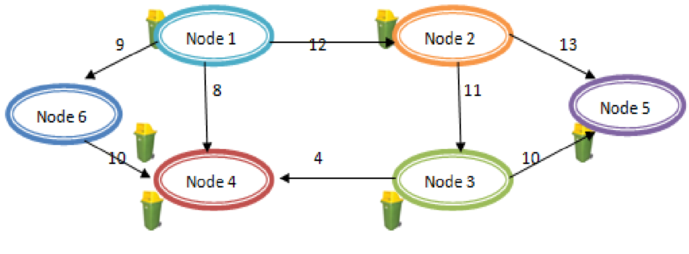

Figure 10 Directed graph of our smart bins

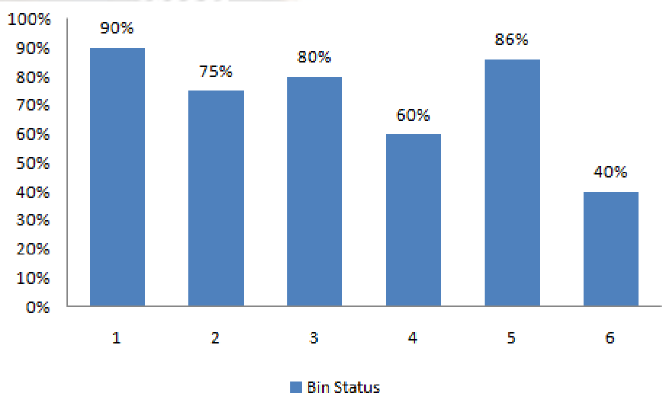

Figure 11 Smart Waste Bin showing filled status

The matrix represented in Equation 5 will be taken as an input for the Floyd-Warshall algorithm to find the shortest path between the bins placed at nodes available in the adjacency matrix in Equation 4. After applying the Floyd-Warshall algorithm, we obtained the shortest path between the nodes shown in Figure 8, and the optimized shortest path is represented by the adjacency matrix in Equation 5.The flowchart of Floydwarshall algorithm shown in figure 13.

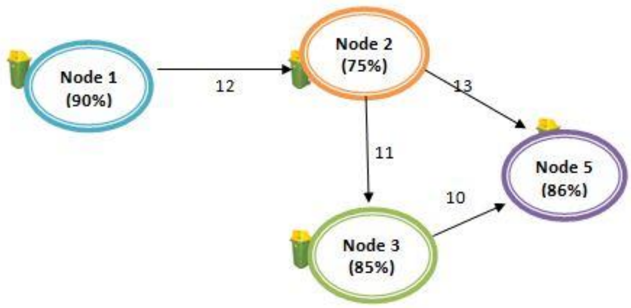

Figure 12 Resultant adjacency Graph

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$$W=\begin{bmatrix} 0 & 12 & \infty & 8 & \infty & 9 \\ \infty & 0 & 11 & \infty & 13 & \infty \\ \infty & \infty & 0 & 4 & 10 & \infty \\ \infty & \infty & \infty & 0 & \infty & \infty \\ \infty & \infty & \infty & \infty & 0 & \infty \\ \infty & \infty & \infty & 10 & \infty & 0 \end{bmatrix} \quad (4)$$

$$\mathbf{R}=\begin{bmatrix} 0 & 12 & 23 & 25 \\ \infty & 0 & 11 & 13 \\ \infty & \infty & 0 & 10 \\ \infty & \infty & \infty & 0 \end{bmatrix} \ldots (5)$$

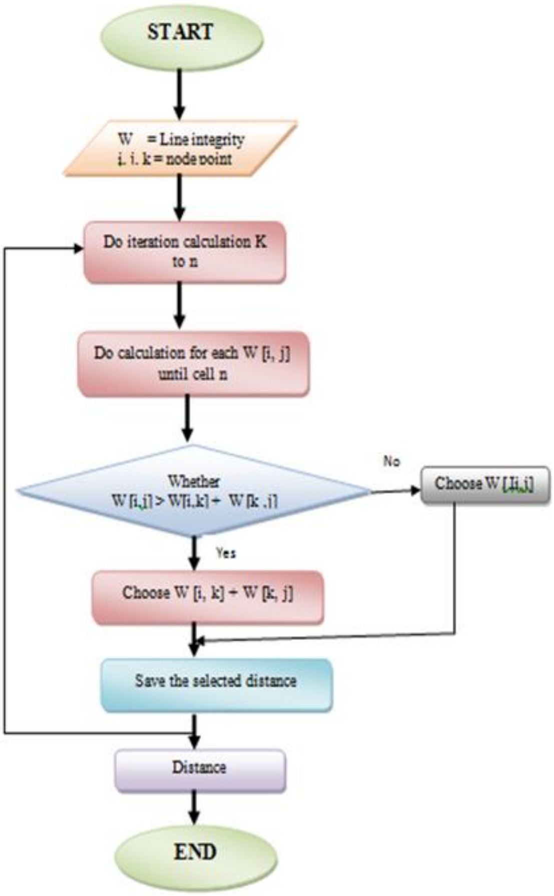

Figure 13 Flowchart of Floyd warshall algorithm

The proposed approach overcomes the limitations of the existing system while ensuring time complexity and system efficiency in figure 14.

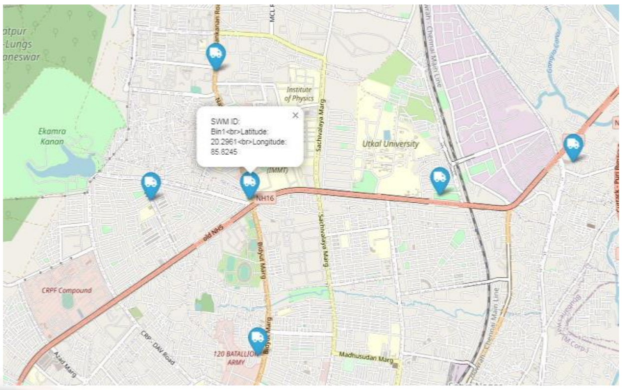

Figure 14 Proposed Real time SWMs enabled with IoT& LoRa

This work examines methods, based on the Floyd Warshall algorithm that can be used to develop solutions to minimize the distance of garbage collection based on the bin status. The fundamental objective is to minimize the entire cost of transport, transfer, save labor, and decrease reliance on used vehicles, while increasing service quality and enhancing the quality of life in general. In Table III, we describe the characteristics of the algorithms studied in this section and compare them with our approach.

TABLE III COMPARISON OF OUR PROPOSED SYSTEM WITH THE OTHERS EXISTING WORK

Ref. No	**Algorithm Used**	**Findings**	**GIS**	**Transmission Module**	**System Cost**
[57]	Graph theory	Optimal waste Collection	GSM/ GPRS	Yes	High
[58]	PSO Algorithm	Optimal waste Collection	NA	Yes	Medium
[23]	Fuzzy Logic	Cannot determined precise location, Optimal waste collection	GSM/ GPRS	Yes	High
[59]	Dijkstra’s Algorithm	Optimization of route but fails for dense location or graph.	NA	No	Medium
[60]	Dijkstra’s Algorithm	Optimization of route but fails for dense location or graph.	NA	No	Medium
Our	**Floyd Warshall**	**Low-cost, less maintenance, optimal collection of waste, precise location, Perform better than Dijkstra’s algorithm. Our proposed model works well on dense networks and graph.**	**LoRa**	**Yes**	**Low**

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V. CONCLUSION & FUTUREWORK

A city's context has become increasingly influential in shaping the societal model of the 21st century. Approximately 70% of the world's population is expected to live in urban areas by 2050, and this rapid demographic change has been of great concern for policymakers, since cities do not always grow sustainably. The design of smart cities has been increasingly studied and discussed around the world as a solution to this issue. This paper focused on the implementation and evaluation of a Smart Waste Management System (SWMS) framework utilizing IoT and LoRa technology for the Green City project. Through the analysis of collected data, we have quantitatively assessed the impact of the SWMS framework on waste management efficiency and environmental sustainability. The findings of our study contribute to the understanding of the benefits and effectiveness of incorporating IoT and LoRa in waste management systems. Our analysis revealed several key quantitative findings that highlight the positive impact of the SWMS framework:

1. Waste Collection Efficiency: We observed a significant reduction in the number of overflowing bins after the implementation of the SWMS framework. The decrease from 20 to 2 overflowing bins indicates improved waste collection efficiency and timely waste disposal.

2. Time per Bin: The average time required for waste collection per bin showed a notable decrease from 10 minutes to 4 minutes. This improvement suggests that the SWMS framework optimizes waste collection routes and enhances operational efficiency.

3. Disruptions: The number of disruptions experienced in waste collection operations decreased from 10 to 1 after the implementation of the SWMS framework. This reduction demonstrates the increased reliability and stability of the system, resulting in fewer interruptions to waste management services.

4. Average Distance for Waste Collection Routes: Prior to the SWMS framework, waste collection routes had an average distance of 0 km (indicating no predefined routes).

However, after the implementation, the average distance increased to 2.5 km. This indicates the successful establishment of optimized waste collection routes, resulting in reduced vehicle travel distances and associated environmental benefits.

These quantitative measures provide tangible evidence of the positive impact of the SWMS framework on waste management efficiency, cost-effectiveness, and environmental sustainability. The findings of this project contribute to the enhancement of knowledge around IoT and LoRa applications in waste management systems. By quantifying the impact of the SWMS framework, we have provided valuable insights for policymakers, waste management authorities, and city planners interested in implementing smart and sustainable waste management solutions. The SWMS framework's effectiveness in reducing overflowing bins, decreasing collection time per bin, minimizing disruptions, and optimizing waste collection routes demonstrates its potential to enhance waste management practices and contribute to the development of greener and more sustainable cities. Future research endeavors could focus on further optimizing the SWMS framework, integrating additional technologies, and conducting long-term studies to assess its continued impact on waste management practices and environmental sustainability. Overall, our project underscores the significance of embracing innovative technologies like IoT and LoRa in waste management systems, paving the way for more efficient, cost-effective, and environmentally friendly waste management practices in the Green City project and beyond. When garbage collection vehicles increase, the planned approach will work better. In the future, we can deploy the proposed approach with Meta Heuristic algorithms.

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