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RESEARCH ARTICLE

Blockchain-Enabled VANET for Smart Solid Waste Management

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ABSTRACT Internet of things (IoT) is being applied in every aspect of daily living to improve the quality of life. Waste management is a critical issue, especially for developing countries. The purpose of this study is to propose an IoT-driven state-of-the-art system for solid waste management for developing countries and urban areas. The lack of planning and availability of resources in urban areas have made a living in densely populated surroundings even more difficult. This research work provides a framework based on blockchain-enabled vehicular ad-hoc networks (VANETs) in the realm of IoT. The step-by-step methods are proposed for the decentralized solution for solid waste management using blockchain-enabled VANET. Advanced ultra-high frequency (UHF) technology is used along with IoT devices for the real-time location of waste vehicles and the detection of waste bins. Geo-fencing techniques are also applied for the monitoring and timely collection of waste from the dump spots. Lastly, blockchain technology is applied in the proposed solution to make machine-to-machine (M2M) communication more secure, reliable and trustworthy across IoT devices. The experimental results are also obtained by deploying a pilot project in Karachi, Pakistan. The real-time dashboard is also obtained to demonstrate the daily statistics of the waste collection and performance of the waste vehicles. The results indicate the successful implementation of SSWMS to achieve real-time tracking, intelligent identification of waste bins, trash weighing, and keeping tabs on waste collection from dump spots using geofencing. In future, the blockchain-enabled VANETs can be applied for route management, intelligent transportation and fleet management systems (FMS) due to the inherent characteristics of blockchain and IoT.

INDEX TERMS Blockchain, distributed ledger technology, fleet management, geo-fencing, Industrial Internet of Things, Internet of Things, machine to machine, solid waste management, trash weighing, ultra-high frequency, VANET.

I. INTRODUCTION

The motivation of this study is to propose an economical solution for urban areas and developing nations to manage and control solid waste management activities for smart administration. The proposed system will help urban areas to be clean and green through the timely waste collection. Several challenges are associated with the traditional systems of developing countries having densely populated cities, which are considered economic hubs or the backbone of any country. Solid waste management is one of the most pressing issues for these cities. Due to a lack of financial and technological resources, municipal authorities are failing to manage solid waste safely and sustainably. For example, Karachi is one of the world's most densely populated cities. Since Pakistan's independence, Karachi has been the focus of

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commercial and financial offices, first as the country's capital and then as a provincial capital. Solid waste management is a critical issue in the city [2]. The lack of resources raises the fundamental challenge of solid waste management. Every day, the city of Karachi creates approximately 16,000 tons of solid trash. It raises the fundamental challenge of how to offer high-quality public service despite budget and skill constraints [1]. The volume of waste generation across different cities of the country (Pakistan) is illustrated in Figure 1, which is steadily rising over time [3].

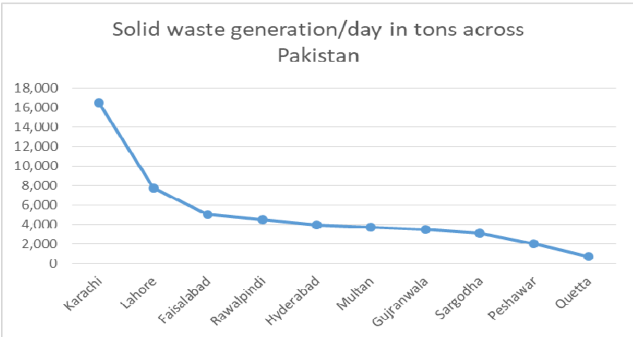


FIGURE 1. Statistics of waste generation across the developing country (Pakistan).

The current inefficient solid waste management procedures necessitate the creation of a solid waste management mechanism. The critical areas of worry are lack of planning, improper technology, and poor management. The waste management boards are taking action to solve these issues daily [4]. They collect solid waste during the monsoon season to minimize flooding. However, they can improve the current system's efficiency by having a smart solid waste management system (SSWMS). It can also effectively control the diseases and spread of viruses to create a good environment through timely waste collection and disposal. Due to the lack of literacy and public awareness in developing countries, solid waste management has become a life-threatening issue. Unlike developed countries, waste management is more like resource management since the waste is appropriately collected, segregated, and recycled [5].

Nonetheless, solid waste management is still a significant problem the world faces. According to a recent study, 1.3 billion tons of solid waste are generated annually [6]. The statistics for the year 2025 are being predicted, showing that this figure will reach 2.2 billion tons. The developing countries will face a severe waste management problem in the following decades, per estimates. The expenditures on waste handling will become $375.5 billion per year. These statistics urge the urge to develop an SSWMS for the cities of developing countries. Manual waste management processes use ordinary bins and vehicles. Trash is collected at fixed time intervals from the bins. However, as the city's population increases, more trash is produced than collected by vehicles. Overflowing trash bins force the citizens to put trash without any bins. The windy weather of the city makes the trash fly everywhere and thus creating an unhealthy situation. Combinations of biodegradable garbage can produce harmful gases like methane [7]. Bad odours and toxic gases can be prevented when bins are emptied on time, resulting in a healthier atmosphere. On the other hand, if solid wastes are supposed to be collected periodically, it wastes time, fuel, and labor if the trash cans are empty [8].

Waste Management in developing countries is always challenging due to continuous waste generation. The waste management system, especially solid waste management, is being collapsed and mishandled in developing countries. The lack of waste management not only imposes a burden on the local budget or economy but also affects the environment for human beings. Therefore, the objective of this study is to determine how to control waste systematically. Using advanced technologies can bring innovation in obsoleted management and collection process.

There is a need for a cost-effective solution for SSWMS. As a result, this study explored a broad range of SSWMS themes to ensure that the system can be employed in real-world scenarios. This study has the following contributions:

- Remote waste monitoring.
- Fleet management of waste vehicles.
- The proposed geofencing mechanism monitors whether the vehicle follows the assigned route and collects waste on time.
- Trash vehicle weighing upon arrival at the dump (kundi) to maintain trash weight record.
- A Mobile application is developed to facilitate residential and commercial users indicating uncollected trash.
- The system can tell which area needs more collection slots using an algorithm.

The malpractices are being observed in this dilemma of waste collection where cost is involved. Therefore a tamper-proof and transparent blockchain-enabled VANET system is proposed to ensure data security and transparency throughout the systematic process. It will reduce the overheads of waste collection and tracking and also helps to contribute to local and global economies by having secure and legitimate calculated garbage on daily waste.

This study provides an economic framework and architecture for solid waste management. It contributes to the advancement of IoT and blockchain to depict the smart use of IoT-enabling technologies for the problems of urban areas. Integrating blockchain and IoT can solve many administration and security issues in developing countries. The advancement of IoT and its implementation in different sectors such as Healthcare, finance, digitalization, textile, oil and gas can be beneficial for the economic growth of the nations. This study is further extended to discuss IoT security issues and blockchain solutions in smart waste management.

The automation of solid waste management processes is achieved in this study by implementing the proposed solution at the district level for experimental purposes. The solution came out to be very economical against the implementation cost and benefits. Real-time information is also obtained to see the complete fleet of waste vehicles and to identify how many bins are collected till time. The feedback and real-time information are also discussed in later sections, which has amazed the administration's concerns.

The sections of this study are classified as follows: section II demonstrates the background of the paper. Section III presents a complete literature review and technologies used to develop SSWMS. Section IV demonstrates the methodology and implementation details. Section V comprises analysis and discussion, and lastly, section VI concludes the framework and highlights future directions.

II. BACKGROUND

A. DISTRIBUTED LEDGER TECHNOLOGY (DLT)

The DLT has been investigated in depth after the emergence of blockchain and digital currency, for example, bitcoin. The DLT provides cutting-edge benefits in various sectors such as IoT, IIoT, finance, agriculture, supply chain, etc. The DLT provides a decentralized framework for sharing data and transactions without depending on third parties. DLT emphasizes distributed databases which are also known as shared ledgers. These ledgers and databases are hard to tamper with and modify. The phenomenon of information exchange in DLT is demonstrated in Figure 2.

The significance of DLT in blockchain-enabled VANETs is vital for information trading across components such as RSUs, vehicles and the cloud. The inherent characteristics of DLT for VANETs provide distributed shared ledger of geo information and a handshaking mechanism across entities. The implementation of DLT in VANETs has eliminated the dependency on centralized servers. The proposed framework is discussed later in this study.

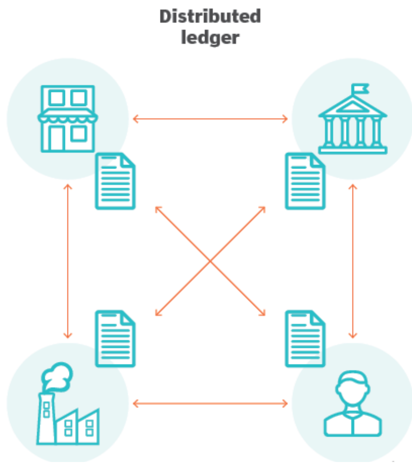


FIGURE 2. Overview of DLT.

FIGURE 3. Overview of blockchain technology.

B. BLOCKCHAIN

The concept of blockchain is self-determined in light of bitcoin. The sequential connection of blocks and corresponding transactional information held by blocks represents the architecture of bitcoin. The hash of each block is used as part of the next block's header, making it immutable and tamper-proof. The sequential chain of blocks helps to create a network where nodes compete with each other to mine a block. Each node has a copy of the ledger. Therefore, any change and modification can be traced easily in the blockchain network. The overview of blockchain technology and connection of blocks is illustrated in Figure 3.

C. INTERNET OF THINGS (IOT)

The IoT is one of the growing technologies, and thousands of research are available on it. The analogy of IoT is self-explanatory and refers to the network of devices. The term 'things' is used for the IoT devices that communicate and work as a team in a network to derive and transfer meaningful information. The implementation of IoT in different sectors is also shown in Figure 4. The devices are responsible for handshaking and hands-off in an IoT network. The research community in various sectors highlights the use of IoT. Healthcare is one of the top research areas in the realm of IoT. Similarly, its implementation in the industry is known as IIoT. The existing research depicts that 75 billion devices will be connected by 2026. Since the emergence of IoT, the limitations such as security, data overhead, storage and connectivity are also being addressed by researchers. The composition of blockchain and IoT is a growing topic for researchers. The support of blockchain to IoT is also essential because, as per predictions, the IoT network will be collapsed when it reaches billions of connected things. Therefore a stable platform like blockchain is required to provide support and stability to IoT and IIoT.

D. MACHINE TO MACHINE (M2M)

The M2M communication deals with correspondence across entities like IoT devices, RSUs, vehicles, infrastructure and other things. The concept of M2M is to eliminate human involvement in correspondence across entities.

The things should be smart enough to communicate and take informed and uninformed decisions based on the perceived information.

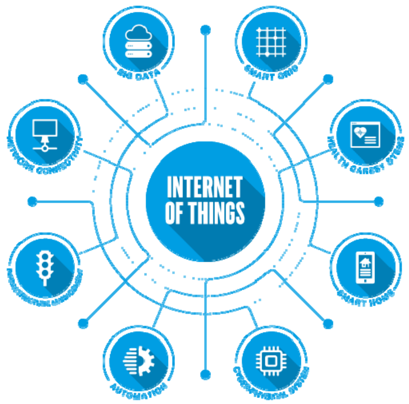


FIGURE 4. Overview of IoT and related sectors.

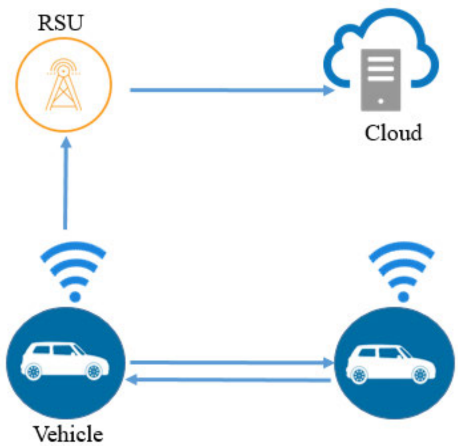


FIGURE 5. Overview of VANETs.

The dynamic resource-sharing mechanism is the beauty of the M2M model, where devices share resources with mutual consensus. M2M plays a critical role across vehicle devices and UHF readers in the proposed methodology. The communication is being achieved based on the M2M model. This model is also being applied to IoT, IIoT and sensor-based environments.

One example of M2M communication is the provision of the static IP address on mobile devices. The mobile operators provide routers with sim cards to provide mobility of static IP on routers through GSM/LTE communication. This provision brought innovation to the telecommunication sector.

E. VEHICULAR ADHOC NETWORKS (VANETS)

The traditional concept of VANETs emphasizes the need for the internet of vehicles (IoV). The IoV is the network where vehicles communicate with each other using IoT devices for information sharing. The communication in VANETs is divided across entities such as vehicles, RSUs, infrastructure, mobile devices, smartwatches, and other things as demonstrated in Figure 5. The concept of VANETs is emerged to handle problems like accidents, road blockage, collision detection, object detection, real-time location sharing, assets transportation and management. It provides a vehicle network for real-time geo location sharing and transmission. It also facilitates drives for road safety mechanisms by providing immediate alerts. The VANETs not only facilitate drivers but also facilitates fleet owners to be aware of the transit of assets and to make decisions in emergencies based on perceived information. The spoofing and security attacks make VANET architecture vulnerable. Therefore the composition of blockchain and VANET is adopted to eliminate such risks.

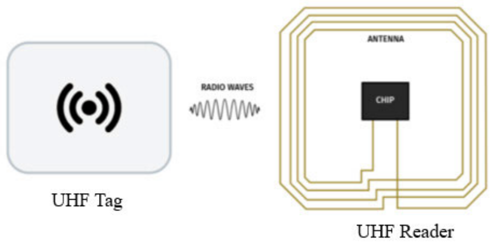


FIGURE 6. UHF reader and tag.

F. ULTRA-HIGH FREQUENCY (UHF)

The UHF is one of the most advanced wireless communication technologies that help to read data from a longer distance. This technology has various applications for example, gate pass management, inventory management, asset management, driver identification, etc.

UHF readers and tags are the two major components for implementing UHF technology. UHF readers are responsible for reading data wirelessly from the UHF tags. The UHF tags are readable from 5 to 20 meters, depending on the antennas used in the readers. Figure 6 demonstrates the communication of the UHF tag and UHF reader.

The UHF technology is widely used for headcount, asset management and positioning systems. Therefore, implementing this technology made the proposed system more robust regarding the timely collection of bins and their reporting. The passive UHF tags are used in the proposed system so that upon arrival of the vehicle UHF reader detects it and reports it accordingly using an IoT device.

G. BLOCKCHAIN ENABLED VANET

Blockchain is also referred to as a DLT. The blocks in the blockchain hold the information in hashed form. Therefore, it is nearly impossible to modify information because it will result in chain breaking. Similarly, bitcoin is one of today's digital currencies, which is also based on DLT. In 2008 the concept of bitcoin was presented in a white paper by Satoshi Nakamoto. The implementation of DLT is being emerged in various sectors due to its characteristics. Therefore, it is applied in this study for secure and reliable data transmission across vehicles, roadside units (RSU) and infrastructure in realm of blockchain network as shown in Figure 7.

VANET is one of the significant components and sub-domain of IoT. The ad-hoc network of vehicles helps transmit real-time fleet location to the fleet owners using GSM/GPRS connectivity. The transmitted data is used to make informed and strategic trip and journey management decisions. The components of VANETs are vehicles, RSU, and infrastructure. The communication across these entities helps to achieve an ad-hoc network for data sharing. The benefits of VANETs are being utilized by oil marketing companies, logistics, insurance and other sectors. Researchers in intelligent transportation are also targeting the implementation of VANET in multiple domains.

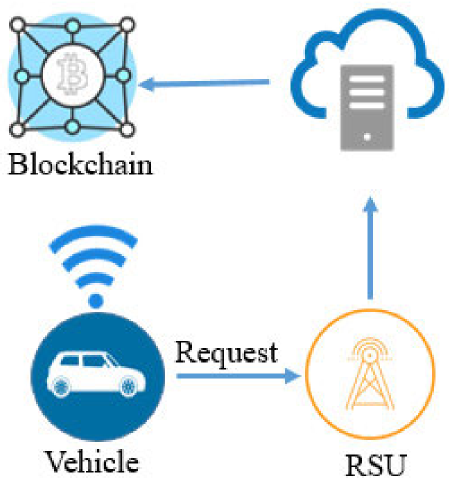


FIGURE 7. Components of blockchain-enabled VANETs.

FIGURE 8. Overview of Geo-Fencing.

H. GEO-FENCING

The geo-fencing techniques provide users with virtual boundaries over google maps for the entry and exit alert notifications of vehicles. Similarly, this technique is used to create dump spots, yards, and parking areas. Circular and polygonal fences are used in this study to create virtual boundaries over the map, as mentioned in following Figure 8.

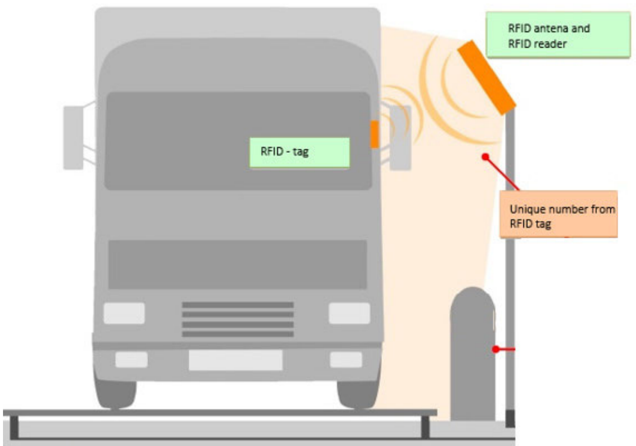


FIGURE 9. Vehicle Identification System.

I. VEHICLE IDENTIFICATION SYSTEM

The vehicle identification system (VIS) is one example of UHF communication. The VIS UHF tag is issued to the vehicle owners to place on the windscreen. The UHF readers are installed at the site and responsible for identifying the vehicle by reading the tags placed on the wind screen as mentioned in Figure 9. The access permission is granted by the server based on identifying the vehicle using UHF technology.

The composition of enabling blockchain technology with VANETs using UHF make the proposed system more secure, immutable, and reliable. However, blockchain-enabled VANET for SSWMS resolved all the management needs for waste collection and real-time waste monitoring.

III. LITERATURE REVIEW

Many researchers have worked on SSWMS utilizing technologies such as IoT, wireless sensor networks (WSN), machine learning (ML) and artificial intelligence (AI). Adam et al. [9] have worked on waste container usage using IoT and WSN. Smart bins use ultrasonic sensors to communicate information about how full they are and when they need to be emptied. Waste vehicles will be informed about full garbage containers' location through GPS. The proposed system helps to indicate when a garbage container needs to be emptied. However, trash vehicle fleet management and determining the optimal path to reach smart bins are not addressed. Similarly, existing research also emphasizes detecting waste levels using algorithms instead of having a proper system to collect waste on it using waste vehicles.

Vishnu et al. [10] have created a smart city IoT-based SWMS to improve the efficiency of conventional SWMSS. Public Bin Level Monitoring Unit (PBLMU) and Household Bin Level Monitoring Unit (HBLMU) are the two types of end sensor nodes proposed by the authors for tracking bins in public and household regions. Experimental results show the system can work for more than 70 days without external power if the battery is fully charged. The proposed

IoT-enabled solid waste management system efficiently monitors real-time waste bin detection in advanced cities. However, route optimization and security for trash vehicles have not been implemented.

Chen et al. [11] have suggested an IoT-based SWMS for timely trash collection. The authors employed an infrared sensor instead of an ultrasonic sensor to monitor trash levels. Furthermore, the authors used a gas sensor and a 3-axis compass to identify a foul odor and an irregular open. The experimental results show that infrared sensors are more stable and valuable when a contactless switch is used to open the bin lid. The proposed system has efficiently managed trash collection on the residential user side. However, features like fleet management and workforce allocation of trash trucks have not been discussed in detail. Hong et al. [12] designed an IoT-based smart waste management system to reduce food waste. Smart bins in the proposed system communicate with one another via wireless mesh networks to manage bin malfunctioning. According to the findings, the average amount of food waste in the implementing city has lowered by 33%; nevertheless, the system can be made more adaptable and scalable so that it may be utilized internationally.

Suresh et al. [13] designed an IoT-based SWMS prototype for garbage pickup and monitoring. IoT, GPS, and SMS modules are included in the prototype. The experimental findings demonstrate the prototype's success. However, considerable work remains to be done to apply the system in a real-world setting. In addition to using technologies to collect waste, some researchers have focused on segregating and recycling household waste to make it valuable to society. Dubey et al. [7] have presented an IoT-based SWMSS for smart cities that focuses on waste monitoring as well as trash separation. They employed ML techniques (KNN) to accomplish this. The experimental results show 93.3% accuracy using this technique. Although the proposed model separates organic and inorganic waste to some extent, features such as trash collection and transportation to disposal are not addressed in detail.

Bharadwaj et al. [14] have upgraded traditional SWMS for smart cities by incorporating IoT technologies. Using the LoRa technology, smart bin data is sent to the gateway, cloud, and the internet using message queuing telemetry transport (MQTT) protocol. Although the system covers significant components, i.e., segregation, monitoring and collection of a SWMS, segregation relies upon the user's responsibility.

Bakhshi and Ahmed [15] have designed a smart bin-based IoT-based SWMS for waste monitoring and collection. Decision tree prediction algorithm is used to predict bin collection patterns; afterward, waste management routing algorithm is used for route optimization of trash trucks. ML approaches help to predict trash collection trends, resulting in cost and time savings of up to 46% and 18%, respectively.

To determine trash level, Khoa et al. [16] used a low-cost single microcontroller board with an ultrasonic sensor and LoRa E32 technology to relay this information to the authorities. Based on past input data, ML predicts the likelihood of collecting waste. The sigmoid function is used for prediction, while Dijkstra's algorithm is used for route optimization. Profits and an optimal number of trash workers are shown in the real-world application. The Table 1 depicts the comparison of the literature review with the proposed SWMS.

The management, transportation and careful handling of hazardous waste for China are proposed by researchers using a blockchain enabling framework [17]. Furthermore, researchers also consider the hospital waste management system due to its hazardous nature using blockchain technology [18]. The research community also targets blockchain-based waste recycling theories [19].

Waste management is also used as a case study in advanced research to emphasize the potential of blockchain and IoT for waste management [20]. The systematic literature review is also conducted by researchers using 27 studies highlighting the adoption of blockchain for waste management and other sectors [21]. Researchers [22] have also surveyed IoT-enabled waste management models for smart cities. The key aspects of IoT-enabled waste management models are timely waste collection, journey management, transportation, and recycling certain types of waste. Intelligent transportation adds to the dynamic waste collection since it uses smart vehicles. A set of steps are being proposed to make the process of collecting trash and disposing of it. Some researchers have also worked on low-power IoT nodes for SWMS [23], emphasizing energy-saving and prolonging battery life. Others have used sensor technology to identify the quantity of a waste container getting emptied, as collection dumpers do not always empty containers correctly [24].

It is challenging to classify wastes in general. The commercial to domestic waste consists of ashes, biomedical, construction, industrial, sewage, organic, inorganic, and hazardous waste [25]. This study focuses on solid waste management since it is the most common type of waste in urban areas. It has been demonstrated in several smart cities, like England, Germany and Hamburg, that properly implementing SWMS provides numerous benefits [26].

In Table 2, the IoT-based security issues are highlighted in which node security and discovery are discussed in the realm of IP spoofing, which can be eliminated by using elliptic curve cryptographic techniques endorsed by the blockchain network. The attacks like man-in-the-middle and denial of service are also mentioned in Table 2 to highlight the vulnerabilities of middleware security, and a solution using asymmetric key management for node-to-node security is also considered. Similarly, privacy, authentication and authorization issues are highlighted because of M2M communication to emphasize the use of smart contracts and trust chain mechanism in which identification of the node is preserved, and a set of rules is defined to ensure compliance and security.

The security of the proposed solid waste management system is critically important due to its implication at a

TABLE 1. Comparison of studies with the proposed solution.

Study	Technologies	Features								Remarks
		1	2	3	4	5	6	7	8	
Adam et al. [9]	IoT, GPS, and WSN	✓	✗	✗	✓	✓	✓	✗	✗	Smart bins have been implemented for smart cities; however, more features could be added to implement the system on a wide scale.
Vishnu et al. [10]	IoT, MQTT, Wi-Fi	✓	✗	✗	✓	✗	✓	✗	✗	An IoT-enabled smart waste management system with a hybrid network architecture for public and private garbage monitoring, a solar module to extend system life, a GPS module to track trash bins, and an intelligent GUI to check the state of every trash bin has been built.
Chen et al. [11]	IoT, MQTT, Wi-Fi, LoRa	✓	✗	✗	✓	✓	✗	✓	✗	Not only does the proposed smart garbage bin detect the amount of waste, but it also detects the foul odor. Because the waste in the containers is not smooth, infrared instead of ultrasonic is recommended for waste detection in this system.
Hong et al. [12]	IoT, RFID,Wifi	✓	✓	✗	✓	✓	✓	✓	✗	Residents are encouraged to reduce their food waste through an adaptive user-oriented fee policy, and IoT-based services are supplied to improve the disposal and pickup procedures. The proposed system's energy efficiency demonstrates a 16% energy savings and a 33% reduction in food waste.
Suresh et al. [13]	IoT	✓	✗	✗	✓	✗	✗	✗	✗	A prototype of an IoT-based SWMS has successfully monitored waste levels and ensured trash collection. The paper is full of useful information for academics; however, it lacks execution.
Dubey et al. [7]	IoT, ML, IR sensor, actuator, ultrasonic sensor, gas sensor	✓	✗	✗	✓	✗	✗	✗	✗	Based on ML and IoT techniques, the authors suggest a smart trashcan to segregate household waste and repurpose the waste for generating bio compost.
Bharadwaj et al. [14]	IoT, MQTT, LoRa, ZigBee, Bluetooth, Wi-Fi	✓	✗	✗	✓	✗	✓	✓	✗	A complete model of IoT-based SWMS has been designed including system architecture, block architecture and protocol stack.
Bakhshi et al. [15]	IoT, Raspberry Pi, Ultrasonic sensor	✓	✓	✗	✓	✓	✓	✗	✗	Smart cities will benefit from an IoT-based SWMS that includes functions such as anticipating garbage collection patterns and optimizing waste truck routes. The method enables administrative officials to keep track of garbage output and make decisions such as installing larger bins in specific areas.
Khoa et al. [16]	IoT, ML, LoRa	✓	✓	✗	✓	✓	✓	✓	✗	A low-cost, energy-efficient optimal garbage collection system based on IoT has been designed.
Rahman et al. [17]	IoT, ML, Bluetooth	✓	✗	✗	✓	✗	✓	✓	✗	It has been proposed to develop a real-time SWMS based on deep learning and IoT ideas. A Raspberry Pi and camera module are used in an architectural waste classification model. A microprocessor and various sensors are used in smart garbage cans to monitor trash in real time. The proposed CNN model, ultrasonic sensor, and load measurement sensor data calculation approach is also provided.
Proposed SWMS	Blockchain, IoT, VANET, UHF	✓	✓	✓	✓	✓	✓	✓	✓	For smart and developing cities, a cutting-edge blockchain enabled VANET based SWMS is developed to efficiently monitor and collect waste. Geo-fencing, route optimization, driver allocation, report production, and other unique approaches to utilize fleet management technologies for trash trucks are used.

1: Trash Monitoring 2: Fleet Management 3: Geo-Fencing 4: System Architecture 5: Route optimization 6: Real-world Implementation 7: Mobile App 8: Workforce Assignment

TABLE 2. Security issues, implications and blockchain solutions.

IoT Security Issue	Implication	Blockchain Solution
Node Security and Discovery	Network spoofing	Blockchain enabled Elliptic Curve Cryptography (ECC) based authentication
Man in the Middle and Denial of Service Attack	Middleware security	Symmetric and asymmetric key management
Data Authentication, Authorization and Privacy	IoT devices communication and handshaking	Ethereum based smart contracts
Node Identity and Access Management	Session establishment and insecure interfaces	Blockchain based trust chain mechanism

TABLE 3. Cost comparison table for SSWMS.

Branded Solution	Hardware Components	Estimated Cost
Omnicomm Russia	OBD IoT Device, BLE Beacon	$365
Totemtech China	3G/4G GPS Tracking Device, RFID Reader and RFID Tag	$189
Teltonika Lithuania	Tracking Device and BLE Beacon	$180
Proposed Solution	Data Controller, UHF Reader, UHF Tag	$136

larger level. Therefore, IoT-based attacks are also considered while proposing a state-of-the-art system for waste management. The malicious insider attacks are prevented using the proposed M2M-based architecture. The man-in-the-middle attack is handled by using an identity management system for the data controller, UHF reader and RSU. Therefore this attack is eliminated because of hashing-based identities of the things for M2M communication. Similarly, network spoofing is another critical attack in an IoT environment and is also prevented using an elliptic curve cryptographic scheme for authentication across IoT devices. Furthermore, session hijacking and denial of service attack is also considered and prevented by using the public and private key mechanism in the VANET environment. Further, it is supported by a blockchain network.

Table 3 consists of cost wise comparison of existing branded solutions of Russia, China and Lithuania providing on-board terminals, BLE beacons, RFID readers, tags and 4G devices for solid waste management. The cost of all these solutions is higher compared to the proposed solution as highlighted in Table 3.

Table 4 is obtained based on an extensive analysis of existing and advanced research till 2022. The articles are analyzed with respect to the proposed technologies and hardware components. The limitations and research gap across articles are also identified and mentioned in Table 4.

IV. PROPOSED SMART SOLID WASTE MANAGEMENT SYSTEM

In an IoT ecosystem, smart items are connected via wired and wireless networks without the need for user participation. IoT devices are used to convert manual systems into digital ones, hence, improving quality of life and providing a clean and healthy environment for the future. If the garbage bin is not collected after it is full, it may overflow or create an unpleasant odor, putting public health at risk. Therefore, a smart SWMS is proposed in this study, which collects trash dynamically rather than at a set time. The following research questions are identified to drive effective smart solid waste management approaches based on extensive literature analysis.

1. How to achieve real-time tracking of solid waste vehicles?
2. How to detect waste bins and ensure timely collection of waste?
3. How to achieve secure data transmission across vehicles, waste bins and infrastructure?
4. How to systematically manage dump spots and yard locations for the assignment of waste vehicles for journey management?
5. How to automate the process of weighing waste at the yard and recycling plant?

In the proposed IoT-based SSWMS, the software includes mobile and web applications along with a dashboard that helps the user monitor trash levels, location of bins, assignment of vehicles to bin locations, route optimization of trash fleet, driver assignment, etc. The system can forecast collection intervals and optimize collection routes if it is aware of waste collection patterns. Furthermore, geofencing techniques determine which bins need frequent trash collection. Figure 10 illustrates the components and overview of an IoT-based SWMSS.

Figure 10 consists of three layers. The top layer demonstrates the physical infrastructure components in which the waste bin, vehicle, and trash area are involved. The middle layer highlights the IoT components that interact with each other to transmit real-time data. The IoT device receives the real-time UHF tag data detected by the UHF reader via the RS232 channel and then transmits it to the RSUs, which further uploads it to the blockchain network via LTE. The bottom layer demonstrates the application layer that represents the meaningful data in the form of a dashboard over the web and mobile application.

In the past few years, an escalation of research, discussions, and projects regarding the IoT has attracted the attention of practitioners. The aim is to propose a complete end-to-end solution for effective solid waste management using advanced technologies. The understanding and technical steps are outlined in this section based on our comprehension and focused research. The concepts of IoT are applied in the proposed methodology to ensure trust between nodes or devices and solve the pain points of M2M interfaces.

TABLE 4. Advanced research comparison and research gap identification.

Article	Hardware Components / Technologies	Limitations/Research Gap
Adam et al. [9]	Ultrasonic Sensor and Arduino	No industrial implementation is discussed in realm of fleet management and tracking Proposed hardware components are not secured Data security cannot be achieved
Vishnu et al. [10]	Lora WAN, Ultrasonic, MQTT, Wi-Fi	Complex hardware architecture Hypothetical conditions are used to validate concept instead of real time implementation Difficult to install and implement Fleet management and tracking is missing Low level implementation
Chen et al. [11]	Infrared, Gas Sensor, MQTT, Wi-Fi, LoRa	Hypothetical conditions are used to validate concept instead of real time implementation Difficult to install and implement due to complex hardware details No proof of concept is discussed for wider implementation Communication details are missing
Suresh et al. [13]	GPS, Ultrasonic Sensor and Arduino	Lacks in execution Hardware and technical specifications are missing No real-time detection
Bakhshi et al. [15]	Lora WAN, Ultrasonic, ESP, Firebase	Lacks in execution due to gateway installations at multiple locations Hardware and technical specifications are missing No real-time tracking and detection of bins
Sivakumar et al. [27]	CNN based Algorithms IoT Technologies	End to End Waste management using hardware implementation and specifications Live Tracking of Waste Vehicles Routing Algorithms Secure Data Transmission
Roy et al. [28]	IoT based Waste Bins Routing Algorithms Smart Bins Genetic Al (Ant Colony Optimization)	End to End Waste management using hardware implementation and specifications Live Tracking of Waste Vehicles Secure Data Transmission Experimental Analysis based on IoT Data
Anjum et al. [29]	IoT Information Communication Smart Bin Smart Truck Work Server	Expensive Solution for Developing Countries Secure Data Transmission
Venkatesh et al. [30]	Ultrasonic Sensor Micro Controller GSM	End to End Waste management using hardware implementation and specifications Live Tracking of Waste Vehicles Routing and Scheduling Secure Data Transmission Experimental Analysis Non Rugged
Bamakan et al. [19]	Blockchain Technology	Systematic Literature Review only addressed the challenges related to Healthcare
Sen Gupta et al. [31]	Waste Segregation Algorithm Optimized Routing Algorithm Blockchain and Smart Contracts	End to End Waste management using hardware implementation and specifications Secure Data Transmission Experimental Analysis No Framework / Architecture for the implementation
Bhubalan et al. [32]	Blockchain Based Decentralized Application	End to End Waste management Solution
Setiawan et al. [33]	Data Science	No Experimental Analysis Experimental Assessment of Blockchain Framework
Proposed SWMS	Blockchain, IoT, VANET, UHF	For smart and developing cities, a cutting-edge blockchain enabled VANET based SWMS is developed to efficiently monitor and collect waste. Geo-fencing, route optimization, driver allocation, report production, and other unique approaches to utilize fleet management technologies for trash trucks are used.

Traditional waste management processes rely heavily on manually recording the data instead of machine interfaces.

Similarly, the techniques of blockchain-enabled VANET are applied for vehicles as mobile nodes, which encompasses vehicle-to-vehicle (V2V) communication for enhancing the safety of waste vehicles (e.g., collision avoidance, geo-fencing, route management) and comfort (e.g., toll payment, locating dump spots). Secure data transmission is achieved using a blockchain network. On the other hand, UHF technology is applied to detect waste bins and ensure timely waste

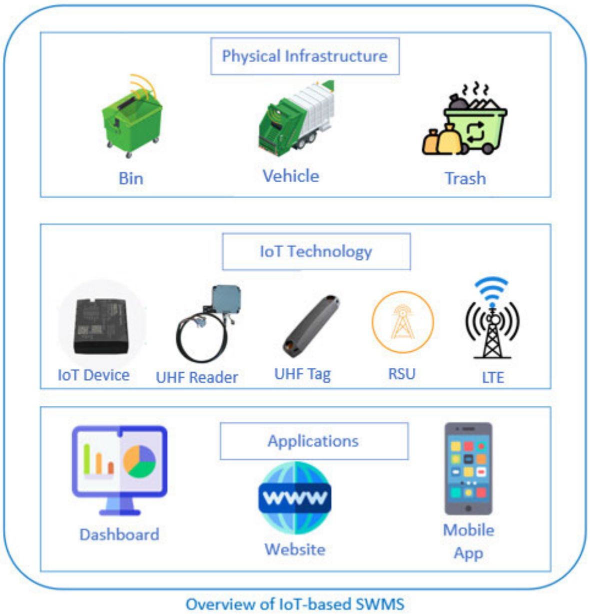


FIGURE 10. Overview of IoT-based SSWMS.

collection automatically. The proposed end-to-end solution comprises the automation of the following waste collection and management processes:

1. The waste collection and management process for the vehicles (Compactors) is responsible for collecting waste from the installed waste bins at multiple locations and bringing the collected waste to the yard.
2. The fleet management process for the vehicles is responsible for collecting waste from specified dump spots or home locations and transferring it to the waste yard.
3. The process of weighing trash at the waste yard is used for the further proceedings of selling and recycling.

The proposed methodology is divided into the following five sub-sections to answer the highlighted research questions:

A. HOW TO ACHIEVE REAL-TIME TRACKING OF SOLID WASTE VEHICLES?

There are the following steps to achieve real-time tracking of solid waste vehicles. The IoT device is proposed in this sub-section, which acts as a tracker for real-time data transmission. The data transmission takes place using a Sim card having GSM/GPRS connectivity. The proposed devices for the transmission store the geo-coordinates and other tracking-related parameters. The data transmission details are discussed later in sub-section C.

The first step is installing an IoT device with GPS and GSM/GPRS features into the compactor or waste vehicles. The compactor is one type of waste vehicle that collects waste bins from multiple locations. The proposed IoT device is equipped with internal high-gain GSM and external GNSS antennas to collect device coordinates and other valuable data to transfer via the GSM network to other entities. The proposed device is suitable for IoT-based applications where end users require real-time tracking. It can provide complete real-time information of any vehicle or object, for example, ignition status, engine status, fuel status, green driving and much more. The proposed device can benefit oil marketing companies, logistics and fleet owners. The features and overview of the IoT device are shown in Figure 11.

The proposed IoT device can be installed on the vehicle's dashboard, and it can also be placed over the metal due to its magnetic feature. Figure 12 demonstrates the installation and data transmission using GSM/GPRS connectivity. It is also highlighted that the GPS antennas are installed to capture the real-time location of the device installed over the vehicle.

The software prototype is also designed to understand its implementation better. Figure 13 illustrates how waste vehicles will display on google maps if we install the device into the solid waste vehicles. The results section further demonstrates the received data and tracking log information.

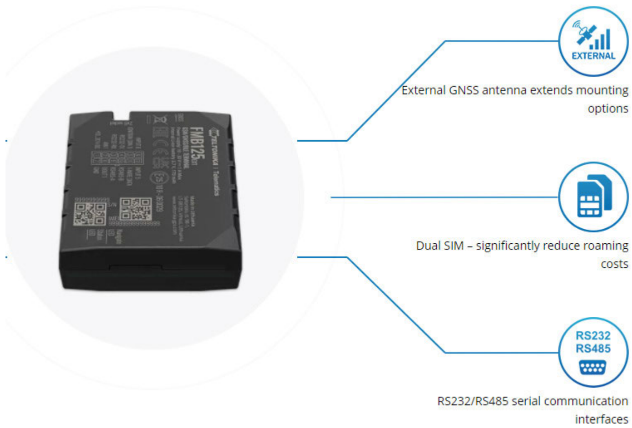


FIGURE 11. IoT device and its features.

B. HOW TO DETECT WASTE BINS AND ENSURE TIMELY COLLECTION OF WASTE?

The following steps automatically detect waste bins using UHF technology and IoT device. The UHF reader and tag are proposed in this subsection to identify waste bins by compactors at the time of waste collection. The IoT device is connected to a UHF reader via an RS232 connection. UHF reader is responsible for reading tag data within proximity and transferring it to the IoT device. IoT device then transmits the received UHF data to the ad-hoc network. Data communication is discussed in detail in the next sub-section.

The first step is installing a UHF reader onto the compactor and connecting it to the IoT device via an RS-232 connection, as mentioned in Figure 14. The proposed UHF reader is an industrial grade, durable and sturdy. It can work in harsh industrial environments having electromagnetic interferences, dust, water droplets, vibration, noise and high temperature. The embedded chip of the proposed reader has built-in high-performance label recognition algorithms

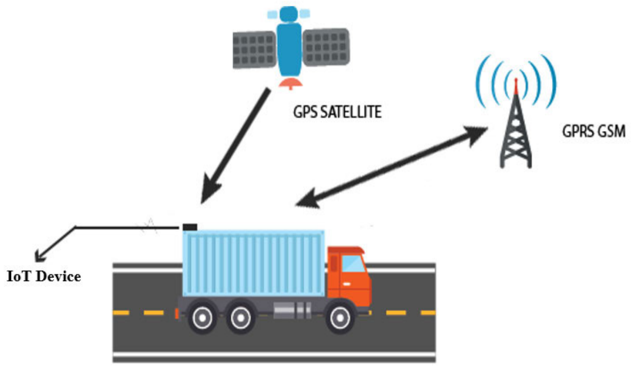


FIGURE 12. IoT device installation and data transmission.

FIGURE 13. Real-time tracking of solid waste vehicles.

for superior reading performance. It further supports standard interfaces like RS-232 for its connectivity with other devices.

The RF output power of proposed reader is adjustable, and the reading distance can be flexibly controlled within a range of 30mm-2000mm. The indicators like buzzer and LED are also embedded in to the reader. The technical UHF specifications of proposed reader are mentioned in following Table 5.

Figure 15 and 16 demonstrates the installation and connectivity of the UHF reader and IoT device onto the compactor. The compactor can collect waste bins using mechanical part of compactor installed at the back of the vehicle as emphasized in the following figure.

The second step is to install UHF tags on waste bins to be detected by the UHF reader installed at the compactor. The installation of tags on waste bins is much easier, as illustrated in Figure 17.

The proposed UHF tag is suitable for Asian and European frequencies to achieve the best reading effect. It has a linear polarization design with ultra-specific directions. It can be used for supply chain management, warehousing logistics, luggage and mail management and other logistics tracking, commodity labelling, and other fields. The design and overview of the UHF metal tag are shown in Figure 18. The technical specifications of the proposed UHF tag are as mentioned in Table 6. The complete overview of bin detection and data transmission from IoT devices to RSU and infrastructure is shown in Figure 19. Figure 19 highlights how the UHF reader detects waste bin.

FIGURE 14. UHF Reader and IoT Device Connectivity.

TABLE 5. UHF reader specifications.

Parameters	Values
RFID Type	UHF RFID Chipset
Acceptable Ranges	~860 to ~868 MHZ
Frequency Type	Fixed
Antenna	3 DBi
Security Protocol	ISO Standard
UHF Range	0 to 3 meters

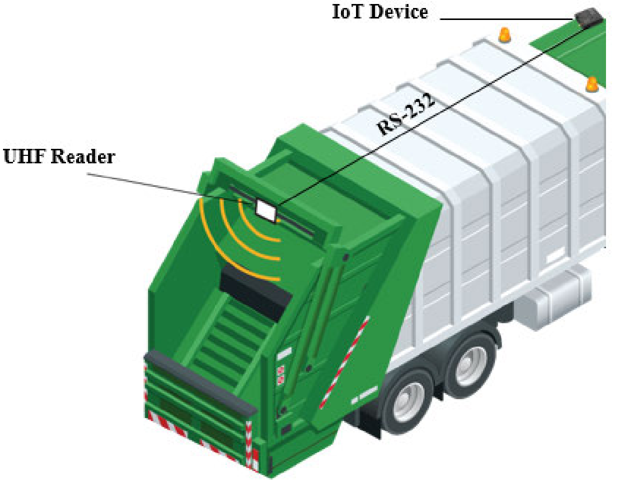


FIGURE 15. Installation of UHF reader and IoT Device.

The software prototype is also designed and demonstrates bin detection and displays detected bins over google-maps and geo-location. The following Figure 20 illustrates how waste bins appeared on google maps after the process of waste bin collection. The collected waste bins are differentiated using green color. Similarly, waste bins that are not entertained are marked in red, and orange color bins help identify bins displaced from their location. The flexible moving bins are also targeted in this article. The proposed system can detect the displaced bins by comparing the last detected location received from the IoT device and RSUs with the real-time location of the bin upon detection. In case of deviation from the last known location, the system highlights it with the orange color over the map for the user's information. The received data and logs are further demonstrated in the results section.

FIGURE 16. Real-time installed UHF reader.

FIGURE 17. Installation of UHF tag over bin.

FIGURE 18. UHF tag.

C. HOW TO ACHIEVE SECURE DATA TRANSMISSION ACROSS VEHICLES, WASTE BINS AND INFRASTRUCTURE?

This subsection is intended to demonstrate the use of blockchain-enabled VANET for solid waste management for secure data transmission. Secure communication across entities like IoT devices, UHF readers, UHF tags, RSUs and the cloud is achieved using the decentralized architecture of VANET. The aim is to achieve immutability and transparency by having tamper-proof data.

TABLE 6. UHF tag specifications.

Parameters	Values
Working mode	Read/write
Protection rating	IP55
Reading distance	4-10 M
Material	ABS
Working temperature	-35ºC to 85ºC
Installation method	Screw or Rivet, back adhesive, ties
Weight	20g

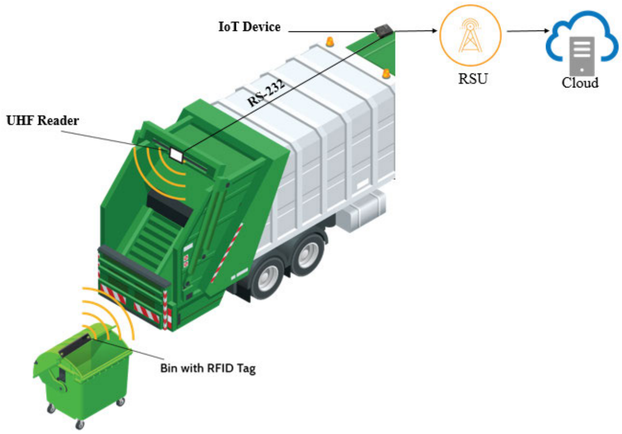


FIGURE 19. Waste bin detection and data transmission.

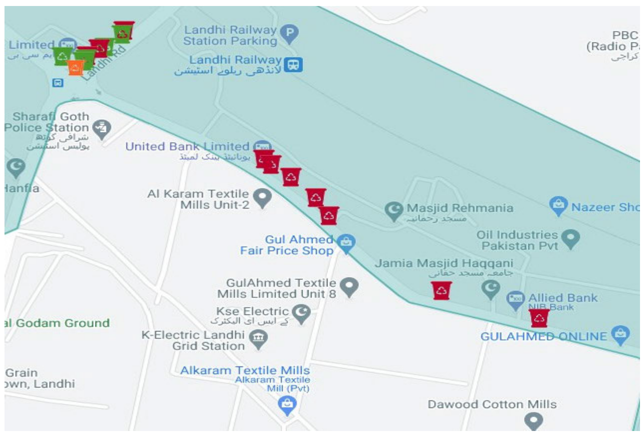


FIGURE 20. Real-time overview of waste bins collection.

Figure 21 highlights the components that play an essential role in the bottom layer highlighting the M2M connectivity of the UHF reader and IoT device to share encoded UHF data via the RS-232 channel. The second and third layer demonstrates the connectivity of the IoT device with the RSU for the data transmission to the infrastructure using the wireless channel. The last layer is the additional layer or blockchain network, which preserves all the received information over the network. The detailed demonstration of data transmission to the blockchain network is highlighted in Figure 22. The figure illustrates that RSU and the IoT device can send data

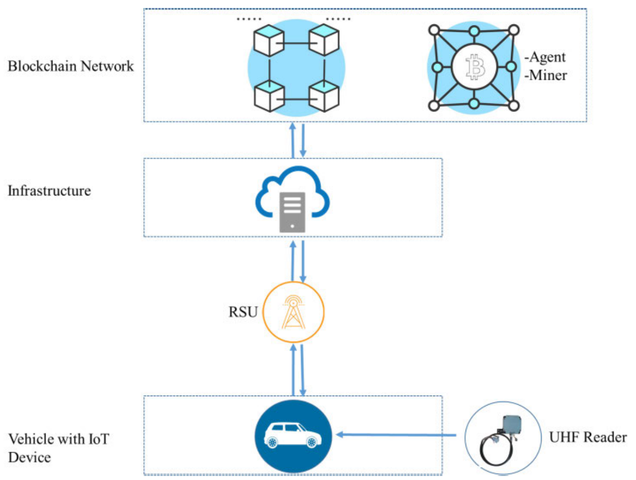


FIGURE 21. Components of blockchain-enabled ad-hoc network.

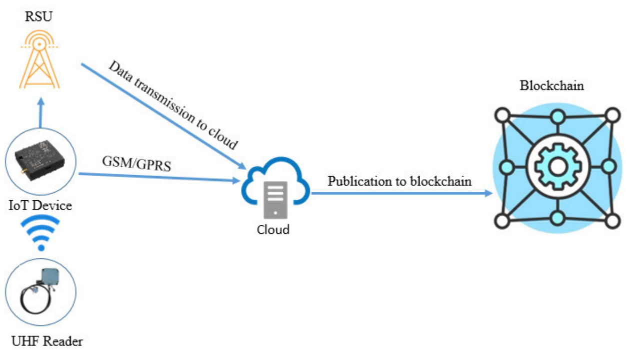


FIGURE 22. Blockchain-enabled VANET Architecture for SSWMS.

to the cloud using GSM/GPRS connectivity to create blocks over the blockchain network.

D. HOW TO SYSTEMATICALLY MANAGE DUMP SPOTS AND YARD LOCATIONS FOR THE ASSIGNMENT OF WASTE VEHICLES FOR JOURNEY MANAGEMENT?

This subsection of the proposed methodology emphasizes the implementation strategy of geofencing. The software-defined fences are created on google maps using circular and polygonal geometry. The objective is to mark and create virtual boundaries for the dump spots and yard locations. The dumping spot is also a waste area from where timely waste collection is mandatory for waste vehicles. On the other hand, the yard location is the designated area where collected waste is disposed. Similarly, the vehicle journey starts from the yard to assigned dump spots. The following Figure 23 represents the geofencing for dump spots and yards. This subsection is further divided into three steps, which are as follows:

The first step is to create fences for all the dump spots, yards, parking stations and rest areas, as shown in Figure 23.

The second step is to ensure the installation of an IoT device into the waste vehicles responsible for collecting waste from dump spots. The installed IoT device is responsible

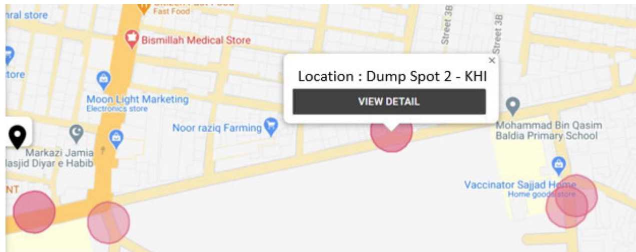


FIGURE 23. Creation of dump spots.

for transmitting geo-location to the server using the data communication model discussed in the above subsection.

The third step is to ensure the execution of an algorithm on the server for the distance calculation. The steps of the algorithm are dependent on two inputs. The first input is the real-time coordinates received from the IoT device, and the second is the list of geometrical fences. The following algorithm is implemented for the circular and polygonal checking of fences.

The continuous execution of the server's algorithm helps generate real-time logs for the fence, in and out. This data helps to identify which dump spots have been entertained by waste vehicles and how many are left in real-time. These logs are also helpful in determining the performance of the operator of the vehicles.

E. HOW TO AUTOMATE THE PROCESS OF WEIGHING WASTE AT THE YARD AND RECYCLING PLANT?

This subsection is intended to automate the vehicle identification process at the yard to measure waste. The end-to-end SSWMS is incomplete without the measurement of waste. Therefore, the identification of waste vehicles at the yard and integration of the weighing scale is achieved in this subsection. This subsection is further divided into three steps.

The first step is installing a UHF reader and IoT device at the weighing scale, as highlighted in Figure 24. As demonstrated in earlier sections, the installation and data communication of the UHF reader and IoT device will remain the same. The second step is placing a UHF tag on the vehicle's windscreen. This installation process is easy, just like placing a sticker on the screen.

The Figure 24 and Figure 25 demonstrates the real-time arrival of the vehicle at the weighbridge area and the placement of UHF readers for the real-time detection of the vehicle. Upon detection of the vehicle, the software reflects the weight on the software screen, as demonstrated in Figure 26. Furthermore, the proposed system also prompts users to insert driver information and view the vehicle's history for further verification and generation of weighing slips.

This subsection can also be considered for the future implementation of the proposed methodology for vehicle identification systems and integration with other interfaces.

There is no need to fabricate expensive vehicles with complex systems. The applied concepts of real-time

Algorithm 1 Circular and Polygonal Fence Checking

Input: P: x, y; Q: e1, e2; R: r1, r2; S: 500 (Given a point P, list of polygonal edges with coordinates x and y Q, list of circular fences R and radius S)

Output: T (Boolean variable true or false)

Where e1 → (A1, B2) → (A1x, A1y), (B1x, B1y)
r1 → (r1x, r1y)

Initialize Boolean Variable

```
1:  T ←false
2:  Foreach Q: Iteration 1
    Start
3:      If ((Py > B1y) or (Py < A1y) or (Px > max (A1x, B1x)))
            Start
4:          T ← true
            End
5:      Else if (Px < min (A1x, B1x)
            Start
6:          T ← false
            End
        Try
            Start
7:          EdgeSlope ← (B1y - A1y) / (B1x - A1x)
8:          Except InfinityError:
            End
        Try
            Start
9:          PointSlope← (Py - A1y) / (Px - A1x)
10:          Except InfinityError
            End
11:          If pointSlope >= edgeSlope
            Start
12:          T ← false
            End
    End
13: Foreach R: Iteration 1
    Start
14:          Distance ← Square root (r1x-Px) ^2+ (r1y – Py) ^2
15:          If Distance < S
            Start
16:          T ← true
            End
    End
17: Return T;
```

tracking, waste collection using UHF technology, and advanced geofencing techniques made the proposed system more robust to provide more benefits.

Real-time monitoring till waste measurement is achieved through a single window platform. The municipal authorities will also completely control all the activities of solid waste management in the field. Lastly, adding a vehicle identification system using UHF identification and weighing bridge integration makes it complete with all aspects of an end-to-end systematic waste collection and management system.

V. EXPERIMENTAL ANALYSIS

This section consists of results from implementing the proposed methodology based on blockchain-enabled VANET. Therefore, this section is further divided into the following sub-sections to represent results in the form of tables and figures for each question answered in the research methodology.

A. RESULTS OF REAL-TIME TRACKING USING IOT DEVICE

Using an IoT device is one of the most significant components of the proposed methodology. Therefore, it is essential to represent data in a table generated and transmitted by the device to the connected things.

Figure 27 represents the information of all the vehicles in which IoT device is installed. The highlighted vehicle is equipped with an IoT device and a UHF Reader. The displayed information consists of the following attributes:

- Category: It represents the vehicle type such as compactor, 3-wheeler, dumper, etc. As discussed in earlier sections, the compactor is used to collect waste bins.
- VRN: It shows the vehicle registration number (VRN) to identify the vehicle.
- Location: It represents the geo-location of the vehicle. The location name is derived by a geo-coding mechanism using coordinates.
- Date Time: It represents the GPS date and time to identify the track and real time location of the vehicle.
- Ignition: It represents the ignition status of the vehicle. The IoT device has the input capability to attach the vehicle's ignition wire to the device.
- Speed: The current speed information is also transmitted by the IoT device for its reflection into the system. Therefore, this feature can also be used to detect waste vehicle speed violations to comply with standard operating procedures.
- Status: The vehicle's current status is calculated using speed and ignition. It represents the vehicle's current status, such as moving, idle or parked.
- Alarm: This field is used to display alert notifications to the users.
- Mileage: The mileage attribute shows the vehicle's current odometer reading as it can also be integrated with the IoT device.
- Last Collected Bin: This attribute reflects the information received by the IoT device from the UHF reader for the real-time transmission of the detected waste bin number.

B. RESULTS OF WASTE BIN IDENTIFICATION AND TRACKING

This subsection demonstrates the results of waste bin identification and tracking data. Figure 28 represents the complete information of detected bins and a vehicle track using IoT device data. The following historical data is extracted against a single vehicle for the specified period.

FIGURE 24. Real-time image of dumping waste and UHF detection.

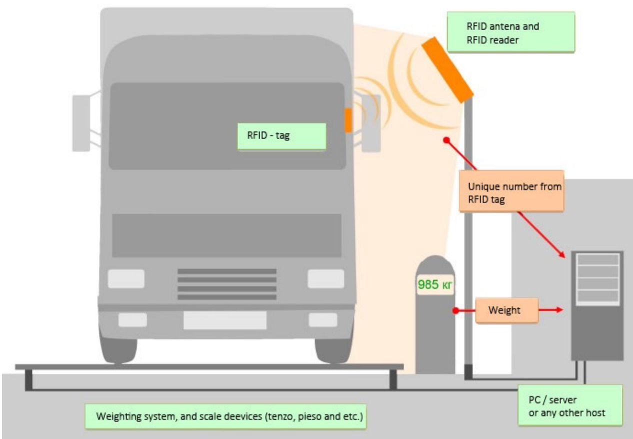


FIGURE 25. Vehicle identification and weighing scale integration.

Point A is highlighted in the Figure 28, indicating the waste vehicle's starting point. The blue polyline represents the track generated using geo coordinates transmitted by the IoT device. The highlighted green waste bins are those waste bins which are entertained by the waste vehicle during its trip starting from point A in the specified period.

C. RESULTS OF GEOFENCING IMPLEMENTATION

This sub-section represents the information gathered against the created fences. Figure 29 displays the list of vehicles that visited the selected dump spot for a specified duration.

The vehicle list mentions the date, time of entrance and exit. Similarly, logs and information can be extracted against any dump spot or vehicle for any duration. The server calculates the data based on real-time location and stores it in the storage database for further representation.

The Figure 30 demonstrates the smart features of the proposed mobile application, the help of which any commercial and residential user can log complain related to the trash along with a snapshot and current location for timely waste collection.

Figure 31 highlights the proposed workforce web portal, where information on signed-up users and received and catered complaints appear and entertained by users by assigning vehicles to each complaint. The dashboard consists of counts of signed-up users, the total number of complaints received the number of complaints entertained, the number of pending complaints and the count of satisfied users based on feedback and detailed information in data representation. The results obtained from the implementation of the proposed SSWMS are mentioned in Table 7, which represents the logs.

Date Time: The specified date time field represents the GPS time of the event. Further, this field gets converted into a cipher along with geo coordinates in the column of the geo-location cipher.

VRN: This is the vehicle registration number (VRN) for the identification of the vehicle

Reader ID: This is the UHF reader's assigned code mapped with the VRN.

Bin ID: This is the assigned code of the bin which is detected upon offloading of waste.

Reader and Bin Identity: This field represents the reader and bin pseudo-identity for secure data transmission. It is also used as the prefix for blockchain addresses.

Geo Coordinates: This field represents the location coordinates based on the GPS data.

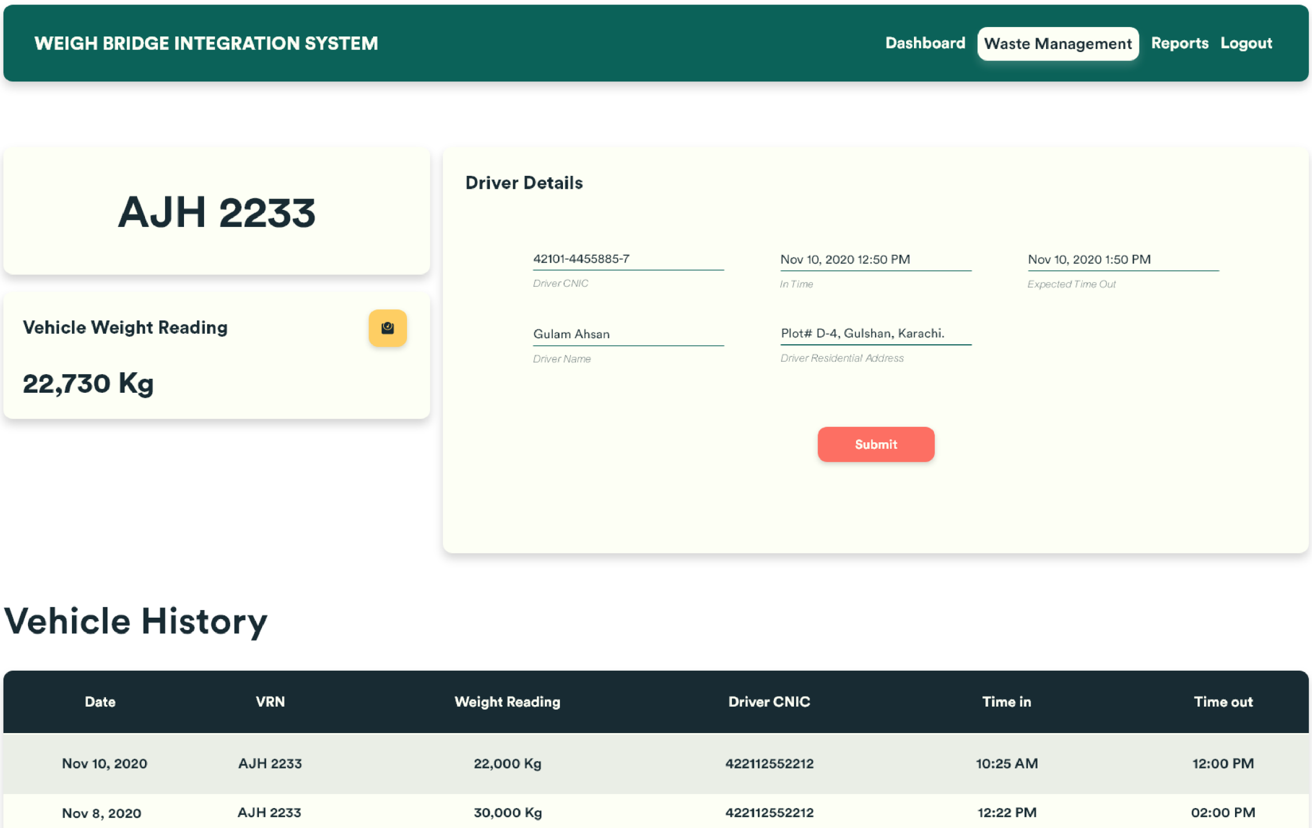
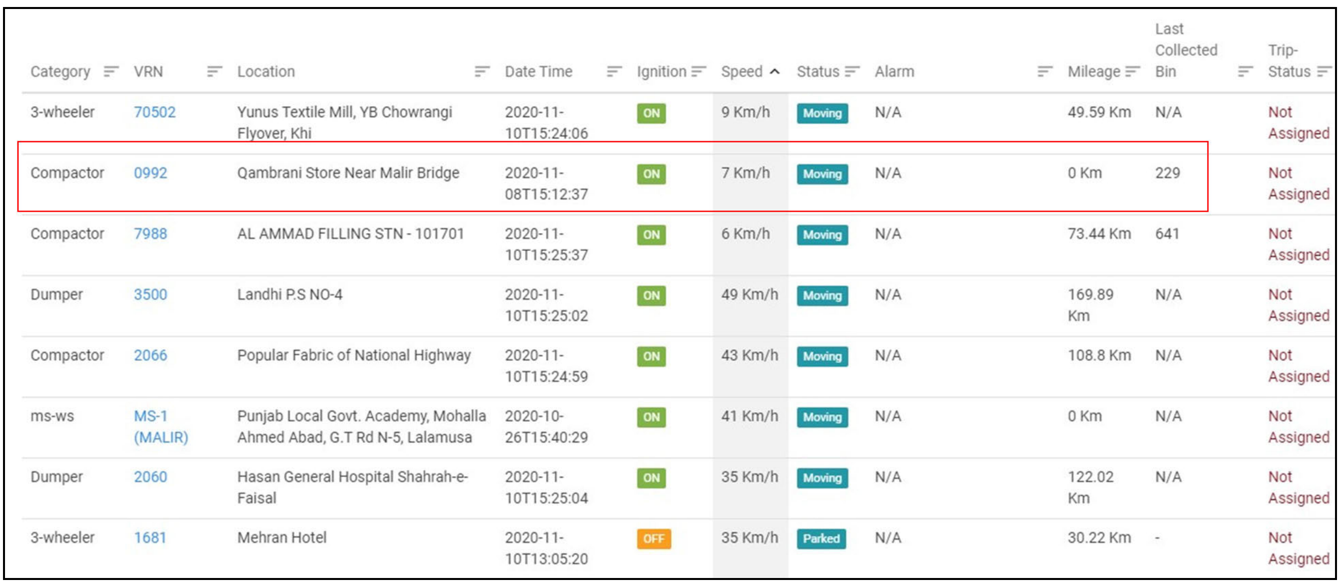


FIGURE 26. Real-time dashboard screen of weight.



Category	VRN	Location	Date Time	Ignition	Speed	Status	Alarm	Mileage	Last Collected Bin	Trip-Status
3-wheeler	70502	Yunus Textile Mill, YB Chowrangi Flyover, Khi	2020-11-10T15:24:06	ON	9 Km/h	Moving	N/A	49.59 Km	N/A	Not Assigned
Compactor	0992	Qambrani Store Near Malir Bridge	2020-11-08T15:12:37	ON	7 Km/h	Moving	N/A	0 Km	229	Not Assigned
Compactor	7988	AL AMMAD FILLING STN - 101701	2020-11-10T15:25:37	ON	6 Km/h	Moving	N/A	73.44 Km	641	Not Assigned
Dumper	3500	Landhi P.S NO-4	2020-11-10T15:25:02	ON	49 Km/h	Moving	N/A	169.89 Km	N/A	Not Assigned
Compactor	2066	Popular Fabric of National Highway	2020-11-10T15:24:59	ON	43 Km/h	Moving	N/A	108.8 Km	N/A	Not Assigned
ms-ws	MS-1 (MALIR)	Punjab Local Govt. Academy, Mohalla Ahmed Abad, G.T Rd N-5, Lalamusa	2020-10-26T15:40:29	ON	41 Km/h	Moving	N/A	0 Km	N/A	Not Assigned
Dumper	2060	Hasan General Hospital Shahrah-e-Faisal	2020-11-10T15:25:04	ON	35 Km/h	Moving	N/A	122.02 Km	N/A	Not Assigned
3-wheeler	1681	Mehran Hotel	2020-11-10T13:05:20	OFF	35 Km/h	Parked	N/A	30.22 Km	-	Not Assigned

FIGURE 27. Data representation received from IoT Device.

Geo-location Cipher: This is the cipher text generated from the real-time GPS location and date and time received from the reader and data terminal. It is used as the suffix for the generation of blockchain addresses.

Blockchain Address: This field represents the block address published on the blockchain network. The specified address is constructed from the reader and bin identity and geo data cipher as prefix and suffix.

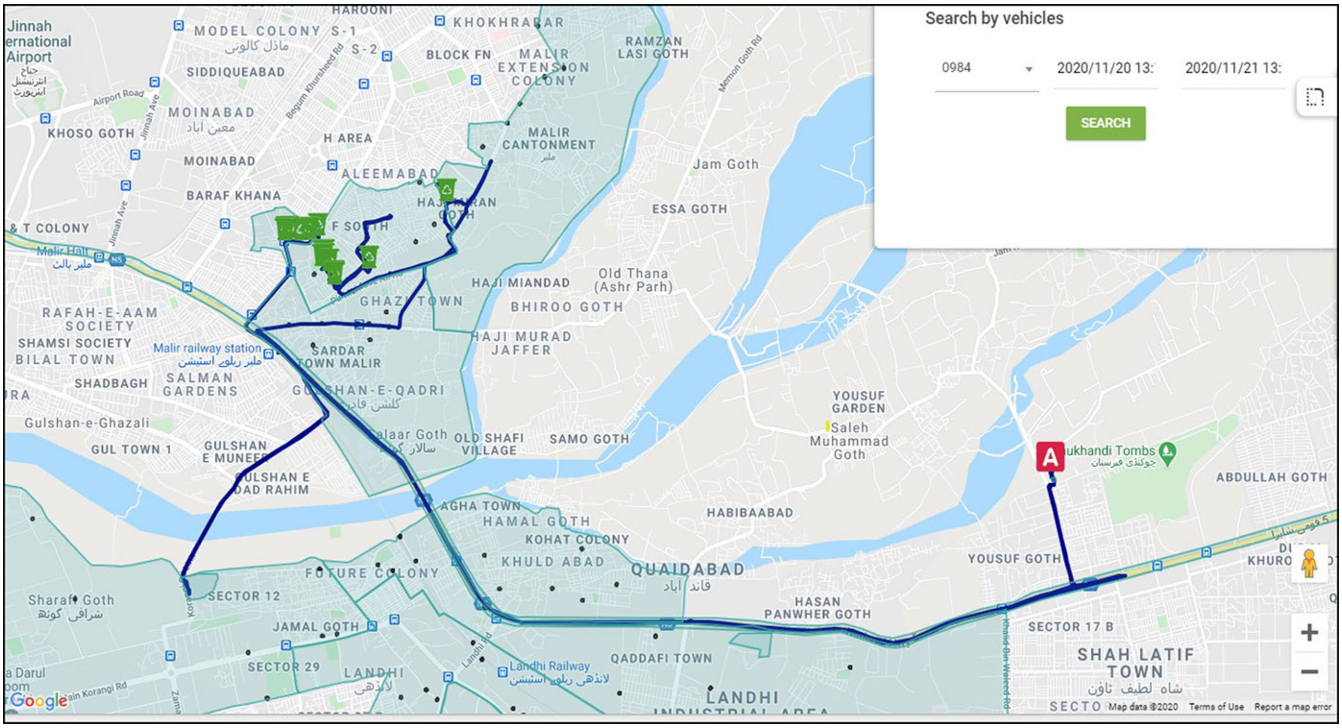


FIGURE 28. Data representation of detected waste bins.

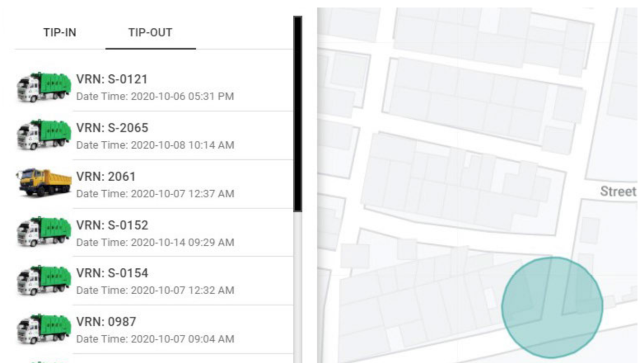


FIGURE 29. Data visualization of Geo fencing.

Signal Strength: This field represents the number of contacts or visible satellites for the identification of the strength of the signal.

Gas Consumption: This field represents the consumption of the blockchain gas, which is fixed to 1 Gwei for processing GPS Data and 3 Gwei for calculating the geo-fence algorithm.

Event: This event field helps the authorities to identify the alert type, whether it is related to bin detection or geo-fence.

The Figure 32 represents the complete real-time dashboard of the proposed solid waste management system. The following details are mentioned.

Total live vehicles which are online and in action.

Count of total and online waste vehicles category-wise (Compactor/Dumper/3-Wheeler/Mechanical Sweeper).

Total mileage of the waste vehicles for the current day.

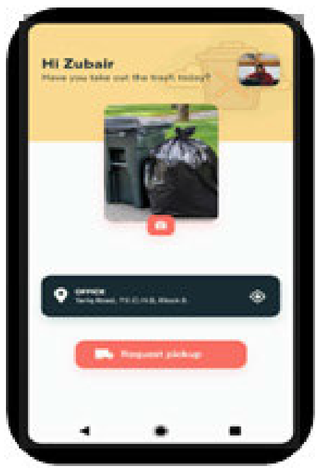


FIGURE 30. SSWMS mobile application for waste complain.

The bin operation tab highlights the total number of bins, and the detected bins picked on time. Furthermore, bins are bifurcated area-wise as well for ease of operations.

D. DESCRIPTIVE ANALYSIS OF THE CORPUS

Real-time tracking is a critical aspect of the proposed waste management system. The proposed system helps administrators focus on real-time information related to waste fleet and collection instead of having historical data. The real-time location of the waste vehicles and the detected bins helps track the drivers' performance based on daily waste

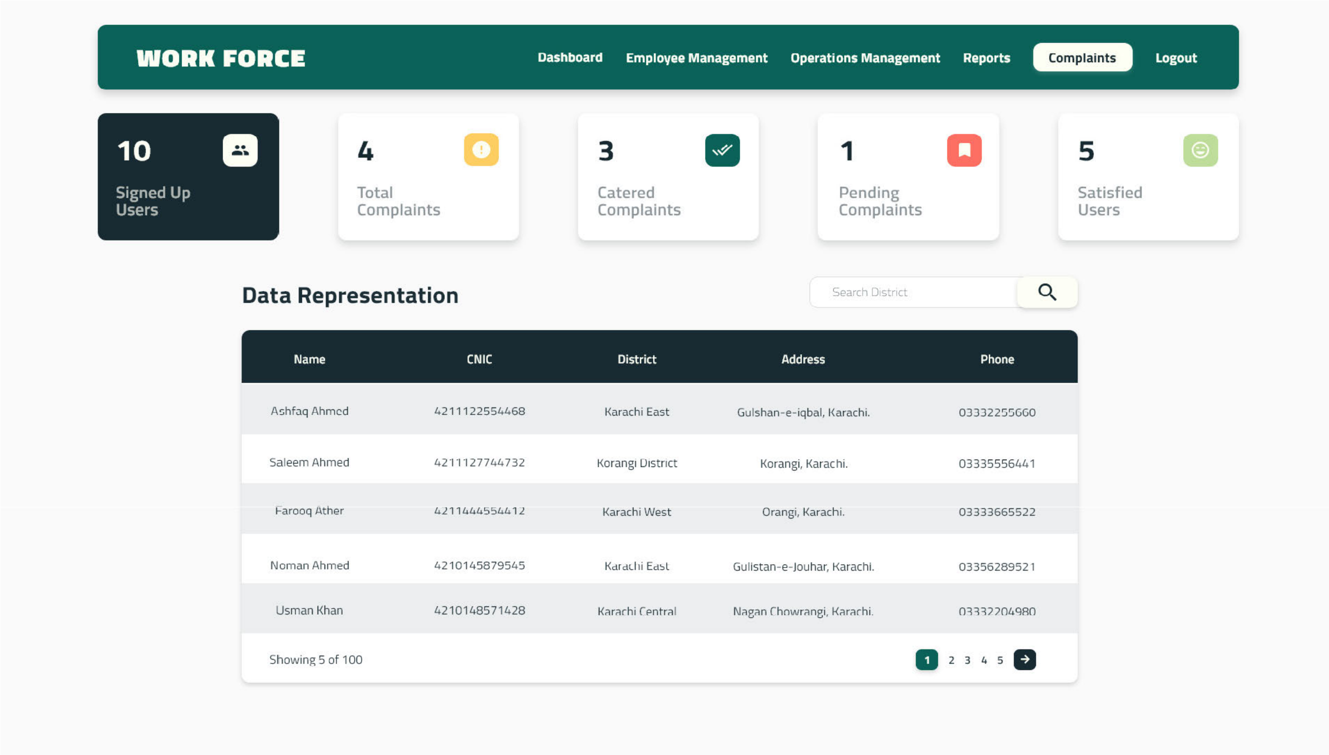


FIGURE 31. SSWMS web application dashboard.

collection operations. The real-time information also highlights areas not entertained for waste collection based on geofencing. Hence, real-time information and blockchain-based storage and data transmission make the proposed system more robust, tamper proof and smart to make operations efficient and useful for urban areas.

The blockchain, IoT, VANET, UHF and M2M technologies are used in the proposed methodology to provide a state-of-the-art comprehensive solution for developing countries to have a SSWMS. The communication and network technologies are also investigated to construct a stable network infrastructure. Our proposed solution allows densely populated cities to manage their solid waste efficiently and smartly. It provides waste management and control and deals with real-time tracking and the vehicle identification system. The authorities will have complete control over the system and process. Ultimately, implementing the proposed system will help reduce the spread of disease and viruses due to timely waste collection. It will also help to enhance recycling and production, which can result in the growth of an economy.

The design of the proposed solution is modular. The different modules can be used for different sectors as a stand-alone application. For example, the real-time tracking module can be used for fleet management solutions. UHF detection can be used for asset management. Geofencing techniques can be applied for isolation management, journey management, etc. In a nutshell, the proposed methodology has a wide range of applications in addition to its precise use for SSWM.

The proposed system is decentralized in architecture, but bad weather conditions can affect real-time data transmission. The proposed device can store more than 150,000 GPS locations in the absence of a network and communication across other devices. Furthermore, weighbridge integration is dependent on RS-232 connectivity. In case of failure of this connectivity, weighing data will not be transmitted to the cloud. Moreover, the resistance of the UHF tag against fire is very low. Therefore the placement of bins should be far from such areas where fire can erupt.

E. ECONOMY AND QUALITY OF THE SOLUTION

The objective of this study is to provide cost-effective solutions for developing countries. Therefore, the used technologies like UHF reader, IoT device and tags are cheaper than shelf products offered by companies for SSWMS. The timely collection of waste from the waste bins and dump spots is a critical problem for solid waste management. Therefore, the proposed solution provides an eagle-eye view of all such activities in a single window. Therefore, adopting the proposed solution will be quick for developing countries as it helps to gain confidence in the system by having a state-of-the-art monitoring dashboard.

The proposed solution is cost-effective as it is only a one-time expenditure for the cities. It will be available to them for long-running operations, resulting in an overall profit from the countries' timely collection, recycling and management.

TABLE 7. Data transmission logs table.

Date Time	VRN	Reader ID	Bin ID	Reader and Bin Identity	Geo Coordinates	Geo Location Cipher	Blockchain Address	Signal	Gas Consumption (Gwei)	Event
4/15/22 11:41 AM	992	111	895	WG4mDdcQQH5cNUAgTIgkOQ==	24.84743,67.165453	4uO7uUbHmcBeCDtceucBhH7fsLCJ2P1ecngWQEKiE2uMZ6ZV3Lr3JCMDZM8JXWDa	WG4mDdcQQH5cNUAgTIgkOQ==4uO7uUbHmcBeCDtceucBhH7fsLCJ2P1ecngWQEKiE2uMZ6ZV3Lr3JCMDZM8JXWDa	7	1	Bin Detection
4/15/22 11:35 AM	992	111	891	pLlLAoyGiHdcIiznM2cOwQ==	24.847583,67.16628	GjPVlDsdohc79MxWOwUywp1WyK8/mk227z+ICELp5VX/Y48qGFeaxotuQ8a8PdNq	pLlLAoyGiHdcIiznM2cOwQ==GjPVlDsdohc79MxWOwUywp1WyK8/mk227z+ICELp5VX/Y48qGFeaxotuQ8a8PdNq	7	1	Bin Detection
4/15/22 11:09 AM	992	111	993	5Np3/ky+X4HNP/Sd6BvEhQ==	24.859555,67.208008	4ySP0gry0Iey64ocPbDj07L4ERFa4NqfH/hRoWrCHMp/beqhCJxb2xsM/Bgr71kh	5Np3/ky+X4HNP/Sd6BvEhQ==4ySP0gry0Iey64ocPbDj07L4ERFa4NqfH/hRoWrCHMp/beqhCJxb2xsM/Bgr71kh	8	1	Bin Detection
4/15/22 11:08 AM	992	111	978	/u6abM0KIWVuAdhjTsS27g==	24.859555,67.208008	/aA+jox7/qYE7NPLxzoNYqly3q5kqCreJjTaB3G3/MiHOOq7WlFxCLfLBgXtFIuV	/u6abM0KIWVuAdhjTsS27g==/aA+jox7/qYE7NPLxzoNYqly3q5kqCreJjTaB3G3/MiHOOq7WlFxCLfLBgXtFIuV	7	1	Bin Detection
4/15/22 11:01 AM	992	111	156	gqe1cp9fFc3QsWzmEVBppQ==	24.86933,67.200863	zudfVYyBuGkQKvOUV5lcQt4gy9Hwhg7gA2+dpuqemVqM0RGZHKSRyWI8WDfc+Ai0	gqe1cp9fFc3QsWzmEVBppQ==zudfVYyBuGkQKvOUV5lcQt4gy9Hwhg7gA2+dpuqemVqM0RGZHKSRyWI8WDfc+Ai0	7	1	Bin Detection
4/15/22 10:58 AM	992	111	114	HLg6ZVHyEob3HT1+Hw4jlg==	24.87153,67.19803	mCInxa7tn4U5M1XaQFqEkVCHJPk5m9Uqxd6iyAFLik6MzruPFpvV9LEcdbQib6Hm	HLg6ZVHyEob3HT1+Hw4jlg==mCInxa7tn4U5M1XaQFqEkVCHJPk5m9Uqxd6iyAFLik6MzruPFpvV9LEcdbQib6Hm	9	1	Bin Detection
4/15/22 10:58 AM	992	-	-	-	24.87153,67.19803	mCInxa7tn4U5M1XaQFqEkVCHJPk5m9Uqxd6iyAFLik6MzruPFpvV9LEcdbQib6Hm	- mCInxa7tn4U5M1XaQFqEkVCHJPk5m9Uqxd6iyAFLik6MzruPFpvV9LEcdbQib6Hm	9	3	Geo Fence In
4/15/22 10:55 AM	7988	222	49	3Bb9pSXHN44GyH2wV9Sklw==	24.875075,67.193752	W8YtNvyGYScnEeCNP6MRob61InDho/AKi4YWxLwrzVuj1n5NtZpPFAKByzMKbjYB	3Bb9pSXHN44GyH2wV9Sklw==W8YtNvyGYScnEeCNP6MRob61InDho/AKi4YWxLwrzVuj1n5NtZpPFAKByzMKbjYB	6	1	Bin Detection
4/15/22 10:51 AM	7988	222	1002	q3UWRWiD6cNJk4iCjoqIeA==	24.878908,67.1885	gEO6FxTk0ZEVEeqn9my5JH52h5pDMETM0u/k5hrEgUiB7u8FR0GEK5kI83zXBDB7	q3UWRWiD6cNJk4iCjoqIeA==gEO6FxTk0ZEVEeqn9my5JH52h5pDMETM0u/k5hrEgUiB7u8FR0GEK5kI83zXBDB7	8	1	Bin Detection
4/15/22 10:50 AM	7988	-	-	-	24.878908,67.1885	4fKf+wwqzqz5q+e31sdkpfdmGfC+LofasNr7iySlxvKjiWN9Zj1bDV5IP7qeu+An	- 4fKf+wwqzqz5q+e31sdkpfdmGfC+LofasNr7iySlxvKjiWN9Zj1bDV5IP7qeu+An	8	3	Geo Fence In

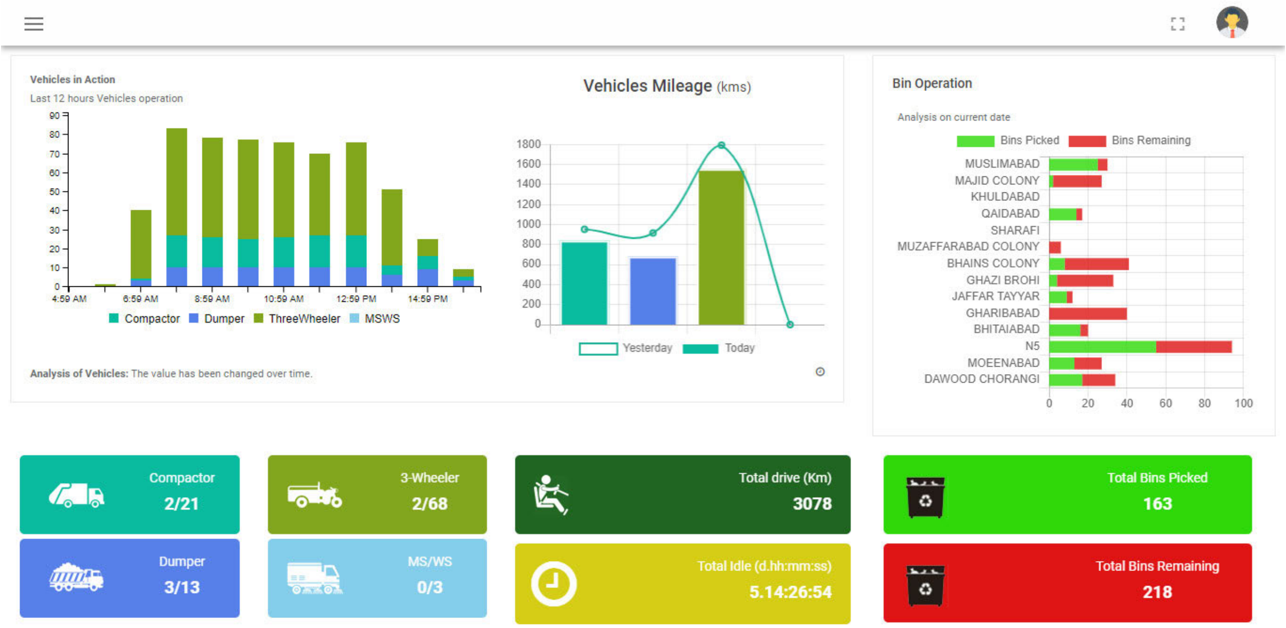


FIGURE 32. SSWMS web application dashboard.

TABLE 8. Cost comparison between tradition and systematic methods of waste collection.

Parameters/Criteria	Description	Cost Incurred by Traditional Method of Waste Collection	Cost Incurred by Proposed Method of Waste Collection
Cost of Gasoline	The cost of gasoline is calculated based on the specific count of vehicles for a specific region to provide comparison. 105 vehicles are observed for the specified region which covers 3000 Kilometers (Km) per day. The specific mileage is obtained using applied system but manually gasoline was being charged w.r.t 5000 Km on average. The average mileage is 10 Km per Liter of the vehicles, therefore the cost is calculated accordingly.	$500	$300
Cost of Labor	In specified region, there are 105 drivers, 200 helpers and 30 supervisors for the waste collection, the average salary of drivers and helpers is $5 per day and the average salary of supervisor is $10 per day. The need of supervisors have been eliminated after the proposed remote monitoring system, therefore it is also saving cost and mentioned accordingly.	$1,825	$1,525
Cost of Maintenance	The average maintenance cost charged by organization is $1 per Km. If we consider same regional situation as discussed above for the cost of gasoline than the obtained cost will be as mentioned.	$5,000	$3,000
Cost of Surveillance	The organization spent on average $45 per day on account of security and surveillance of the vehicles, this cost will also be saved upon applying proposed method due to remote surveillance.	$45	$0

Furthermore, the modular nature of the solution makes it more scalable, and its implementation will also help to reduce the workforce and additional expenditures.

In Table 8, cost wise comparison is obtained across traditional and systematic methods of waste collection. The Table 8 consist of four major parameters which are considered for the cost comparison. The total cost which is incurred by the traditional method of waste collection per day is $7370 and after the implementation of the proposed system the average cost per day has been reduced to $4825 estimated. The table depicts that the 35% cost is being saved with the help of the proposed system, therefore return on investment is prominent and the proposed system can be adopted by developing countries with ease.

The following Table 9 demonstrates the quality of the solution based on comparison of data accuracy across received GPS data from the data terminal and the physical geographical location obtained through survey. The table depicts that the obtained coordinates are highly accurate and within acceptable ranges despite GPS standard constraints

The proposed data terminal and the other IoT components are industrial grade components designed for

TABLE 9. Comparison for data accuracy and quality of the solution.

Date Time	Received GPS Data	Physical Geographical Location	Inaccuracy (Meters)
4/15/2022 11:41	24.84743,67.165453	24.847391, 67.165465	2
4/15/2022 11:35	24.847583,67.16628	24.847560, 67.166288	1
4/15/2022 11:09	24.859555,67.208008	24.859548, 67.207980	1
4/15/2022 11:01	24.86933,67.200863	24.869283, 67.200806	4

harsh external environment to maintain quality. The GPRS connectivity issues can be observed in certain areas where real time monitoring of the vehicles can be effected but the proposed terminal has the ability to store GPS data into its memory and transmit it upon reestablishment of its connectivity. Furthermore, the carbon vapors can also arise across joints due to harsh environment, therefore Periodic maintenance will be required half yearly to clean the connectors and to remove carbon from the joints of RS-232 connection for long and better life.

VI. CONCLUSION AND FUTURE WORK

Blockchain and IoT play an essential role in developing growing cities. Several pilot projects based on blockchain and IoT-enabling technologies are being deployed in various sectors such as Healthcare, agriculture, trade, finance, etc. Therefore, implementing blockchain-enabled VANET for SSWMS is an effort to overcome the research gap between advanced technologies and waste management in developing countries. The implication of blockchain and IoT-enabled architecture toward the automation of solid waste management processes is achieved using advanced M2M technologies. This study investigated the relationship between blockchain and VANETs. IoT-enabled technologies like VANET are used to devise a smart solution for developing countries to ensure timely waste collection and complete control of all the operations for systematic waste management. A complete end-end solution is proposed to address the needs of real-time tracking of waste vehicles, identification of waste bins, and vehicle identification using UHF, blockchain and IoT-enabled technologies to facilitate the municipal authorities. The geofencing techniques are also applied in the proposed solution for the timely collection of waste from the dump spots instead of having an eye only on waste bin monitoring.

The proposed solution has some limitations in data transmission. Therefore, 5G technology can be explored in future research to make the proposed solution more advanced. The sensors and actuators can also be added in later research to route vehicles towards the full bins automatically. Practitioners can also use the proposed concept of blockchain-enabled VANETs for fleet management and intelligent transportation. A comprehensive study can also be proposed based on its more extensive implementation at the country-wide level for developing countries. Furthermore, adding a mobile digital video recorder to the proposed solution can bring innovation to real-time security and vehicle surveillance. Moreover, the recycling and segregation of waste can also be introduced as a research study for a more comprehensive solution.

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