Municipal Waste Management
Project Report

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1 Introduction

Waste Management are minimization of domestic, medical, hazardous, and non-hazardous wastes, separate collection at the source, intermediate storage, establishment of transfer centers for wastes, when necessary, transportation, recovery, disposal of wastes, operation of recovery and disposal facilities, closure, post-closure maintenance, it is a management style that includes monitoring and control processes.

The basic policy is to reduce the amount of waste, recycle waste, reuse, and recycle as an energy source.

In Waste Management, we have a hierarchy.

i. *Prevention*
ii. *Decrease*
iii. *Re-use*
iv. *Recycling*
v. *Energy Recovery*
vi. *Disposal*

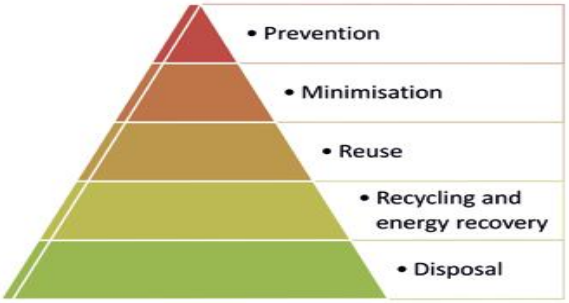


Figure 1

In the world where billions of people live, waste is produced as a result of every product it produces in order to raise the living standards of people. These wastes can pose a serious health issues if not managed properly. Moreover, we need to manage these wastes correctly in order to protect our world because of the fact that if we do not have an optimized waste management system, the methane gas (CH_4) emitted by the garbage primarily affects the global warming in our world, but in addition to these effects, it has many damages.

Figure 2 [28]

How to Manage Waste?

i. *Identification of Waste*
ii. *Separate Collection of Waste at Source*
iii. *Establishment of a Temporary Waste Landfill*
iv. *Waste Pre-Treatment*
v. *Send Waste to Disposal / Recycling*

As it is known in our world, wastes are collected by municipalities and many municipalities place waste containers at certain points of the streets; therefore, cleaning team travel around the specific routes in order to collect waste on a route, whether the garbage container is full or not.

In the scope of this project, it uses IoT-enabled sensors in waste bins to monitor conditions such as filling level and methane gas measurement of garbage containers to optimize waste collection with smart waste management, and these sensors transmit the data to the operation management department in the waste management center of the municipality.

When the garbage containers reach a certain garbage level or specific methane gas (CH_4) level, data is transferred to the employees in the Operations management department with the IoT-enabled sensor, hence the employees in the operation management will be able to see in which route the garbage containers are full and the cleaning team will be able to direct them to that location.

When waste management is not implemented in optimized way, it causes many problems such as, health conditions or especially climate change. With this project, these issues will be solved since the United Nations (UN) aims to implement the Sustainable Development Goals (SDGs) with a plan to achieve a better and more sustainable future for all. One of these plans is "Climate Action: Take urgent action to combat climate change and its impacts" plan number 13, which aims to minimize climate change with this plan. In this project, with the IoT sensors placed in the garbage containers, when the garbage reaches a certain level in the waste container, it sends a signal to the operation management department and the operation officer directs a cleaning team to the location where the signal comes from, and the cleaning team goes to a specific area with the optimized way and team collects the garbage there instead of going around the entire route. For this reason, we reduce the carbon-dioxide (CO_2) emissions which we generate from the exhaust of cars in our world, thus we reduce the carbon-dioxide (CO_2) emission and carbon footprint that affect global warming. With the methane gas measurement sensor placed in the garbage containers, even if the filling level in the garbage containers does not reach a certain level, it is aimed to collect the waste by sending a signal to the operation unit only in the formation of intense methane gas (CH_4).

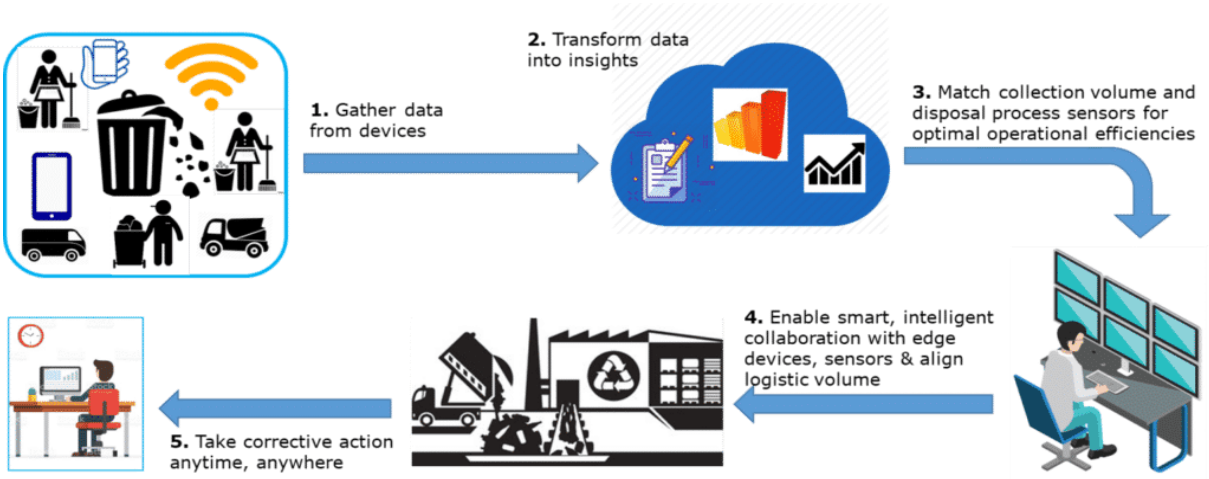


Figure 3 [13]

With this project, it is aimed to create a smart waste management system and reduce the carbon-dioxide (CO_2) and methane gas (CH_4) emissions that occur in our world with using Internet of Things (IoT) devices; therefore, our earth can reach sustainable life.

How should optimized waste management be done in order not to be exposed to these effects?

i. *Place an IoT sensor in garbage containers to measure garbage level and methane gas.*
ii. *These raw data are converted into analog or digital signals.*
iii. *Process the data which is obtained with the IoT sensor in the cloud.*
iv. *Send the data which is processed with the help of the cloud to the Operation Center with the Wi-Fi.*
v. *In the Operations Center, the most efficient way to direct the cleaner team to the location is calculated.*
vi. *The cleaning team cleans the garbage container that has reached a certain level.*

2 Literature Research

This section includes academic and technological research on waste management systems using Internet of Things (IoT).

2. 1 Academic Research

2.1.1 Waste management using Internet of Things (IoT)

Himadri Nath Saha, Supratim Auddy, Subrata Pal, Shubham Kumar, Shivesh Pandey, Rakhee Singh, Amrendra Kumar Singh, Swarnadeep Banerjee, Debmalya Ghosh, Sanhita Saha

Waste management is responsible for disposing of the items and materials that we have used in a safe and cost-effective way. Researchers have been studying waste management for over a century, and waste utilization analysis for over forty years. There are eight main waste management techniques, each of which is classified into different categories. Fortunately, the Internet of Things (IoT) provides a solution for assisting the utilization process at each level of waste management.

Smart waste containers with IoT sensors and working with solar energy is a compacting container. With this container, wastes that have reached a certain level are determined with using the IoT sensor and bins compacted the garbage, so 10 times more than a normal waste container can hold waste. Also, detects how much waste is in the container and it wirelessly transmits the filling level information to the cloud server.

In my opinion, compressing the wastes at a certain level and storing more waste in that container is an optimistic approach, but the release of methane gas (CH_4) generated in the bin will harm the nature to some extent.

2.1.2 Waste Management System Based on IoT

Sapna Suryawanshi, Rohini Bhuse, Megha Gite, Dhanashri Hande

Waste management is a major issue that the world faces, regardless of whether a country is industrialized or emerging. The main problem with waste management is that garbage bins in public locations overflow long before the next cleaning process begins. This work is based on a smart garbage system to eliminate any potentially dangerous scenarios and to ensure public cleanliness and health.

This paper proposes a smart warning system for garbage collection that sends an alert signal to the municipal web server for immediate dustbin cleaning with sufficient verification based on garbage filling levels. Android application is developed and connected to a web server to send alerts from the microcontroller to the city office and to conduct remote monitoring of the cleaning operation performed by the staff, minimizing the manual monitoring and verification process. The Wi-Fi module is used to send the notifications to the Android application.

I think, the goal of the project is to provide real-time access to information about the garbage bin. With the IoT devices used, it will make a great contribution to smart waste management systems in cities.

2.1.3 Waste Management as an IoT-Enabled Service in Smart Cities

Alexey Medvedev, Petr Fedchenkov, Arkady Zaslavsky, Theodoros Anagnostopoulos, Sergey Khoruzhnikov

Efficient Waste Collection is considered a fundamental service for Smart Cities. Internet of Things (IoT) can be applied smart cities to provide an innovative platform for new technologies. Surveillance devices may be used as a support technology for waste management with a high Quality of Service (QoS).

In this paper, they are proposing an advanced Decision Support System (DSS) for efficient waste collection in Smart Cities. In order to perform waste collection and dynamic route optimization, the system includes a model for real-time data sharing between truck drivers. The Smart City's waste management system addresses inefficient waste management in inaccessible locations.

In my opinion, ensuring a continuous flow of information between the waste collection system and truck drivers makes it possible to provide high quality service to Smart City citizens.

2.1.4 Implementation of a smart waste management system using IoT

P Haribabu, Sankit R Kassa, J Nagaraju, R Karthik, N Shirisha, M Anila

Waste collection services, today, are exhausted and unable to bear the burden of rising cities. It is one of the most critical issues facing emerging countries, in which a wide range of products, from vehicles to electronics, end up in poorly handled and untreated dumpsites, spreading diseases and increasing pollution.

As a consequence, they are recommending a system involving a mobile application associated with a Smart Trash Bin. The primary objective of this system is to minimize human resources and efforts while also improving the idea of a smart city. Hence, in order to do these process the waste bin will be squashed at daily intervals.

I think, it can be managed efficiently by replacing the traditional garbage containers that are available today, as it prevents unnecessary piling of wastes on the roadside; however, we will throw more waste into the garbage container with the crushing of the wastes, which will cause an increase in the methane gas (CH_4) formed in the garbage bins.

2.1.5 Smart Waste Management System using IoT

Prof. S.A. Mahajan, Akshay Kokane, Apoorva Shewale, Mrunaya Shinde, Shivani Ingale

With the exponential growth of the human population, sanitation and waste management issues are rapidly deteriorating. This causes unsanitary conditions for residents of the immediate area, allowing infectious diseases to spread. In order to avoid this issue, IoT based "Smart Waste Management" is the best solution.

In the proposed system, municipal garbage container would be equipped with an embedded device that allows for real-time control of garbage levels in the containers. The load sensors will improve the reliability of garbage level data, while moisture sensors will be used to provide data of waste segregation in a dust bin.

With the assistance of numerous devices produced reports, the review of continuous data gathered will assist municipalities and government authorities in improving plans related to smart waste management.

2.2 Technologic Research

2.2.1 Smart Waste Management

IoT will help communities to enhance the garbage collection systems and decrease costs by transforming waste management into data-driven collection processes. Sensors placed in waste containers receptacles monitor fill levels and alert city collection services when bins are ready to be emptied in smart waste management solutions. The cost of these sensors is steadily decreasing, making IoT waste bins more feasible to implement.

Two companies, Sensoneo and eCube Labs, are working on sensors and garbage containers in waste management. Sensoneo produces two types of ultrasonic sensors that can monitor the fill level for waste bins of various types and sizes. The CleanCUBE, produced by eCube Labs, is a solar-powered trash compactor that can hold up to 8 times more waste than a non-compression bin. As trash accumulates in the CleanCUBE, the sensors monitor the amount of fill in real time and, when the bin is full, automatically activate a compaction cycle. All sensor data is submitted to their platform.

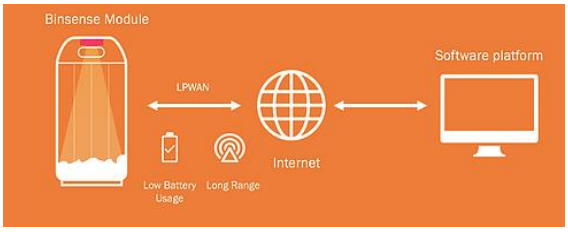
2.2.2 Municipal Waste Management

Smart urban waste management uses IoT-enabled sensors in waste receptacles to detect conditions such as fill level, temperature, and tilt. Predictive analytics and real-time sensors are used in smart waste management solutions to optimize collection routes to ensure that recyclables are collected and sorted correctly. Managers may change collection schedules on a weekly or regular basis using this additional data to ensure optimum productivity and minimum time spent on empty bins.

Smart waste management solutions use sensors to monitor the fill level of receptacles, to automatically compress waste, or to optimize pickup schedules. Alerts, GPS, and data management configuration. Integrated to RoutiLogix and the optimization engine to plan and schedule collection activities with compatible vehicles, existing routes or assigned to subcontractors and tracked in real time.

2.2.3 IoT Waste Management in Smart Cities

It is important to note that almost all the smart waste management IoT technologies currently in development are focused on industrial waste and municipal, public waste containers. In addition to collect the garbage with traditional ways, they are using the IoT based sensors to collect the garbage.



The solution is beautifully simple but can have significant impacts on a city's operation and environment. Ultrasonic sensors in the bin measure how full the bin is, and report the fill-level back to a centralised system using either a LoRAWAN, SigFox or NB-IoT network.

Figure 4 [9]

The operator will also use the centralised system to prepare an optimum route that means only the bins that need to be filled are emptied, preventing unnecesery route.

2.2.4 Smart Waste Management: How IoT Can Help Solve Waste Problems

Waste is a challenge in all metropolitan areas. When the population grows, so does the amount of garbage generated, even that which ends up in street bins. Cities must discover new ways to deal with waste and improve current processes as a result of this. In most cities, a waste management service provider follows a predetermined route to empty street trash bins. Bins will be emptied whether they are full or not, which means wasting fuel and other resources.

Metropolitan areas can improve productivity and reduce pollution by implementing Internet of Things technologies.

I. *Ultrasonic sensors*

Trash bins with ultrasonic sensors can detect the fill level. A full bin sends a notification to the collection company, which compiles that data to help plan collection routes that take into account only the full bins.

[Figure 5 [10]]

II. *Recycling stations*

Major cities like New York are introducing smart recycling bins to help increase the amount of recyclable material that is successfully diverted from landfills. These bins are equipped with fill-level monitoring sensors and compaction systems and can send notifications when full.

[Figure 6 [10]]

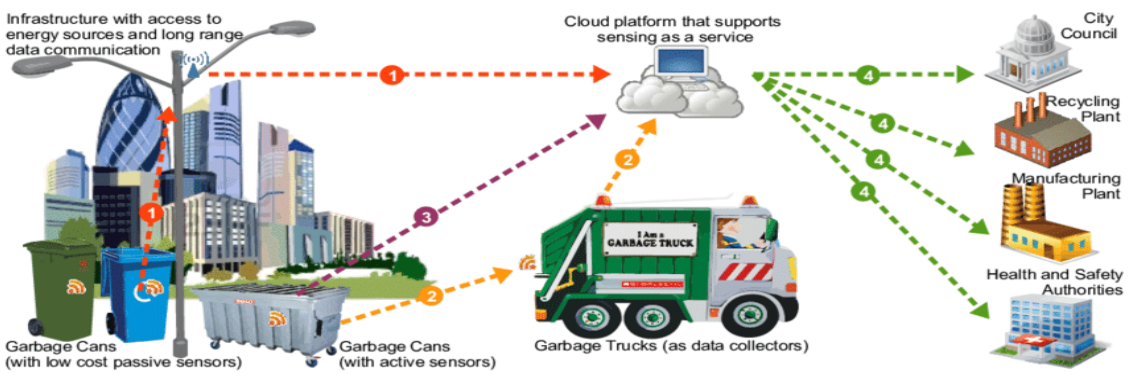
III. *Underground trash bins*

Some countries, like the Netherlands, have installed underground trash bins that can hold more waste while taking up less space on the street. They're equipped with fill level sensors so that waste collectors can easily track their condition and plan routes accordingly.

2.2.5 How Smart Cities are Leveraging IoT for Waste Management

Smart waste management is a new frontier for local authorities looking to reduce municipal solid waste and boost community recycling rates. IoT-driven waste management solutions implemented in Smart Cities typically consist of endpoint devices (sensors), gateways, cloud platforms, and web and mobile applications.

i. *Wireless solar or battery-powered ultrasonic sensors are attached to waste bins and dumpsters.*
ii. *The sensors use ultrasonic sound waves to measure waste levels.*
iii. *They transmit the data to the gateway using low-power or cellular connectivity. The sensing devices may communicate directly with the gateway (star networks) or pass the data to neighboring nodes (mesh networks).*
iv. *Sensor data is sent to the cloud through the gateway. Edge machines that process sensitive data locally can be used in advanced waste management systems.*
v. *The cloud system converts raw sensor data into actionable insights and visualizes them in dashboards.*
vi. *Plant dispatchers and waste truck drivers access the data on PCs and mobile devices to detect bins and containers that need emptying and adjust their routes accordingly.*



[Figure 7 [13]]

3 System Features, Architecture, Process and Technologies

3.1 System Features - Customer Side

Citizens living in the big city will be able to see the occupancy rate and mathane gas (CH_4) level in the garbage containers continuously from the mobile phone application with the smart waste management system. In addition, they will be able to send a request to the operation management department in the municipality for garbage collection via the mobile phone application.

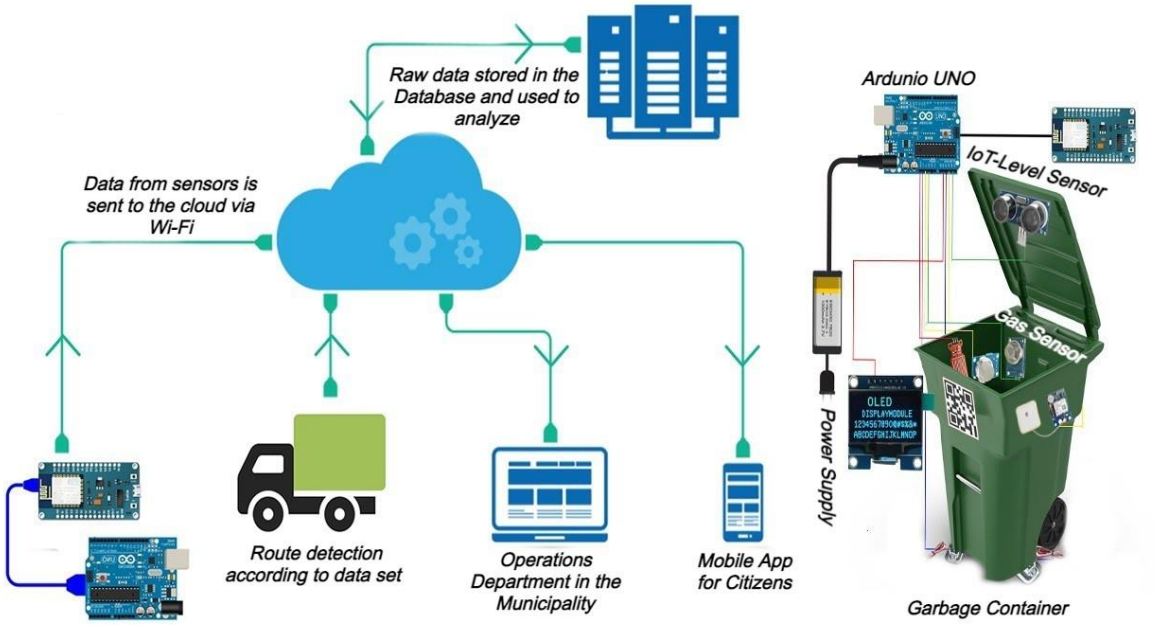
3.2 System Features - Enterprise Side

Operation Manager: *Thanks to the IoT sensors integrated into the garbage container, the incoming raw data will be sent to the operation management department in the municipality, the raw data received in this section will be analyzed, an optimized route will be created, and the necessary cleaning team will be kept informed.*

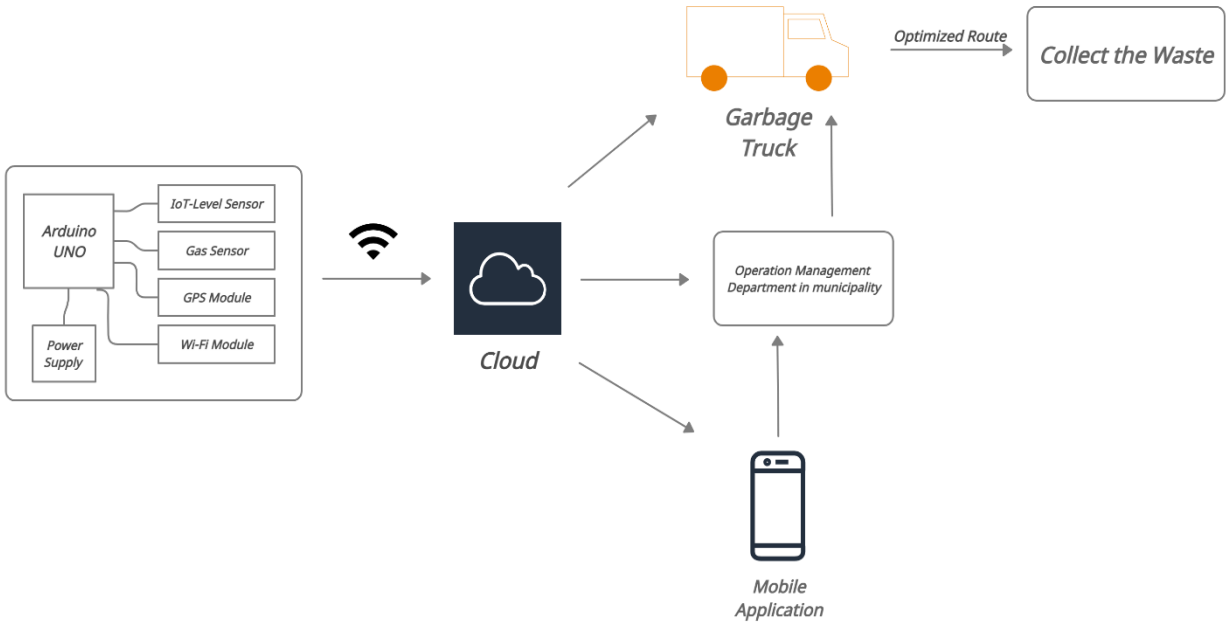
Analysis and Reporting: *The system should be able to capture and analyze historical data as well as provide operation managers in municipality with reports.*

3.3 System Architecture

Raw data from IoT sensors will be collected and transmitted to the cloud via Wi-Fi. The operation manager will analyze the raw data before monitoring data via the user interface and the citizens can alert the municipality using the mobile app.



3.4 System Process



The data will be collected by the sensors and the system will send a signal to the cloud via Wi-Fİ in case of any increase in the level of garbage or Mathane gas (CH_4), but with the analysis of the data, the operation manager in the municipality will be informed when the level of garbage or Mathane gas (CH_4) reaches a certain level. At the same time, the data streaming will be sent to garbage trucks and mobile applications via the cloud and the data will be monitored by citizens. If citizens send a warning signal to the operations manager, the operations manager will send the team to the specific location with the optimized route and the team collect the garbage.

3.5 Technologies

Technology	***Details***
Communication Protocol: *802.11 Wi-Fi*	*RF protocol to manage the communication between IoT sensors (Ultrasonic and Gas) and wireless (Wi-Fi) router, Wireless Sensor Gateway*
Messaging Protocol: *MQTT*	*Supporting messaging protocol between Wi-Fi router and cloud*
Ultrasonic sensor	*Used to measure the level of garbage in the garbage container*
Gas Sensor	*Used to measure the Methane Gas (CH_4) in the garbage container*
Arduino UNO	*Used as a Microcontroller*
GPS Module	*To find out the location of the garbage truck and the garbage container*
Wireless Sensor Gateway	*Sufficient to collect the data and send it to the cloud*
Wireless (Wi-Fi) Router	*2.4 Ghz Wi-Fi, 150+ m range*

4 Identifying Assets

Assets	*Type*	*Details*
Ultrasonic Fill Level Sensor	*Hardware*	*We have Level sensors put into the container to determine the fill rate of the garbage container*
Gas Sensor	*Hardware*	*We have Gas Sensor to determine Methane Gas rate of the garbage container*
Arduino UNO	*Hardware*	*A Microcontroller board / 14 Digital I/O pins, 6 Analog Pins, 5V, 16Mhz Clock Speed*
GPS Module	*Hardware*	*To detect the location of the garbage container and truck*
Sensor Gateway	*Hardware*	*Gateway collect the sensor in the related area*
Cloud Infrastructure	*Hardware Software*	*It consists of the apps and the databases*
Arduino IDE	*Software*	*It used to write the code for Arduino and upload the programs to Arduino Microcontroller*
Mobile App	*Software*	*For citizens to see the level of garbage and Methane gas (CH_4) and to alert the municipality when necessary*
Analytic System	*Software*	*Analyzed the raw data and send the necessary data*
Sensor Data	*Information*	*It consists of data that our system uses to determine the state of the container*

5 Security Requirements, Challenges and Functions

5.1 System Challenges

In today's world, security is very crucial due to the increase in the information and data. Security is also at the forefront in the system we will implement, because many of sensitive data from sensors will be stored in the system; therefore, we must protect our data with an end-to-end security mechanism.

5.2 System Requirements

5.2.1 Basic Requirements

1. *The data must be send and stored in a **hashed** form.*
2. *The system should be **updated** periodically*
3. *Sensitive data within the system should be kept **confidential**.*
4. *The data **integrity** should be ensured.*
5. *System **availability** and use of components should be provided.*

5.2.2 Security Management

1. *We should identify the assets and analyzed their risk. Furthermore, we should develop a security policy to them.*
2. *A well-known information security management system should be implemented.*

5.2.3 Data Center Security

1. *Multi-factor authentication must be provided for access to the data center.*
2. *A safe place in the building should be chosen as the data center.*

5.2.4 Server Security

1. *Technical Hardware and Software (Firewalls, SSH keys, AntiVirus and AntiMalware) should be provided to protect the server.*
2. *Privileged access should be performed over secure channels, (e.g., encrypted network connections using SSH or IPsec).*
3. *We should remove or turn off all unnecessary services.*
4. *We should use intrusion prevention software to monitor login attempts to protect the server against brute force attacks.*

5.2.5 Network Security

1. *DDoS mitigation (protection against DDoS attacks) should be used, and strong infrastructure should be established against DDoS attack.*
2. *Security precautions (Firewall, Application Layer Gateway, IPS/IDS systems) should be supplied against network-based attacks.*
3. *IPS/IDS should be used for detect and log or prevent the malicious movement and link.*

5.2.6 Platform Security

1. *The system should have updates managements to fix the vulnerabilities.*
2. *Tests should be done at regular period to determine the risks.*

5.2.7 Data Security

1. *Crucial data (Citizens and Sensor Information, e.g.) must be stored with hash function; therefore, we can use SHA-256 Algorithm.*
2. *Authentication system should be provided.*
3. *We should keep the sensitive data elsewhere and delete it when necessary.*

5.2.8 Key Management

1. *[17] Key management provides the foundation for the secure generation, storage, distribution, use and destruction of keys.*
2. *One-Time Pad should be provided.*

5.2.9 Identity and Rights Management

1. *Access control should be role-based, and responsibilities and roles should be reviewed on a specific period.*
2. *The authentication system must be correctly defined.*

5.2.10 Monitoring and Security Incident Management

1. *The system should log and monitor administrator activities.*
2. *Anomaly situations should be detected and reported to senior management.*

5.2.11 Vulnerability Management and Security Testing

1. *Vulnerability analysis should be conducted at regular time intervals.*
2. *Anomalies should be determined and updated periodically for software vulnerability.*

6 Entry Points

Entry Point	*Type*	*Description*
Ultrasonic Fill Level Sensor	*Hardware*	*The attack can be a vulnerability discovered in the ultrasonic Fill Level Sensor's receiver that results in a fake pulse that is produced by misleading input.*
Gas Sensor	*Hardware*	*Gas Sensor can receive a fake pulse by misleading input.*
GPS Module	*Hardware*	*The vulnerability of GPS to "spoofing," "shading," and "active electronic countermeasures" are can be shown as an example.*
Sensor Gateway	*Hardware*	*Via remote networking over the Wi-Fi network (via SSH), attackers obtain access to the sensor gateway administrative account.*
Mobile App	*Software*	*Attackers can access crucial citizens' information by accessing their register or login credentials.*

7 Threat Matrix

No	*Security Threats*	*S*	*T*	*R*	*I*	*D*	*E*
	Municipal Waste Management Threats						
1	*Attacker can capture the user's information such as password and username information and they can change them*	✓	✓				
2	*The attacker can login to the customer account and send wrong alerts to the municipal*	✓					
3	*Attackers access customers' data history via the unauthorized way*				✓		
4	*Attackers can enter the operations manager account and they can change all information*	✓	✓		✓		
5	*Data leakage and data manipulation can be exploited by manipulating security vulnerabilities in the authentication mechanism*	✓	✓	✓	✓		✓
6	*Attacker can interrupt waste management operations by putting a rootkit on backend servers*						✓
7	*Attackers can send a jamming signal to the GPS module*			✓			
8	*Security weaknesses in the authorization process can be exploited privilege enhancement*			✓	✓		✓
9	*Malicious actor shuts down municipal waste management system through a DDoS attack*					✓	
10	*Attacker can affect SRAM which is the part of Microcontroller*		✓				

8 Threat, Attack Techniques, Countermeasures

Threat 1	*Attacker can capture the user's information such as password and username information and they can change them*
Threat Target	*Login information of the customer*
Attack Techniques	*MITM attacks, Social Engineering, Database Compromises, Phishing*
Countermeasures	*We should raise awareness that citizens do not share their privacy information and lead the citizens to use Multi-Factor authentication*

Threat 2	*The attacker can login to the customer account and send wrong alerts to the municipal*
Threat Target	*Operation manager and garbage team in the municipality*
Attack Techniques	*MITM attacks, Social Engineering, Phishing*
Countermeasures	*Citizens should be more careful about their privacy information*

Threat 3	*Attackers access customers' data history via the unauthorized way*
Threat Target	*Data History of Customer*
Attack Techniques	*Spoofing Attack, Spyware*
Countermeasures	*Creating more secure software system*

Threat 4	*Attackers can enter the operations manager account and they can change all information*
Threat Target	*Operation Manager Account Information & Citizens Account Information*
Attack Techniques	*SQL Injection, Spoofing attack, MITM attack*
Countermeasures	*We should be control and analyze the user input to watch for attack patterns*

Threat 5	*Data leakage and data manipulation can be exploited by manipulating security vulnerabilities in the authentication mechanism*
Threat Target	*Crucial information of Citizens*
Attack Techniques	*Social Engineering, Spoofing, MITM attacks, Phishing*
Countermeasures	*Multi-Factor authentication system should be used*

Threat 6	*Attacker can interrupt waste management operations by putting a rootkit on backend servers.*
Threat Target	*Municipal Waste Management System & Citizens*
Attack Techniques	*Kernel rootkit, Hardware or Firmware rootkit, Memory rootkit, Bootkit*
Countermeasures	*The system should use the Anti-Malware solutions*

Threat 7	*Attackers can send a jamming signal to the GPS module*
Threat Target	*GPS Module*
Attack Techniques	*Jamming, De-Synchronization Attack*
Countermeasures	*We should be adding a verification signature to the module*

Threat 8	*Security weaknesses in the authorization process can be exploited privilege enhancement*
Threat Target	*System for Authorization Management*
Attack Techniques	*Application or System Vulnerabilities*
Countermeasures	*The system should be updated specific time period*

Threat 9	*Malicious actor shuts down municipal waste management system through a DDoS attack*
Threat Target	*Disabling the system to serve*
Attack Techniques	*UDP or SYN Flood, ICMP (Ping), Ping of Death, Slowloris, NTP Amplification*
Countermeasures	*DDoS mitigation should be used, and strong infrastructure should be established to prevent the DDoS attack*

Threat 10	*Attacker can affect SRAM which is the part of Microcontroller*
Threat Target	*Data in the Microcontroller*
Attack Techniques	*Microcontroller vulnerabilities*
Countermeasures	*Readback protection should be used*

9 Rating Threats (DREAD)

Threat 1 *Attacker can capture the user's information such as password and username information and they can change them*				
Category	***Description***			***Score***
Damage	*The attack affects the single user's information*			*3*
Reproducibility	*There is a small possibility of recurrence*			*4*
Exploitability	*This attack can be easily launch by a middle knowledge person*			*8*
Affected users	*Single user in most scenarios*			*2*
Discoverability	*This threat is mediumly discoverable*			*6*
Overall Score				*4.6*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 2 *The attacker can login to the customer account and send wrong alerts to the municipal*				
Category	***Description***			***Score***
Damage	*The attack affects the Municipality and Citizens*			*9*
Reproducibility	*There is a small possibility of recurrence*			*3*
Exploitability	*Middle knowledge person can easily realize this attack*			*7*
Affected users	*Citizens & Garbage Team in most scenarios*			*7*
Discoverability	*This threat is highly discoverable*			*5*
Overall Score				*6.2*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 3 *Attackers access customers' data history via the unauthorized way*				
Category	***Description***			***Score***
Damage	*A single person is affected by this attack*			*2*
Reproducibility	*There is a small possibility of recurrence*			*3*
Exploitability	*Exploitation of this threat can be done by unskilled persons*			*8*
Affected users	*A Citizen in most scenario*			*3*
Discoverability	*Easy to understand as data may be changed*			*6*
Overall Score				*4.4*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 4 *Attackers can enter the operations manager account and they can change all information*				
Category	***Description***			***Score***
Damage	*All Citizens & All System can be affected*			*9*
Reproducibility	*Possibly repeated with a slight chance*			*5*
Exploitability	*This attack can be easily launch by a middle knowledge person*			*4*
Affected users	*Citizens, Garbage Team & Operation Manager*			*9*
Discoverability	*Threat can be discovered with using high Technology activities*			*7*
Overall Score				*6.8*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 5 *Data leakage and data manipulation can be exploited by manipulating security vulnerabilities in the authentication mechanism*				
Category	***Description***			***Score***
Damage	*A single person is affected by this attack*			*3*
Reproducibility	*There is a small possibility of recurrence*			*5*
Exploitability	*Exploitation of this threat can be done by knowledgeable persons*			*7*
Affected users	*A Person in most scenario*			*2*
Discoverability	*It can be easily detecting as there is data manipulation*			*7*
Overall Score				*4.8*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 6 *Attacker can interrupt waste management operations by putting a rootkit on backend servers*				
Category	***Description***			***Score***
Damage	*All system is affected by this attack*			*9*
Reproducibility	*It will be repeated to a large extent*			*7*
Exploitability	*It is difficult to realize this attack*			*4*
Affected users	*All Citizens & Employees are affected*			*8*
Discoverability	*It can be easily detecting*			*8*
Overall Score				*7.2*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 7 *Attackers can send a jamming signal to the GPS module*				
Category	***Description***			***Score***
Damage	*System can be affected by this attack*			*6*
Reproducibility	*It cannot easily repeat*			*4*
Exploitability	*The abuse of this threat can be done by unqualified persons*			*8*
Affected users	*Operation Manager can be affected*			*2*
Discoverability	*It can be easily discoverable*			*6*
Overall Score				*5.2*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 8 *Security weaknesses in the authorization process can be exploited privilege enhancement*				
Category	***Description***			***Score***
Damage	*Attack affects all system*			*9*
Reproducibility	*There is a small possibility to repeat*			*4*
Exploitability	*Exploitation of this threat can be done by medium knowledgeable person*			*6*
Affected users	*Operation Manager, Garbage Team & Citizens*			*8*
Discoverability	*It is difficult to discover this attack*			*7*
Overall Score				*6.8*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 9 *Malicious actor shuts down municipal waste management system through a DDoS attack*				
Category	***Description***			***Score***
Damage	*Attack affects the entire waste management system*			*9*
Reproducibility	*It will be repeated to a large extent*			*8*
Exploitability	*It can be done easily by a qualified person*			*5*
Affected users	*All people in most scenario*			*9*
Discoverability	*It can be easily understood*			*8*
Overall Score				*7.8*
Action	***Accept***	***Mitigate***	***Defer***	

Threat 10 *Attacker can affect SRAM which is the part of Microcontroller*				
Category	***Description***			***Score***
Damage	*Data in the microcontroller is affected*			*7*
Reproducibility	*There is a small possibility to repeat*			*4*
Exploitability	*It can be done by a qualified person*			*5*
Affected users	*Citizens & Operation Manager*			*6*
Discoverability	*It cannot be easily detecting*			*5*
Overall Score				*5.4*
Action	***Accept***	***Mitigate***	***Defer***	

10 Privacy Evaluation

In the Municipal Waste Management System, we keep the registration information of citizens registered in the system; therefore, we need to protect them at a certain local and global policies. For this reason, information data should be obtained with the consent of citizens in accordance with KVKK or GDPR. Citizens allow us to store their data by approving the KVKK or GDPR.

References

[1] *Himadri Nath Saha, Supratim Auddy, Subrata Pal, Shubham Kumar, Shivesh Pandey, Rakhee Singh, Amrendra Kumar Singh, Swarnadeep Banerjee, Debmalya Ghosh, Sanhita Saha, "Waste management using Internet of Things (IoT)", 2017.*

[2] *Sapna Suryawanshi, Rohini Bhuse, Megha Gite, Dhanashri Hande, "Waste Management System Based on IoT", 2018.*

[3] Alexey Medvedev, Petr Fedchenkov, Arkady Zaslavsky, Theodoros Anagnostopoulos, Sergey Khoruzhnikov, "Waste Management as an IoT-Enabled Service in Smart Cities", 2015.

[4] *P Haribabu, Sankit R Kassa, J Nagaraju, R Karthik, N Shirisha, M Anila, "Implementation of an smart waste management system using IoT", 2017.*

[5] *Prof. S.A. Mahajan, Akshay Kokane, Apoorva Shewale, Mrunaya Shinde, Shivani Ingale, "Smart Waste Management System using IoT", 2017.*

[6] *Jamrozik, N. (2019, October 28). Smart Waste Management - Nadia Jamrozik. Medium. https://medium.com/@NadJam/smart-waste-management-17db1bd5bc6b*

[7] *All, I. F. (2020, April 29). Municipal Waste Management. IoT For All. https://www.iotforall.com/use-case/municipal-waste-management*

[8] *BinLogix Smart Bins App – IoT Sensor Connectivity Platform. (2021, February 1). IoT For All. https://www.iotforall.com/solution/binlogix-smart-bins-app-iot-sensor*

[9] *S. (2020, May 20). IoT Waste Management in Smart Cities. Wellthatsinteresting.tech https://wellthatsinteresting.tech/iot-waste-management-in-smart-cities/*

[10] *Smart Waste Management: How IoT Can Help Solve Waste Problems. (2021, March 29). HQSoftware. https://hqsoftwarelab.com/blog/smart-waste-management-iot/*

[11] *Klubnikin, A. (2020, November 3). How Smart Cities are Leveraging IoT for Waste Management. Softeq. https://www.softeq.com/blog/how-smart-cities-are-leveraging-iot-for-waste-management*

[12] *Municipal waste management systems for domestic use. (2017, November 15). ScienceDirect. https://www.sciencedirect.com/science/article/pii/S0360544217313464*

[13] *All, I. F. (2020b, June 4). How IoT Solutions Can Improve Waste Management Processes. IoT For All. https://www.iotforall.com/smart-iot-solution-assist-legacy-process-management*

[14] *C. (2020a, October 11). Atık Yönetimi | CEVREONLINE. Çevre Bilgi Portalı. https://cevreonline.com/atik-yonetimi/*

[15] *Kanat, Y. Ç. (2020, March 6). Atık Yönetimi Nedir? Haliç Çevre Danışmanlık. https://hlccevre.com/atik-yonetimi-nedir/*

[16] *UNEP, (2010). Waste and Climate Change: Global trends and strategy framework. United Nations Environment Programme https://wedocs.unep.org/bitstream/handle/20.500.11822/8648/Waste&ClimateChange.pdf?sequence=3*

[17] *Recommendation for Key Management. (2020, May). National Institute of Standards and Technology. https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-57pt1r4.pdf*

[18] *Data Security and Platform Security Specifications. (2019, December 23). MindTickle.* *https://www.mindtickle.com/data-security-and-platform-security-specifications/*

[19] *Berry, B. M., & Berry, M. (2012, April 16). Network Security: Top 5 Fundamentals. IT Manager Daily.* *http://www.itmanagerdaily.com/network-security-fundamentals/*

[20] *Minimum Information Security Requirements for Systems, Applications, and Data / safecomputing.umich.edu. (2020). Information and Technology Services-Safe Computing-University of Michigan.* *https://safecomputing.umich.edu/information-security-requirements*

[21] *Simic, S. (2021, April 26). 21 Server Security Tips to Secure Your Server. Knowledge Base by PhoenixNAP.* *https://phoenixnap.com/kb/server-security-tips*

[22] *What is Data Center Security? (2021, May 6). Forcepoint.* *https://www.forcepoint.com/cyber-edu/data-center-security*

[23] *The year of decision for GPS vulnerability. (1998). Military & Aerospace Electronics.* *https://www.militaryaerospace.com/computers/article/16707650/the-year-of-decision-for-gps-vulnerability*

[24] *Spoofing Attack on Ultrasonic Distance Sensors Using a Continuous Signal. (2020, November 1). PubMed Central (PMC).* *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7663762/*

[25] *Hewitt, N., Hasson, E., & McKeever, G. (2021, February 14). DDoS Attack Types & Mitigation Methods. Imperva.* *https://www.imperva.com/learn/ddos/ddos-attacks/*

[26] *Cucu, P. (2021, May 13). Rootkit – the (Nearly) Undetectable Malware. Heimdal Security Blog.* *https://heimdalsecurity.com/blog/rootkit/*

[27] *Veracode. (2021). Attacks.* *https://www.veracode.com/security/attacks*

[28] *Hazardous Waste Management and Disposal Training Course. (2021, May 16). Zoe Talent Solutions.* *https://zoetalentsolutions.com/course/hazardous-waste-management-and-disposal-training-course/*