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Implementation of IoT Based Waste Segregation and Collection System

Bhupendra Fataniya, Aayush Sood, Deepti Poddar, and Dhaval Shah

Abstract—**Waste management is a challenging problem for most of the countries. The current waste segregation and the collection method are not efficient and cost-effective. In this paper, a prototype is presented for smart waste management. It is also capable of waste segregation at the ground level and providing real-time data to the administrator. Impact and cost analysis of the deployment of smartbin is also presented considering one ward of Ahmedabad Municipal Corporation. It is clear from that deployment of this smartbin will save about 40% of the current expenditure for that ward.**

Keywords—**Smart City, IoT, smart waste management, waste segregation**

I. Introduction

WASTE management has been always an integral part of the development of society. With the increase in population and urbanization the waste generation rate is rising exponentially. According to a World Bank report [1], the world waste generation has crossed a whopping 2.01 billion tonnes in 2016 and is most likely to increase to 3.40 billion tonnes by 2050.The municipalities of developing as well as developed countries are having various issues in implementing their waste management model. In the common waste collection approach, trash collecting vehicle goes around the cities for waste collection on a daily basis. This solution is not proven effective as many times the bins are overflowing with waste causing unnecessary cleanup cost. If bins are empty the trash collection vehicle consumes unnecessary fuel. The inefficient collection of waste is harmful to the environment. The issue of inefficient collections by the corporation's vehicle has been prevalent due to the lack of real-time data and information, which has increased the overall expenditure of the municipality. The current solid waste management system of Municipal Corporation of Ahmedabad, a metropolitan city in India costs the government an amount of INR 400 crores per year [2]. This trend is similar in most of the countries in the world. This demands a sustainable and economical waste management system across the globe. Using technology with proper planning will create an effective and efficient model for the waste management system.

Recently, there have been several projects reported for smart waste management. In [3] the idea of smart dustbin for a smart city is implemented. In this concept, level and load sensors have been used to estimate the waste in the dustbin and GSM modem for data transfer to the municipality head office. In another approach [4], the real-time data about the status of dustbin is sent through the wireless mesh network. Addition of a sleep mode feature in this method reduces the power consumption of the model. M. Talha et. al. have proposed a big data analysis method for waste management [5]. This approach is implemented using a microcontroller and GSM module. GSM module is used to transfers the data to a cloud server and SMS will be sent about the location to drive as and when trash collection is required. In [6] Mohammad Aazam et. al. have discussed the prevailing waste management system and problems associated with it. Later, they specify the importance of data uploaded on the cloud for several stakeholders like industries, healthcare, city admin, NGOs. Waste segregation is also an integral part of a solid waste management system. Mixing up dry and wet waste produces greenhouse gases in the landfills in addition to toxic leachate which is harmful to the environment. Performing waste segregation at the initial level of waste management will help in reducing pollution, labour cost and recycling various elements from the garbage. Recycling of materials such as glass and paper can be performed easily after initial segregation. In [7] the authors propose a method of waste segregation by dividing solid waste into three categories: biodegradable, metal and plastic, with the help of sensors, STM32 MCU and IoT for monitoring the system. In [8] the authors discuss various technologies for waste segregation and solid waste management. For waste segregation, the authors suggested techniques such as magnetic separation, eddy current separator and image processing. This adds cost and complexity to the system. These techniques are most suitable for laboratory experiments and are not for practical applications. From all the above literature it is clear that currently there is no efficient waste collection and segregation model. Also, these ideas do not cater to the needs of a Smart City completely. In this paper, we have proposed a model which is capable to segregate the waste at the initial stage of waste collection. It further senses the level of the dustbin and uploads data on the cloud server to notify the administrator and trash collecting vehicle drivers through email and mobile application. This helps the administration to send the trash collecting vehicle as and when required.

The rest of paper is organized as follows: Section II presents the block diagram and working of the proposed model. Implementation and results are discussed in section III. Section IV contains impact and cost analysis of our model for Ahmedabad city. Finally, the conclusion of this work is reported in section V.

Bhupendra Fataniya (first Author) and Dhaval Shah (corresponding author) are with Electronics and Communication Department of Nirma University, India (e-mail: bdfataniya@nirmauni.ac.in, dhaval.shah@nirmauni.ac.in).

Aayush sood and Deepti Poddar are with Electronics and Communication Department of Nirma University, India (e-mail: 15bec004@nirmauni.ac.in, 15bec029@nirmauni.ac.in).

II. SmartBin Model

Figure 1 shows the block diagram of the proposed SmartBin model which is divided into hardware and software implementation. The model consists of three basic entities that are sensing nodes, cloud, and mobile application. The sensing node consists of ultrasonic, moisture and gas sensor. The ultrasonic sensor returns the value of the garbage level of the SmartBin to the NodeMCU. The moisture sensor senses the volumetric content of water in the waste which helps to differentiate between dry and wet waste. The smoke sensor is used to check the presence of gases in case of a fire inside the dustbin. Next part comprises of the cloud which obtains data from NodeMCU. This data is stored on the cloud server(Adafruit) and is further retrieved on the mobile application. DataFeeds application is used to monitor real-time garbage level and notify the administrator about the status of the dustbin.

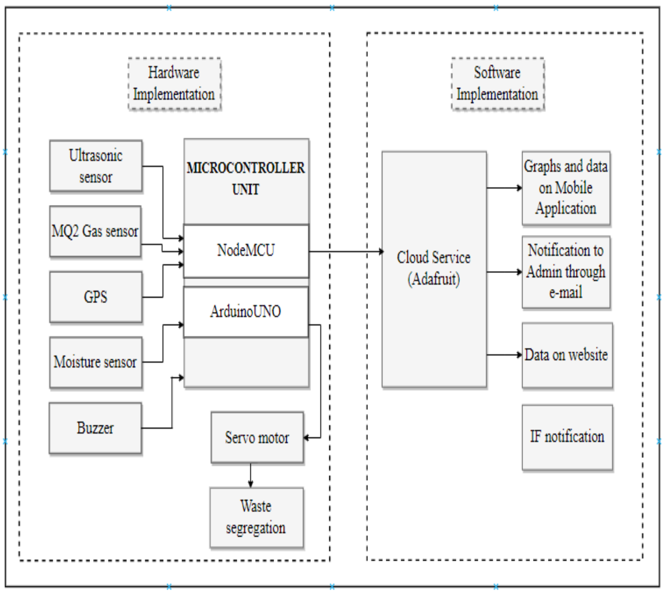

Fig. 1. Block diagram

The hardware is responsible for level sensing and waste segregation process. The SmartBin is divided into two halves, each covered with a flap, one for wet waste and the other for dry waste. In order to perform waste segregation, a moisture sensor is deployed at the top of the SmartBin. A user keeps the waste on the platform and the moisture sensor senses the volumetric content of water in the waste material and differentiates between wet and dry waste. The moisture sensor is connected to the servo motors. Depending on the conductivity, the moisture sensor triggers the corresponding servo motor, either dry or wet, which opens up the respective flap. An ultrasonic sensor is used for the level sensing of the dustbin. MQ2 gas sensor is used for sensing various pollutants and gases present in the dustbin. The GPS module helps in knowing the location of the dustbin. The Buzzer gets activated in case of fire. The software part is responsible for uploading data on a cloud server and mobile application with the help of NodeMCU. All the received data from the sensors is sent to Adafruit, a cloud platform at an interval of 3 seconds. This data then can be displayed on DataFeeds app. DataFeeds is a real-time monitoring application for Adafruit. It maintains and checks the current status of the dustbin feeds and monitors the change over the period. DataFeeds also presents a graphical representation of the data over specified timelines. The specifications of each sensor mentioned above are discussed in detail in Section III. The flow of the working of this model can be understood from Fig. 2.

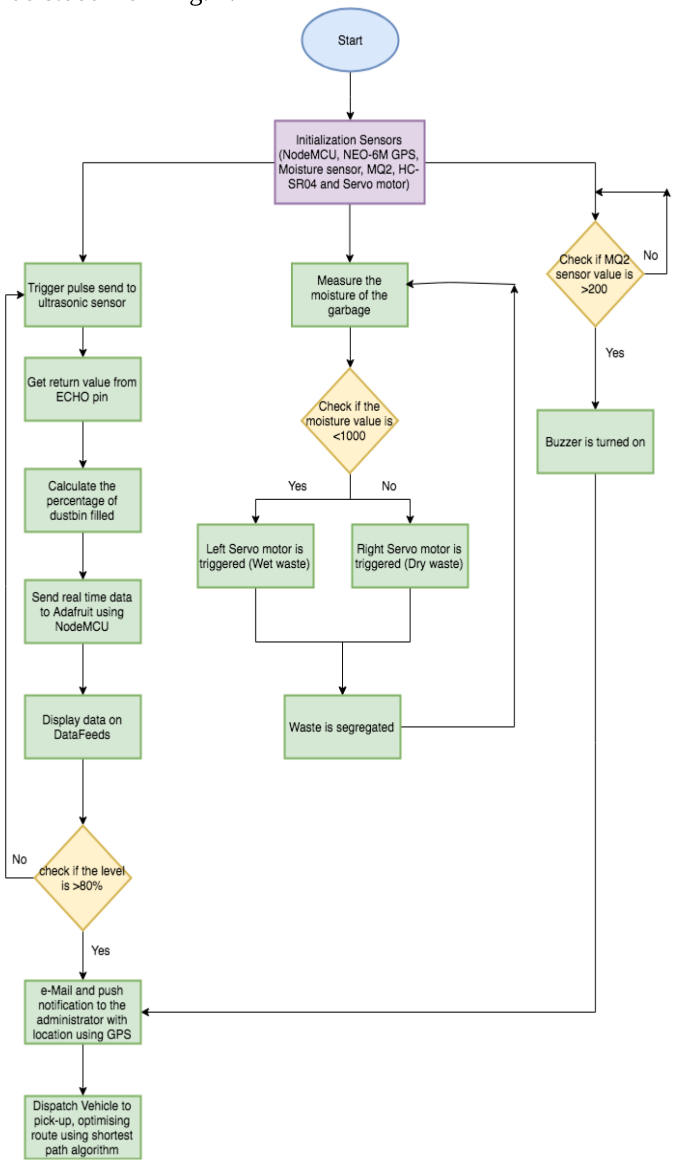

Fig. 2. Flowchart of the SmartBin

III. Implementation and Results of SmartBin

The development of the SmartBin is mainly divided into two parts: hardware and software implementation. The hardware portion consists of ultrasonic, moisture and MQ2 gas sensor. It also consists of a GPS module for tracking the location of the dustbin. The programming of the microcontroller unit to access various cloud services are a part of the Software implementation and results. The specification of each sensor is discussed below.

A. *Hardware implementation and results*

1) *Node MCU*

A combination of ESP8266 Wi-Fi microchip and ESP 12 module, NodeMCU is a single board microcontroller with the memory of 128kbytes and storage of 4Mbytes. NodeMCU has better clock speed, SRAM and flash memory than Arduino Uno. This low-cost board can be programmed on the Arduino IDE. The NodeMCU has 10 GPIO pins which are capable of PWM and I2C. The major advantages of using NodeMCU over other microcontroller units is that it contains a built-in Wi-Fi module and cost-effective. [9].

2) Ultrasonic Sensor HC-SR04

The moisture sensor is used to measure the volumetric content of water inside any substance. It measures the capacitance of the medium to further infer its dielectric permittivity. The difference in conductivity and volumetric content of water in dry and wet waste helps in waste segregation.

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4) Servo Motor

It is a basic DC motor with gears and a control circuit which gives a precise angular hold position owing to the requirement. A control signal representing a desired angular output position is sent to the servo motor which further drives the DC motor.

5) MQ2 Gas Sensor

MQ2 is a smoke sensor which is suitable for sensing various gases like LPG, CH4, and CO2, etc. MQ2 gas sensor contains a metal oxide semiconductor which is subjected to a change in resistance when it comes in contact with the gases. The sensor has a range of 200-10000 ppm [11].

6) Adafruit

It is a cloud platform which is used for storing the sensors output data on the internet rather than keeping it on physical computers. It provides various features such as analyzing data on graphs, integration with mobile applications such as DataFeeds, notifications to the administrator via IFTTT (If This Then That), a free web service used for creating loops of conditional statements, called applets.

7) NEO-6M GPS MODULE

The Ublox Neo-6m module has 25*25 mm active GPS antenna giving best positioning output. The module uses EEPROM for saving the configuration settings. The antenna is externally connected via UFL cable thus can be aligned to the best position [12].

8) BUZZER

The piezo buzzer works at an operating voltage of 3-10V and produces a sound of 3 KHz tone at a level of 85dB at 25 cm. The buzzer is connected with the smoke sensor to inform people of fire in the SmartBin.

The inner circuitry of the dustbin is shown in fig. 3. The block marked as (a) shows the ultrasonic sensor used for level sensing. Blocks (b) and (c) represent MQ2 gas sensor and the buzzer respectively which are connected to the Arduino-UNO. The smoke sensor senses the density of gases and in case of a fire, it sends a trigger signal to the buzzer. The buzzer alerts the people nearby of the fire inside the SmartBin.

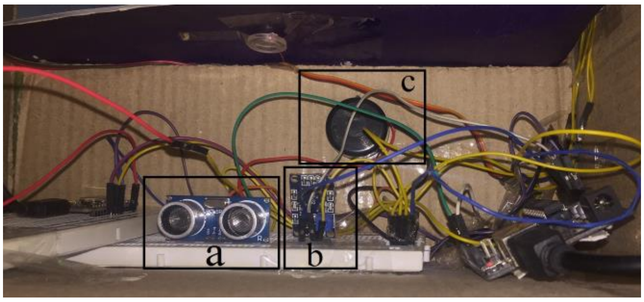


Fig. 3. Inner circuitry of the SmartBin

Fig. 4 depicts the top view of the model. Wet waste material has been placed on the moisture sensor. The moisture sensor senses the volumetric content of water in the waste material and sends a signal to open the wet flap. Two servo motors can be seen on either side which opens the wet or the dry flap.

Fig. 4. Wet Flap opening due to the moisture content of the waste

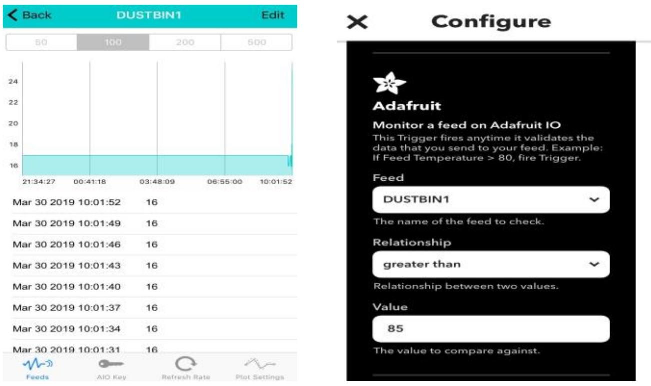
Fig. 5 shows the SmartBin model proposed in the paper. The moisture sensor is installed at the top of the dustbin where the garbage is kept and its conductivity is checked.

Fig. 5. A prototype of the SmartBin model

B. *Software implementation and results*

The NodeMCU has been programmed on Arduino IDE. The board sends a trigger signal to the ultrasonic sensors which calculate the distance and returns the value to the NodeMCU. This value is further sent to the cloud by ESP8266 SoC through Wi-Fi. The moisture sensor returns the resistance value to the microcontroller unit which further sends a signal to the respective servo motor.

Fig. 6a shows the DataFeeds mobile application which shows the value at an interval of 3 seconds and a graph of the data. Fig. 6b displays the IF THIS THEN THAT (IFTTT) mobile application. IFTTT is a free cloud service, which works on conditional statements named applets. Applets get signal of performing the action by a change in data that occurs on various sites and on cloud services like Adafruit. IFTTT notifies the administrator at the municipality whenever there is a change in data.



(a) (b)

Fig. 6. Mobile notification (a) DataFeeds (b) IFTTT

The administrator sets an IF condition after linking Adafruit and IFTTT that Send an email if the value exceeds a threshold of 85. As soon as the value of the dustbin exceeds 85, the administrator receives an email and a notification on his mobile phone. Fig 7 displays the block created on Adafruit cloud platform for displaying the data. It informs the administrator that the dustbin is 16% full. Adafruit provides various blocks such as maps, switching, reset, graphs, etc. Multiple feeds can be created on the cloud server which can be used to monitor multiple dustbins.

Fig. 7.Cloud service (Adafruit)

IV. Impact Analysis of Smartbin in Ahmedabad

This section presents the cost and impact analysis of the proposed model for Gota ward under Ahmedabad Municipal Corporation (AMC), Ahmedabad, Gujarat. Table 1 shows various specifications of the current solid waste management system in the city. Presently, AMC controls solid waste management using RFID and GPS technology. The trolley contains the RFID tag and the trash collector vans have RFID readers. Whenever a trolley is emptied into the vehicle, the reader identifies the bin. So, at the end of the day, the administrator is informed about the locality from which the garbage was collected. This system is not able to suffice the needs of the increasing population of the city. It has increased from 6.2 million in 2010 to 7.8 million in 2019 which led to an increase in the number of trolleys and dustbins installed in the city each year. The problems associated with the current system include inefficient utilization of resources, labour cost, and pollution as well as an increase in the required number of trash collector vehicles for picking up the garbage without any real-time information. This contradicts the idea of Smart Cities. Being a part of the Smart City project, the AMC should implement a model where statistical and predictive analysis of data can be used to optimize its waste management system.

TABLE I
DATA SURVEY OF AHMEDABAD [2]

Ahmedabad City Profile	
Population	78 lacs
Area	466 sq. km
Wards	48
Solid Waste (TPD)	3800
Vehicle (equipment)	1500
Annual Budget of SWM	400 crores
660L Trolley	199
1100L Trolley	847
90L Bin	1240
Total bins	2286
Per Capita Daily waste	600g
Community and Residential collections	
Residential Unit	1.5 million
7000L Dustbin	803
Collection points	757

Owing to the disadvantages in the current waste management system, the SmartBin model proposed will help in reducing the budget of Ahmedabad Municipal Corporation. One SmartBin cost about 1500 INR and the cost would reduce significantly in mass production. The reduction in cost can be better understood from the following case study.

A case study for Gota ward of Ahmedabad Municipal Corporation is presented in fig. 8. It shows a map for a trash collector vehicle visiting five pickup points marked A, B, C, D, and E respectively. Each value on the line represents the shortest distance between two garbage pickup points. A cost= analysis is performed in order to calculate the amount of money that can be saved by installing the proposed method of waste collection. There are two parts of this analysis, first the present day costing and second the new future way of costing

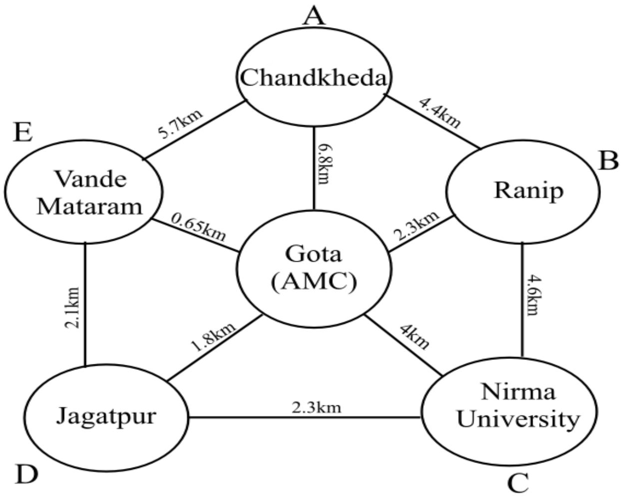


Fig. 8. Case study of a municipality in Ahmedabad

A. Current model evaluation:

In Fig. 8, the trash collector vehicles are stationed at Gota, a ward under Ahmedabad Municipal Corporation. The following route is taken by the vehicle:

- *Gota - Vande Mataram - Chandkheda - Ranip - Nirma University - Jagatpur - Gota.*

The below mentioned cost analysis is done for the same route where a vehicle visits each location every day and follows the same path.

Total distance covered in one day = 19.45 km
Total distance covered of 1 month = 583.5 km
Total distance covered in 1 year = 7099.25 km
The mileage of a trash collector van = 8 km/L
So, there will be 887.40 L of petrol consumed by one vehicle in one year.
The total cost of that petrol = Rs.63893.25

The total costing is Rs.63893.25 + maintenance cost is the total costing for one vehicle for one year of waste collection for the above-mentioned region.

B. Proposed model evaluation:

In a real-life scenario, on an average two to three dustbins are filled on each day. The following is route considered on various days:

DAY 1: Gota- Chandkheda-Jagatpur-Gota
Total distance = 14km
DAY 2: Gota-Ranip-Nirma University-Gota
Total distance = 10.9km
DAY 3: Gota-Vande Mataram- Nirma University-Gota
Total distance = 10km
DAY 4: Gota-Chandkheda-Nirma University-Gota
Total distance = 14km
DAY 5: Gota-Ranip-Jagatpur-Gota
Total distance = 11km

The average distance of 1 day = 11.9 km
Total distance covered in 1 month = 359 km
Approximate total distance covered in 1 year = 4312 km
The mileage of a trash collector van = 8 km/L
So, there will be a 539L of petrol consumed by one vehicle in one year.
The total cost of that petrol = Rs.38808

The total costing is of Rs.38808 and maintenance cost is the total costing for one vehicle for one year of waste collection from the above-mentioned region.

C. Comparison between the current system and the proposed model:

Cost comparison between current and proposed waste management is shown in fig. 9. It clear from that graph that implementation of the proposed method in an only small region with a single trash collector vehicle can save about 25,000/- INR. This shows that the implementation of this method for a whole Smart city will be very cost efficient and also the amount of pollution caused by these vans will be reduced.

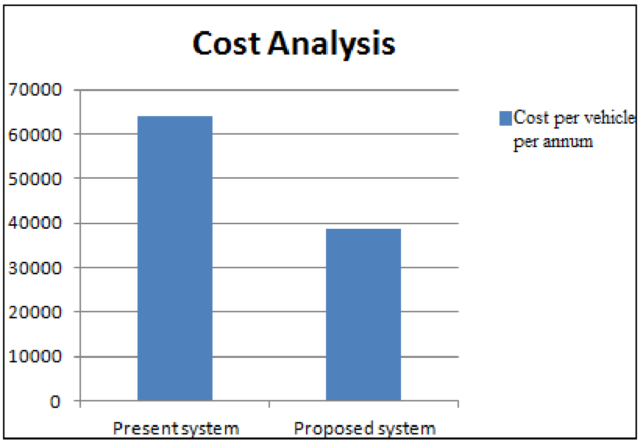


Fig. 9. Comparative cost analysis

Further, the current system for waste collection is inefficient as there are having static routes and schedules for solid waste collection. Hence time, money, labour, and fuel are not used efficiently. 60% of solid waste is not collected from the city and is rather burnt on the roadside causing harm to the environment. The current waste management system uses RFID tags and RFID readers which together inform the administrator whether the garbage is collected from a particular dustbin or not. This system is not effective, as it does not provide the administrator with any kind of useful information and does not cater to the needs of a Smart City. Implementation of the proposed model would offer the following advantages over the current existing model:

I. If trash collector vans are GPS enabled, routes can be optimized according to the pickup points, traffic, fleet availability and road conditions of the city. Drivers can follow the updated GPS navigation, which will provide them with the shortest path, and therefore they can collect efficiently from the city.

II. All the data is relayed to the Adafruit cloud server platform. One can access this data in real time and optimize routes by skipping empty bins. One can also run the predictive analysis by using active learning and data analytics. It will help in predicting the fill levels of the dustbins in advance. The access to all the information is possible via the mobile application, emails and push notifications.

III. The amount of air pollution caused by CO_2 emissions by the trash collector vans reduces to a great extent by deploying the proposed model. Since the number of visits to the pickup points will decrease, hence fuel consumption will reduce. Fire in the dustbin will be detected with the help of smoke sensors hence ensuring the safety of the system.

IV. The operational and capital expenditure too will be reduced at the same time. The SmartBin model can be installed to any existing bin of any size, shape, and dimension so there will be no need for new infrastructure for deploying the system. The decrease in unnecessary cleanups and visits to the pickup points by the trash collector vans will lead to a reduction in the manpower required, labour cost, maintenance cost, and operating fuel consumption. Hence by deploying the SmartBin, a Clean and green neighborhood will be maintained.

V. CONCLUSION

In this paper, the SmartBin model has been designed for solid waste management with automatic waste segregation at the initial stage for smart cities. It helps in reducing human interaction and pollution. The SmartBin also performs accurate cloud-based level sensing notifying the administrator about the amount the dustbin is filled. It fulfills the requirement of Smart City by providing real-time data stored in the cloud for 30 days. This reduces transport cost and pollution caused during the collection process to a great extent. The impact and cost analysis of the proposed model for a ward of AMC of Ahmedabad city have been carried out. This analysis shows that the deployment of the proposed model in that ward will save about 25000 INR per annum. This also indicates that deployment of this model at a large scale will provide cost effective solution for any city. Predictive and statistical analysis can be performed using real time data that provided by this model which will help the municipal corporation to take further steps for the betterment of the city.

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