An ICT-based solid waste management system for smart cities: a case of municipality in India

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Abstract: Smart cities are technology enabled and data driven intelligent cities with prominent use of information and communication technology (ICT)-based technologies integrated with sensor devices. This paper proposes a low-cost, dynamic, energy-efficient and easily deployable smart solid waste management system for municipalities in urban localities. A kit comprising of a micro-controller, a pair of ultrasonic sensors and global system for mobile communication (GSM) module is installed into the garbage container. The contribution of this study can be seen in two folds. Firstly, the proposed system helps in achieving sustainable development goals namely, clean water and sanitation industry (SDG 6), innovation and infrastructure (SDG 9), sustainable cities and communities (SDG 11) and life on land (SDG 15). Secondly, contribution is the innovative solution for municipality solid waste management which could help in achieving three pillars of sustainability: economic, social and environmental, for sustainable development of future smart cities.

Keywords: smart cities; solid waste management; SWM; information and communication technologies; ICTs; linear regression; India.

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1 Introduction

In near future, globally, it is expected that more than a half of the total population will be living in urban areas and may cause critical challenges in providing sufficient, sustainable and quality resources such as clean water, energy and food. Moreover, basic infrastructure for sewage treatment plants, door to door garbage collection, internet services, ground water recharge, rain water harvesting, etc. will be highly crucial for sustainable development of future smart cities (Prasad and Alizadeh, 2020; Lai et al., 2020). Indeed, substantial rise in the population and urbanisation, causing significant increase in residential and commercial regions, has been a prevailing factor in the generation of huge amount of solid waste. This growing amount of municipal solid waste affects living standard of human beings and also leads to adverse environmental impact through soil and water contamination as well as air pollution (Singh, 2019). Therefore, it has become critical to address the issue of solid waste in a digital way in order to protect the urban surroundings and to maintain a clean and healthy society as inefficient and ineffective management of waste acclivities global warming effect by release of greenhouse gases (Ayvaz-Cavdaroglu et al., 2019). Moreover, efficient waste management system plays a major role in circular economy by reducing landfilling and increasing recycling and reuse

(Peri et al., 2018). To address this issue, the government of India launched ‘Swachh Bharat Abhiyan’ (Clean India Mission) in 2014 seeking different solutions for effective and efficient management of domestic and industrial solid waste to clean up the infrastructure and lanes of Indian cities, towns and rural areas. Researchers, from different domains such as healthcare, water pollution, speaker recognition and grammatical evolution, have contributed in addressing these issues by proposing the solutions using wireless communication technologies, algorithms and neural networks (please refer Bhattacharya et al., 2020; Wang et al., 2018b; Liu et al., 2018; Xie et al., 2017; He et al., 2017, 2016; Tan et al., 2018; Fan et al., 2016; Huang et al., 2018) but, one issue which is being addressed frequently is waste management. Incineration of solid waste is one of the key concerns in smart city projects. Incineration is mainly performed via process of co-incineration with coal because municipal solid waste has a low heating value (Havukainen et al., 2017). Nabavi-Pelesaraei et al. (2017) discussed environmental and energy consumption of incineration and landfill scenarios in Iran while, Jara-Samaniego et al. (2017) suggested composting as a promising method for sustainably managing and recycling of municipal solid waste. Camilleri-Fenech et al. (2017) suggested to improve waste collection process and use of route optimisation tools to significantly reduce carbon emission. Various solid waste management (SWM) systems found in literature use potentials of diverse information and communication technologies (ICTs) such as wireless sensor network (WSN), radio frequency identification (RFID), geographic positioning system (GPS), geographic information system (GIS) along with distinct transportation models for their application in container monitoring and waste collection (He et al., 2017, 2016; Rovetta et al., 2009; Longhi et al., 2012). Ghinea et al. (2016) proposed a prognostic tool with regression analysis and time series analysis which helps to predict municipal solid waste generation. Arebey et al. (2012) proposed a grey level co-occurrence matrix (GLCM) method for bin level detection and classification. However, there is a lack of studies that provide a complete end-to-end system design for optimal management of municipal solid waste.

As discussed, globally, one of the essential requirements in smart city project is to have a smart, efficient, sustainable and cost-effective waste management system. In recent years, Indian Government has planned to develop about 100 smart cities in India and shown a major concern over the SWM in order to protect human health, environment and fuel resources. According to Kumar et al. (2017), major challenges for local municipalities in India are related to waste generation and insufficient waste collection, transport, disposal and treatment. Moreover, cost of solid waste collection, its transfer and transportation contributes about 80% to 95% of the total SWM cost (Alagöz and Kocasoy, 2008). Therefore, monitoring and management authorities of solid waste are constantly looking for more cost effective and efficient solutions through application of modern and innovative technologies. However, despite substantial advancement in notable fields, the field of SWM systems in India remains comparatively untouched (Kumar et al., 2017). Moreover, adoption of ICT-based technologies allows effective and efficient data collection, acquisition, communication and analysis which ultimately result in higher operational efficiency of SWM system. It also acts as a control mechanism to ascertain the effectiveness waste collection process and transportation of containers with optimised collection route. It also facilitates in accurate forecasting and planning of solid waste collection and disposal process.

The purpose of the present study is to propose an ICT-based smart SWM system for future smart cities which can:

a Monitor the status of garbage containers at various locations of the municipality in order to manage adequate man-power.

b Show graphical analysis of the garbage collection activities performed in order to keep check on workers.

c Predict the number of containers required in a particular area in upcoming days in order to effectively manage solid waste.

d Suggest the optimised route for collecting garbage from the containers in order to lessen the fuel consumption.

The paper is organised as follows: Section 2 reviews various ICT-based SWM system reported in the literature followed by detailed description of the proposed smart SWM system with its elements in Section 3. Section 4 presents a case study to demonstrate the implementation of the proposed system and presents the test results of data analysis. Conclusions and future work scope are discussed in Section 5.

2 Literature review

India, one of the fastest developing economy in the world and planning to develop more than 100 smart cities in near future, with a population of about 1.33 billion people staying in 29 different states and seven union territories facing critical challenges in managing the huge volume of solid waste generated on daily basis. According to Dutta and Jinsart (2020), Ahmedabad, one of the major cities of the state of Gujarat, generates about 4,000 tons of municipal solid waste per day with the generation rate of 0.45 per capita (kg/capita/day). Recent studies conducted in various foreign countries such as Italy (Greco et al., 2015; Agovino et al., 2016; Simões and Marques, 2012), Tehran (capital of Iran) (Azadi and Karimi-Jashni, 2016; Shirazi et al., 2016; Nabavi-Pelesaraei et al., 2017), Africa (Din and Cohen, 2013; Henry et al., 2006), New Zealand, Taiwan, Turkey, Bangladesh, New South Wales (Australia), Vietnam indicated various issues faced by these countries in managing the operational and environmental variables influencing the collection efficiency of the municipal solid waste. A review of contemporary literature, addressing various issues related to SWM, is exhibited below.

To improve the onsite handling of solid waste and optimise the transportation process in waste management process, a sensor and data transfer node-based architecture was proposed by Longhi et al. (2012) which allows for the retrieved data measurements from the garbage containers to a remote server. One of the major limitations of this prototype was the use of a custom garbage container, which may lead to higher system cost of replacing each current container with the new one. Bhuiyan et al. (2017) also developed a waste management system with wireless vibration sensor network (WVSN) which was capable to reduce the energy consumption by at least six times in comparison to the existing approaches. However, bandwidth limitation is a major challenge to apply WVSNs to this area. With an intension to provide a solution to municipal SWM, Faccio et al. (2011) and Cavdar et al. (2016) employed internet of things (IoT) technology in their approaches. Faccio et al. (2011) proposed a SWM system using ultrasonic sensor, volumetric sensor and RFID tag to sense the garbage level and estimate the volume of the container. In their framework, they adapted a traceability technology and an innovative routing model for route optimisation. However, the implementation of these systems in the real-life scenario is challenging.

In recent years, a number of mainstream forecasting models have been implemented on present and past solid waste generation data. The study of Jiang and Liu (2016) in Europe forecasted the complex waste generation under latent parameters and uncertainties (i.e., economic growth, geographic change, individual behaviours, festivals and management policies) with the help of probability model driven by a statistical learning model which hybridises a Gaussian and hidden Markov model. Study illustrated by Akhtar et al. (2017) represented a backtracking search algorithm in a capacitated vehicle routing problem model with the concept of smart garbage containers to discover the optimised route for waste collection. This study introduced threshold waste level for every container to decrease number of containers to be emptied and thus, minimising the distance for garbage pickup. These results were found optimum for optimisation of the route, economic costs and environmental effects. However, a highly skilled professional is required to understand the results and it could not be efficiently used unless properly managed. Moreover, the study carried out by Asefi et al. (2017) proposed a framework for efficient location-routing of garbage trucks to minimise the irrelevant cost (i.e., transfer station, disposal centres, treatment facility) with an adaptation of annealing algorithm. The studies of Adamović et al. (2017) and Abbasi and El Hanandeh (2016) presented the application of artificial intelligence using different models to forecast the MSW generation. The first approach shows the prediction of MSW generation for 44 countries each having unique size, population and economic development with the support of artificial neural network enhanced by structural break analysis. The next study held in Queensland, Australia aimed to forecast the MSW generation on the monthly data using four different intelligent system algorithms which include support vector machine, adaptive artificial neural network, neuro fuzzy inference system and k-nearest neighbour (Abbasi and El Hanandeh, 2016). In the other recent works, Brian et al. (2018), Shin et al. (2019), Jhaveri and Patel (2017), Jhaveri et al. (2018), Priya et al. (2020) and Deepa et al. (2020) addressed the security issues in such systems, while Chang et al. (2020), Goyal et al. (2016), Somayaji et al. (2020) and Rajadurai et al. (2020) touched import issues of battery life, energy conservation and latency for such systems.

Encapsulating the studies aiming to find a solution for MSWM all over the globe, in most of the proposed systems, the hardware failed to fit in the current MSWM system in their respective countries. Problems such as high implementation cost, uncertain maintenance and uneven utilisation of the workers lead to a failure. Despite of numerous studies proposing various graphs and models using different techniques, it remained as a random value on the screen because of its limitations to eradicate MSW. A proper combination of software and hardware is necessitated in order to achieve a complete system which can be successfully adapted as the municipality waste management system. The present work addresses the limitations of existing work by proposing a low-cost and low-maintenance system integrating data analytics and recommendations for effective pickup of waste and reducing fuel cost.

3 Development of ICT-based SWM system

As cellular and Wi-Fi technologies have proved to be successful over the past few decades, wireless communication has become an integral part of day-to-day communication (Jhaveri et al., 2018; Bera et al., 2020). This section will critically discuss and justify the use of ICT-based SWM system in comparison to other approaches or methodologies available in the literature. This section will also discuss and highlight three points:

1 hardware-kit integration with the garbage container
2 back-end system for storage and status update on cloud
3 web platform for the municipality authority.

Oralhan et al. (2017) proposed a machine-to-machine technology-based system in which, an integrated sensor unit positioned over the top of garbage container transmits temperature value, carbon dioxide ratio and fill level in real-time to the waste management software on cloud. This data along with the distance between garbage container and garbage wagon was utilised for discovering routes in dynamic manner. Zhao et al. (2017) proposed a system called VibeBin which regularly checks the fill-level and takes a sample of vibration local maxima. The local maxima comprises of numerous duos of voltage and vibration intensity. The sample is then propagated to the backend server where it is stored. The resonant voltage and intensity change according to the changes in the fill-level. The backend server, with a customised clustering technique, learns the fill-level by collecting samples which are then divided into different groups, each indicating a specific garbage fill-level. The system then automatically analyses the results in order to discover recurring cycles of empty-full containers. Each group is then assigned different level numbers. The profiles of different levels are then created with selected representative samples from each group. In order to estimate the current garbage container fill-level, new samples are then matched with historical profiles. Hannan et al. (2011) proposed a theoretical framework along with an interface algorithm which can be utilised to integrate different communication methods such as RFID, GPRS, GPS and GIS in order to implement a prototype. The proposed framework can analyse the location of the pickup vehicles and estimate the fill-level of the container. Al Mamun et al. (2013) proposed a three-tier architecture in which sensor nodes are located in the lower tier. In order to measure the fill-level, wastage weight, temperature and humidity of the container, a specific set of sensors are deployed inside the container. RF technology is used to transmit the collected data to the upper tier. The middle tier contains gateways consisting of ZigBee and global system for mobile (GSM)/GPRS modules which receives data from the lower tier and forwards it to the upper tier containing the control station where servers reside. The servers have the storage and a group of applications for data storing and monitoring. Rovetta et al. (2009) proposed the clean wings scheme which is based upon web-access architecture for a distributed sensor network. There are three main tiers of the network:

1 a group of back-end applications incorporating data application layers (DALs)
2 the storage for geographical information and the database management system (DBMS)
3 a front-end application to allow direct information access to all the authorised users.

From the network of sensor embedded containers, the data is transmitted for processing. Each container's data are frequently updated at the levels of DAL and DBMS. Moreover, each container transmits data every time during opening and closing of its cover.

During the review of each of the existing solutions, it is found that it is hard to achieve cost effectiveness, ease of deployment and high accuracy simultaneously. The existing solutions to SWM in one way or another include elements which are costly and not so accurate all the time. In order to deal with these limitations, the advanced communication technology solutions such as Arduino, GSM, ultrasonic sensors must be utilised. In view of this, proposed study uses these technologies as well as the combination of software and hardware into a system which is divided into three parts (Figure 1):

1 hardware-kit integrated with the garbage container
2 back-end system for data storage which is being collected from each container and status update on cloud
3 web platform for the municipality authority.

3.1 Hardware-kit

In the proposed kit, we use a set of ultrasonic sensors (HC-SR04) integrated with a micro-controller (ATmega328), and a GSM module (A6 mini) for sensing the level of garbage inside the container and sending a text alert to concerned municipality authority, respectively. For hardware interfacing, we use Arduino IDE and Arduino programming language.

Both the sensors are situated at a predefined distance from each other in order to cover the whole area of the container for accurate garbage sensing process. The whole system is powered using 24 volts 20 watt solar panel which is ideally connected with 12 volts 7 Amp hour rechargeable battery. The embedded system costs INR2,500/- approximately. We use Arduino Nano microcontroller:

1 to collect and store the data from sensors
2 to signal the GSM module for sending text alerts.

The system uses any available cellular network to communicate with the municipal authority and to share the acquired data with the server, which will also eliminate the cost of internet data charges. In the proposed system, whenever the GSM module receives a signal from the microcontroller, it sends a message containing information regarding container identity, current status, current date and time.

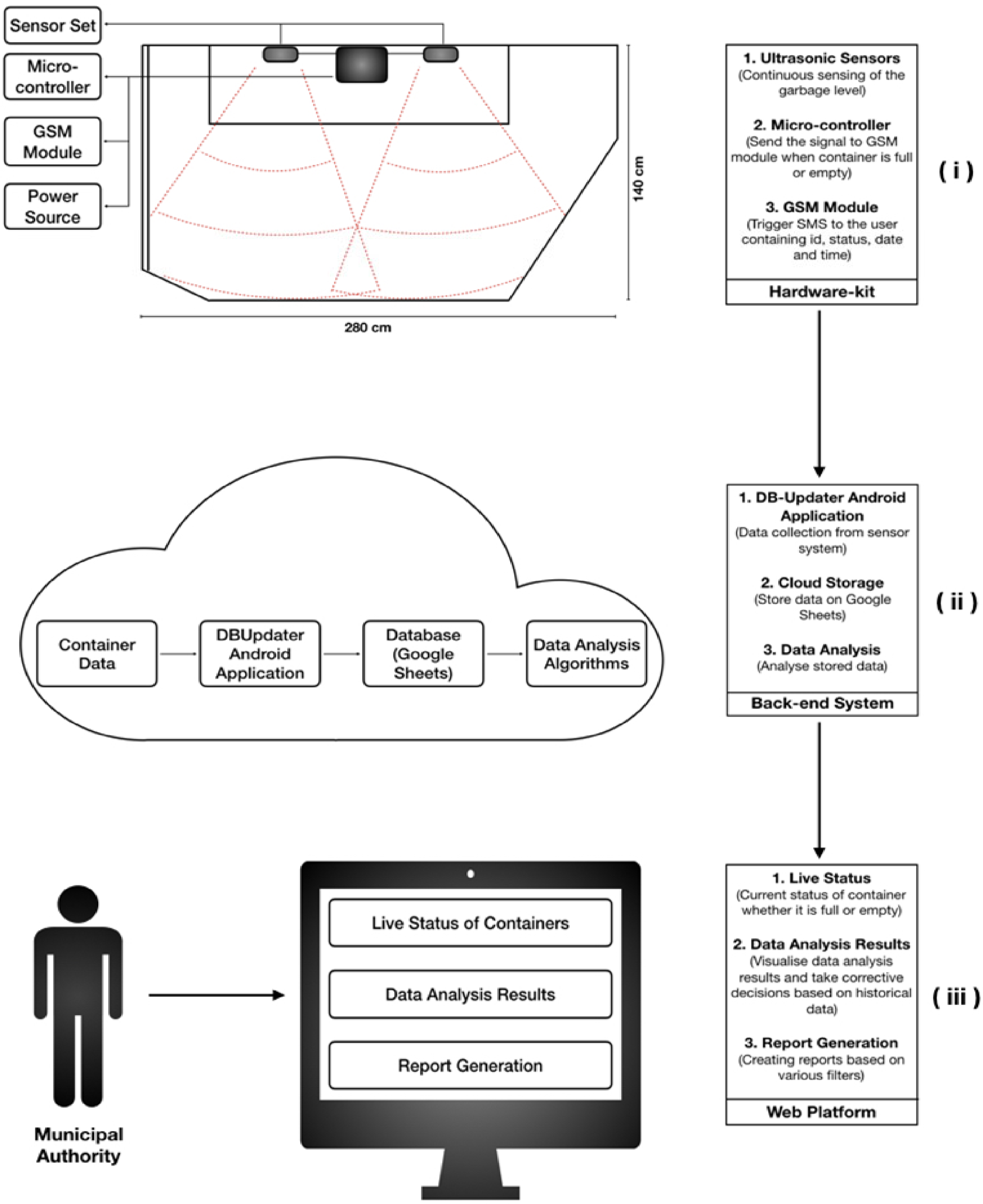
3.2 Back-end system

Back-end system is proposed for the developers and engineers to handle the data. This section describes the whole back-end system which would be operated and maintained by the developers.

3.2.1 DB-updater – Android application

An Android application is developed to automatically upload the data to the cloud storage which is being received from the cellular network. This server-side application runs in the background of the device and needs to be configured only once before its use. Google Sheets play role of the cloud storage as it fluently integrates with DB-updater to fetch the data as well as with the web-platform to display the data, keeping all the things updated dynamically.

Figure 1 Proposed system work-flow (see online version for colours)



3.2.2 Database

In recent years, cloud computing has proved its capability in information exchange by addressing numerous challenges including resource scheduling, security and privacy (Lin et al., 2017; Zhang et al.,2017; Wang et al., 2018a; Xie |et al., 2017; Joshi and Ahmed, 2016). Therefore, the data collected from the hardware-kit is forwarded as a text message containing container's identity, status, date and time. This information is then transmitted on the cloud storage using the aforementioned Android application. Currently, the database is created keeping in mind the data collection in the real-world scenario.

3.2.3 Data analysis

Data analysis plays an important role by helping the municipal authorities to predict future garbage flow of a particular container, to discover the probability of the container getting full which helps the authority to predict whether the container is eligible to enter today's pickup list.

Predicting flow of garbage

We use linear regression to predict how many times a container will be full in the upcoming month based on historical data. Algorithm 1 represents operations for predicting flow of garbage.

Algorithm 1	
Step 1	Start
Step 2	Read month and full_count columns data from database
Step 3	Apply linear modelling (LM)
Step 3.1	Create a linear model using LM (MONTH, FULL_COUNT)
Step 4	Set outcome variable and store that data as a frame
Step 4.1	LinearModelVar <- LM (MONTH, FULL_COUNT)
Step 5	Apply 'predict' function and store results
Step 5.1	Predict the count of the next month(FULL_COUNT) using counts of previous months(MONTH)
Step 6	Forward results to web platform
Step 7	Stop

Finding probability of container getting full

In machine learning, naive Bayes classifiers assume strong independence between different features. To find probability, first it generates a frequency table of items in the dataset followed by a likelihood table. Finally, by applying the naive Bayes formula, we can get the probability of particular variable. In our system, we find the probability of the container getting full on the next day using the following equation (1):

$$P(FULL_{PROBABILITY} \mid Container_{ID}) = \frac{P(FULL_{PROBABILITY}) * P(Container_{ID} \mid FULL_{PROBABILITY})}{P(Container_{ID})} \quad (1)$$

where

P	probability
$Container_{ID}$	unique ID of each container
$FULL_{PROBABILITY}$	probability of container getting full.

If the probability is more than 70%, that container is included on the route for the pickup van.

Algorithm 2 represents operations for finding probability of container getting full.

Algorithm 2	
Step 1	Start
Step 2	Read container_ID and full_count columns data from database
Step 3	Clean and pre-process data
Step 4	Wrap data into a frame
Step 4.1	Naivebayes <- data(Container_ID, FULL_Probability)
Step 5	Generate model using 'naïve bayes'
Step 5.1	Model <- P(Naivebayes)
Step 5.2	Follow equation (1)
Step 6	Apply 'predict' function and store results
Step 6.1	Predict <- P(Naivebayes)
Step 6.2	Predict the count(FULL_Probsbility) of the containers getting full using the counts of previous containers(Container_ID) getting full
Step 7	Forward results to web platform
Step 8	Stop

3.3 Web platform

A web platform is developed to:

1. show the live status of a particular garbage container
2. visualise data analysis
3. generate reports for better monitoring.

3.3.1 Live status of containers

The live status shows the latest alteration in the container's status. For example, if the status of the container has become 'full' to 'empty', then the status will be automatically updated on the website, and will display the container's identity, date and time it got emptied on. The status remains unchanged until that container gets full again.

3.3.2 Data analysis visualisation

In order to better visualise the data analysis for the municipality authority, we plot a variety of graphs. This provides ease of interpretation and filtering of required results. All the graphs are plotted using Google Chart's JavaScript library which links dynamically with Google Sheets database.

3.3.3 Report generation

The proposed system generates various reports to provide:

1. daily, weekly, monthly and yearly tracking of waste collection process
2. several charts to summarise activities perform in defined duration.

4 Case study

To demonstrate the implementation of the proposed SWM system, complete garbage collection process of the Bharuch municipality was thoroughly studied with the support of the municipality president. As data collection is an important part of this study, it is decided to visit solid waste collection points in the city as well as nearby rural area in person to get in-depth understanding of waste collection and loading process. Moreover, solid waste dumping sites are also visited for few times to visualise the container emptying process. The officers responsible for waste collection and emptying process were requested to participate in semi-structured interview to collect the information related to number of containers, number of fleets, fuel consumption, etc. Also, the log-books available with municipality staff, involved in this process, were also used as a source of secondary data to confirm the information and data provided by the officers. Currently, there are 11 wards in Bharuch city with 130+ places where containers are placed and 90–95 tons of solid waste is generated daily. Following are the information and data collected during the study:

1 The municipality is responsible for the solid waste collection process amongst Bharuch city along with four rural areas nearby Bharuch.

2 A total of 50 vehicles including tractors, pickup van, dumper placer and garbage compactor trucks are assigned into this work to accomplish day to day waste collection process.

3 There are approximately 250 garbage containers in Bharuch municipality, each having the size of 4.5 cubic metres.

4 Municipality empties 35 containers, filled or partially filled, every week.

5 Whole process takes 348 workers working on fix salaries and 30 other workers working on hourly wages (depending the work load).

6 A dumper consumes 28 litres of diesel per week (approximate cost is INR1,930/-).

Like other municipalities across India, Bharuch municipality is yet to have an ICT-based system for effective SWM and therefore, the SWM in the municipality is carried out manually.

The purpose of the data collection was to understand:

1 the process of waste collection

2 the process of emptying containers to conclude whether it damages the area where proposed kit needs to be located.

As indicated in Figure 2, the waste collection process starts at 7:00 AM in the morning, where all the dumper place has their fixed route which they have to visit regardless of the status of the container (viz., full or empty). The process includes collection of one container at a time and emptying it at the dumping yard. Soon after, the emptied container is carried onto another location and replaced by a fully filled or partially filled container which is then carried back to the dumping yard. The process continues until 7:00 PM in the evening for every area of the municipality.

Figure 2 Waste collection and management process

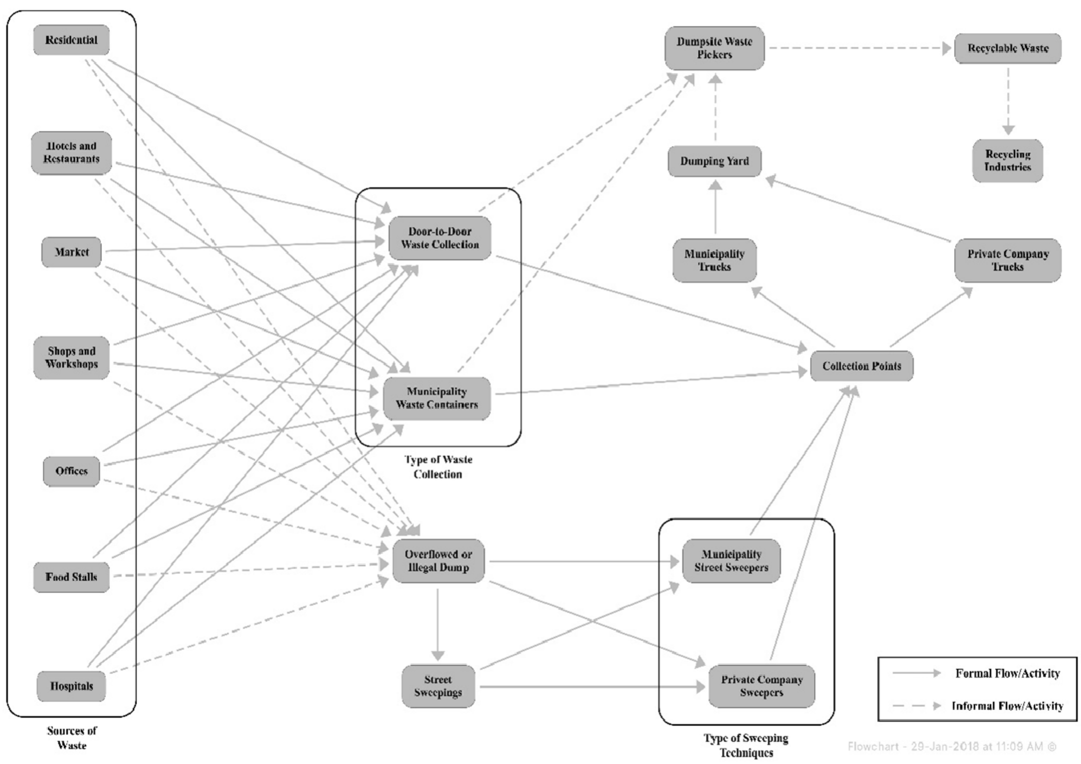


Figure 3 emphasis that the whole process of collecting and emptying would not be playing any role in damaging the proposed the system. During lifting process, the container is lifted at certain degrees in dumper placer as well as garbage compactor (widely used nowadays all over India) which keeps the top area of container safe which is necessary for the kit to be fitted.

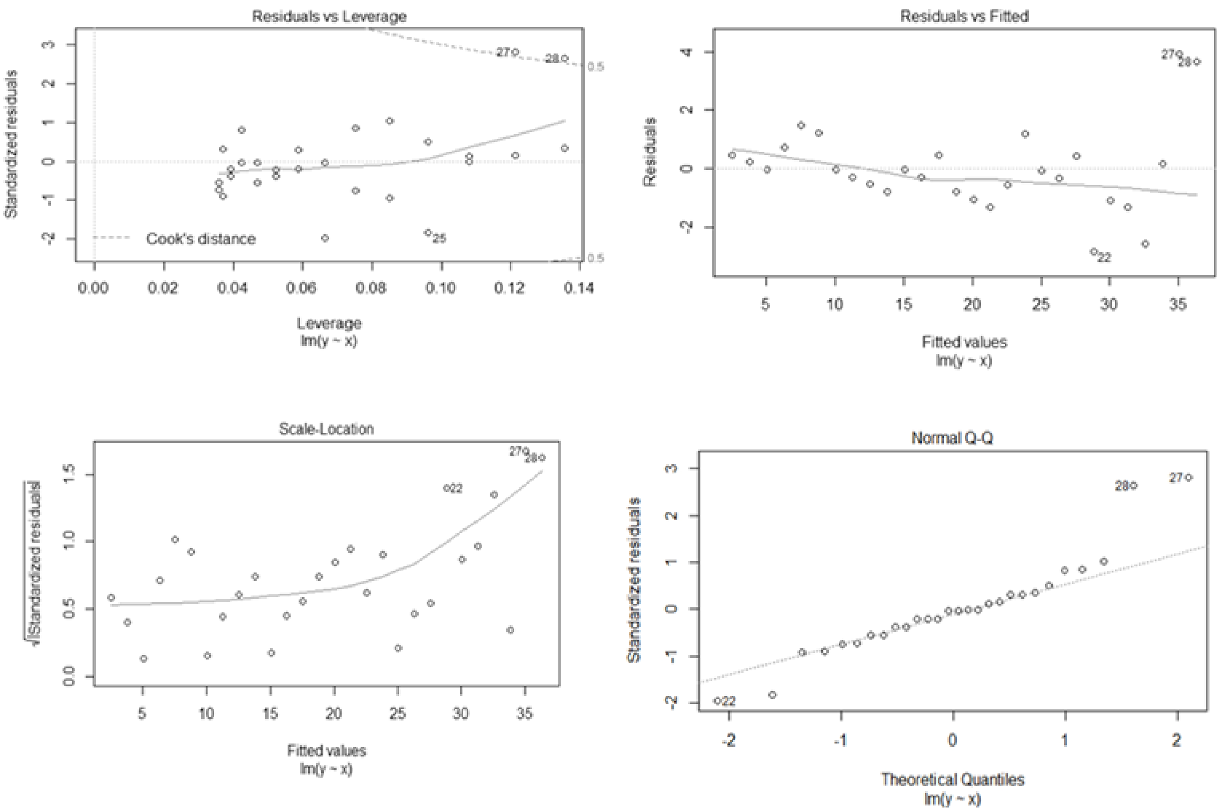
Figure 3 also shows the two dump yards on the peripheral of Bharuch city which are likely to be filled in next two years as per the information provided by the municipality authority. Dumping yards release so much of toxic gas, which in turn, generates heat and results into garbage catching fire on its own. Additionally, the whole cycle of the waste collection covers a long route consuming a big chunk of fuel. This fuel cost could be significantly reduced by implementing the proposed system.

Moreover, the current waste collection process acquires large manpower, high maintenance cost (of vehicles and fuel) and creates environmental pollution. To vanquish the current scenario, we propose a cost-efficient and smart way to manage the generated solid waste in the cities and rural areas. We implanted the proposed system into a 1/3 size of a replica of the original container and results were promising. We worked along with the municipality officers to get the correct data. However, due to no digital record of daily generated data for each container, we placed stochastic data to check the system. Moreover, following plots will show that the data used to check the system tidy and with minimum outliers.

Figure 3 Waste collection and container emptying process in the dump yards (see online version for colours)

In Figure 4, the diagnostics of regression on stochastic data is shown. It represents the residuals vs. leverage chart which helps to find exceptional or influential cases if any. Even though data have some uttermost values, they might not be influential to determine a regression line. That means, the results would not be much different if we either include or exclude them from analysis.

Figure 4 Diagnostics of regression on stochastic data

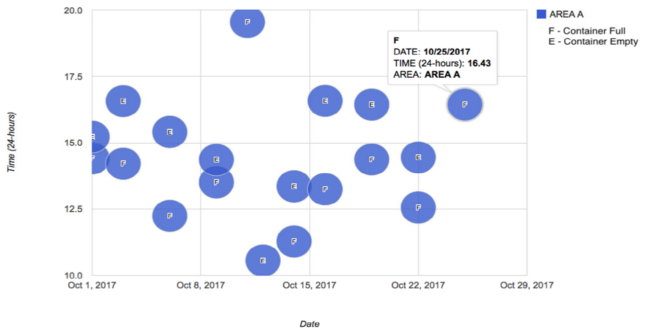


As presented in Figure 4, a good residuals vs. fitted plot indicates that there are no nonlinear relationships between data. Ideally, this plot should not show any pattern. Predictor variable and outcome variable may have a nonlinear relationship between them. Scale location is how one can check the assumption of equal variance. It is preferable if we have a horizontal line with equally spread points. Normal Q-Q plot is used to find out the normal distribution of errors where standardised residual values are used. In normal case, this plot shows a straight line, however, a distorted or curved line indicates an issue where residuals have a non-normal distribution.

4.1 Data analysis results

Figure 5 shows one-month statistics of the time of the day when a container is full and the time when the container is being emptied after that. This chart lets the municipality authority to monitor the efficiency and dedication of the assigned man-power.

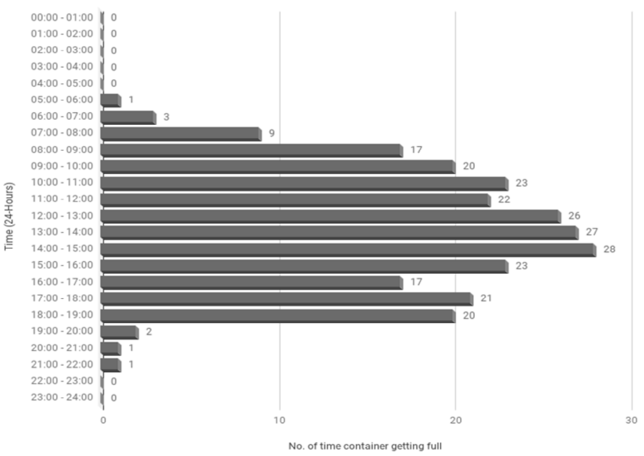
Figure 5 Statistics of picking and emptying the container (see online version for colours)



4.1.1 Most active hours of garbage flow

Figure 6 presents a chart indicating the peak hour(s) of the day at which the container usually gets full and empty. This lets the municipality authority to make a plan to empty those containers before peak hours which considerably reduces environmental pollution.

Figure 6 Most active hours of garbage flow



4.2 Future predictions results

4.2.1 Predicting flow of garbage

Table 1 discusses the sample outcome of the algorithm represented in Algorithm 1. We enter data for 20 months (predictor variable) and the outcome variable (next month) is set for 21. Hence, full count of a particular container at the end of the 21st month will be 28. This predicted value is included in the input file and the similar process continues for predicting data for the upcoming month. This prediction assists the authority to decide whether the quantity of containers should be added or removed in a specific area.

Table 1 Prediction of garbage flow

Months	*Full count*
1	3
2	4
3	5
4	7
5	9
6	10
7	10
8	11
9	12
10	13
11	15
12	16
13	18
14	18
15	19
16	20
17	22
18	25
19	25
20	26
21	*28* (predicted value)

Table 2 Probability of container getting full

Container ID	*% probability (container full)*
1	0.11
2	0.11
3	*95.76*
4	0.11
5	0.11
6	*78.50*
7	*95.76*
8	0.11
9	0.11
10	0.11

4.2.2 Finding probability of container getting full

Table 2 presents the outcome of the algorithm represented in Algorithm 2. The input data is filling and emptying information for ten different containers, and as the output, we get the probability of each container getting full on the next day. The containers having more than 70% probability of getting full are marked as ‘pickup tomorrow’. This assists the authority to decide an efficient route for the container pickup van which optimises overall cost by saving fuel.

5 Conclusions and future work

Research focused on defining smart cities, identifying diverse dimensions of smart cities and proposing solutions for various future challenges in developing smart cities including waste management is raising. Implementation of effective and efficient SWM will be one of the key challenges in near future in smart city projects. To address this critical issue, firstly we investigate the key challenges in managing solid waste generated in the urban and rural parts of India. The study proposes an ICT-based SWM system with deployment of a safe-guarded kit into all the garbage containers which consists of a pair of ultrasonic sensors, a microcontroller and a GSM module. The ultrasonic sensors continuously observe the waste level of the container. When the container gets full or empty, the integrated micro-controller triggers the GSM module to inform the municipality authority about the change in the status via text message. At the same time, we propose automatic updating of the container status on the cloud storage. In order to provide efficient monitoring for the authority, we propose a web-based platform which can provide data analysis of:

1 zone-wise frequency about the containers getting full/empty in a given time span

2 the average time duration spent by the assigned worker(s) in collecting the waste from a specific container in a given month.

Moreover, the machine learning algorithms are employed to:

1 predict the need of the number of containers in a particular area in the upcoming months based on the historical data

2 calculate the probability of the container getting full on the next day based on the historical data about the time span between a container getting empty and full.

This prediction helps the authority to decide:

a the optimal route for the container pickup vehicle in order to reduce the fuel costs

b the labour requirement for waste collection which is to be carried out on the next day, which in turn, optimises man-power costs.

Additionally, the system provides functionalities for additional check from higher level authority:

1 If a container is full, and if no action is taken by the authorised person (viz., sanitary inspector) for a predefined time period, a text message is automatically sent to a higher authority of the municipality.

2 In the case if the system fails to collect the status of the container, a manual check can be performed by sending a text message to the GSM module of the specific container to know the status of the erroneous component.

Moreover, this study represents a cost-effective smart SWMS which was developed based on a case study conducted in Bharuch, India [population: 1.69 L (Joshi and Ahmed, 2016)]. The study addresses the issues raised because of inefficiency in SWM such as: overflowing garbage containers, unmanaged routes for garbage pickup leading to unnecessary fuel consumption and undisciplined utilisation of man-power. Many red flags were hoisted addressing the above issues, according to which various smart systems were developed. Compared to other systems, the SWMS shown in this study is quite economical, dynamic and modular. Main factors which highlight the system are:

1 integrating the whole system on existing municipality environment

2 the data transmitted all across the system is dynamically updated

3 the municipality authority has a centralised view via the web platform to effectively monitor and manage solid waste in all areas of the city.

The proposed system can effectively contribute in:

1 reducing environmental pollution in the city

2 optimising routes for the garbage pickup and thereby, reducing the fuel consumption

3 predicting the man-power requirement for the next day

4 predicting requirement for the number of containers in a specific area.

Talking about limitations, the system would be placed in a public property which could be an open invitation for theft. It could be prevented but not be totally secured. The climatic change such as high, low or humid temperature could cause to partial system failure.

Keeping in mind, the issue of MSW exist not only in India, but it is a global chaos, specifically in smart city projects. Consequently, the smart SWMS developed in this study not only fits to work for Indian municipality’s but can also be adapted by any developing countries after applying some minor modifications. However, according to authors’ apprehension, presently, there exists few challenges which need to be dealt for successful implementation of this proposed system in India:

- There is no independent authority to regulate SWM in India.
- There are no clear rules and regulations about managing the solid waste.
- Littering and waste in streets can be challenging for implementation of the system.
- There is no vision for training the employees and capacity building at each level.
- Recharging battery of the proposed system during different weather conditions is one of the major challenges.

In future, data analysis based on reviews of the local people would be provided on the web platform for more interesting and effective results. For a smart (Wi-Fi enabled) city, the GSM module can be replaced with a Wi-Fi module which would further reduce cost of the hardware. Moreover, a weight sensor would be placed at the bottom of container which would be synced with the ultrasonic sensors and the micro-controller in order to provide a more accurate garbage level detection. Along-with, a heat sink fan cooler would be attached at the bottom of microcontroller to avert the failure caused due to overheating. RFID technology would be introduced which could keep track of all other details such as which employee emptied the container, in which truck arrived did the employees arrived and at what time the truck arrived. Basically, the use of RFID would keep track of pickup van arriving from one container to other container resulting that the drivers are working efficiently.

Availability of data and material

The data analysis showcased in this paper is carried out on a dummy database created on Google Sheets. The database was arranged in a specific format similar to the data collected from the system.

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