A Graph-Theoretic Model For Optimal Collection of Municipal Solid Waste Using Clustering Method

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ABSTRACT

This paper presents the simulation of Graph-Theoretic Model and GSM-enabled Smart Bin prototype for strategically enhancing the garbage bin deployment and optimizing the garbage collection of municipal solid waste. Garbage Collection has been a problem of every municipalities and/or cities due to its rapid population growth and urbanization. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Hence, this study developed this prototypes integrating the concept of Dominant Set inspired by Dominating Set in Graph Theory and K-Means Clustering method to enhance the garbage bin deployment and to optimize the collection of municipal waste. Data preparation, developing the prototypes, simulating the prototypes and collecting results were conducted. The findings can be summarized as follows. (1) Dominant Set able to suggest the best and unnecessary locations for the deployment of Smart Bins in the city and/or in municipality. (2) The simulation of the Graph-Theoretic model and the GSM-enabled Smart Bin prototype helps transmit Smart Bin information, monitor Smart Bins' garbage volume (in cubic meter) in real-time, clustering Smart Bins and accumulate each clusters' garbage volume (in cubic meter), and determine each clusters' garbage status if it's ready for collection or not. (3) The method of clustering Smart Bins help in getting the approximate amount of municipal solid waste in each cluster for optimal collection with least possible time.

Keywords: **Graph-Theoretic Model; Solid Waste; GSM-enabled**

1. INTRODUCTION

1.1 Background of the Study

According to the World Bank (2017), waste generation rates are rising around the world. In 2012, the worlds' cities generated 1.3 billion tons of solid waste per year, amounting to a footprint of 1.2 kilograms per person per day. With rapid population growth and urbanization, municipal waste generation is expected to rise to 2.2 billion tons by 2025.

A recent study conducted by Hoornweg and Bhada-Tata (2012) shows Municipal Solid Waste (MSW) generation rates are influenced by economic development, the degree of industrialization, public habits, and local climate. Generally, the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Income level and urbanization are highly correlated, and as disposable incomes and living standards increase, consumption of goods and services correspondingly increases, as does the amount of waste generated. Urban residents produce about twice as much waste as their rural counterparts.

As can be seen in Table 1.1, regions where the standards of living are higher and there is a greater consumption of goods such as Organization for Economic Co-operation and Development Regions (OECD) produce greater amount of waste in kg/capita-day, while underdeveloped countries such as those in the South Asian Region (SAR) present lower waste generation levels per capita. Furthermore, within each single region, there can be large variations of waste production depending on local conditions and specific dynamics (Hoornweg & Bhada-Tata, 2012).

Table 1.1 Waste Generation Data in 2012 (by Region)

Region	Total Urban Population (Millions)	Total Urban MSW Generation (tons/day)	Urban MSW Generation per Capita (kg/day)
Africa	261	169,120	0.65
East Asia and Pacific	777	738,959	0.95
Latin America and Caribbean	400	437 545	1.09
Middle East and Caribbean	162	173 545	1.07
OECD	729	1 566 286	2.15
South Asia	426	192 411	0.45
Total	**2982**	**3 532 255**	**1.19**

Waste composition varies greatly between different areas, regions and countries of the world. It is influenced by many different factors such as culture, economic development, climate, and energy resources. Based on previous considerations, Figure 1.1 illustrates the different waste composition on a regional level. It interprets countries in the OECD region that is strongly reflecting the profile of the high-income society while suffering nations such as East Asia and the Pacific present large fractions of organic waste products (Hoornweg & Bhada-Tata, 2012).

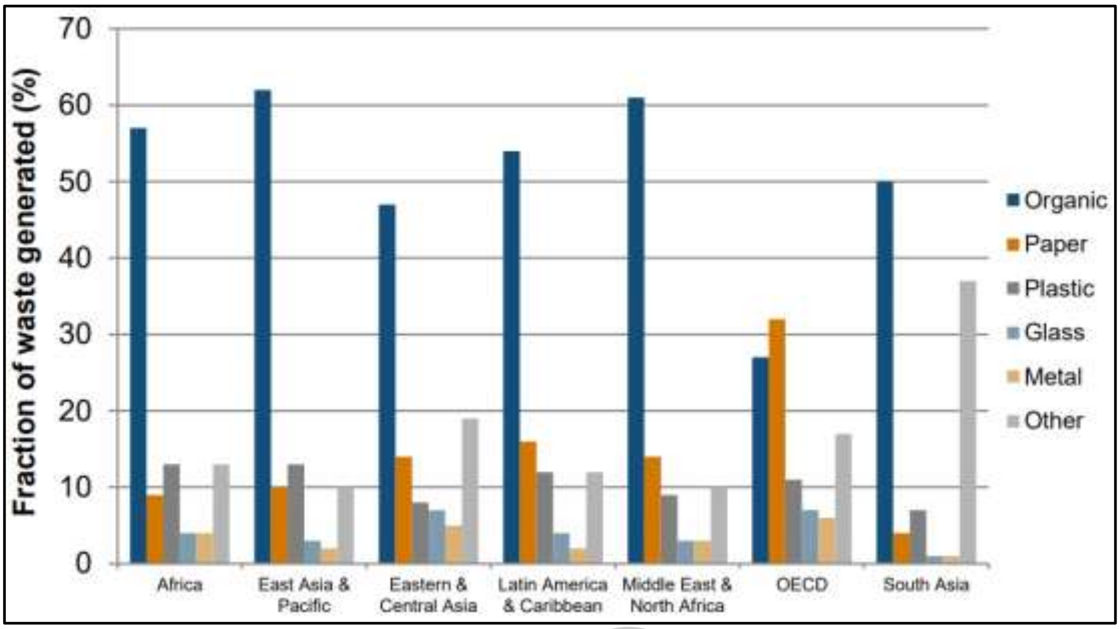


Figure 1.1 Composition of Solid Waste in 2012 (by Region)

In 2010, Ejaz et al. (2010) investigated environmental impacts of improper solid waste management in Rawalpindi City, Pakistan. It was concluded that improper solid waste management systems in Rawalpindi City are resulting negative impacts on the environment as shown in Table 1.2.

Table 1.2

List of Negative Impacts on Environment Due to Improper Solid Waste Management in Rawalpindi City, Pakistan

No.	List of Negative Impacts on Environment
1	Dispersed solid waste from the illegal open dumps often blocks the drains and sewers. Ultimately, these blockages are creating flooding and unhygienic conditions in the city.
2	Flies breeding are directly linked with open solid waste dumps. During the filed investigation, it was observed that during summer the flies are increasing their population so rapidly due to these waste dumps and they are very effectual vectors that spread disease in the community.
3	Associated with the above problems, blocked drains and wastewater flooding in the city are greatly supporting the mosquitoes breed and diseases like malaria and dengue are spreading in the Rawalpindi City.
4	The proportion of food waste in open dumps and waste drains are providing an attractive shelter for rats. It was also reported that these rats are spreading diseases, damaging electrical cables, and other materials in the study area.
5	The open burning of collected solid waste is causing air pollution issues in Rawalpindi city.
6	Uncollected solid wastes from few locations in the city are degrading the urban environment and discouraging efforts to keep streets and open spaces clean.
7	Discarded polythene bags in collected solid waste from Rawalpindi City are generating an aesthetic nuisance, and they may also cause the death of grazing animals which eats them.
8	Due to a lack of health and safety facilities to the waste collection crew in Rawalpindi City, occupational hazards including strains from lifting, injuries from sharp objects and traffic accidents are one of the most common problems the city is facing.
9	Open dumps on the roadside and heavily sized solid waste storage containers are also creating traffic blockage in the study area.
10	The city government is not providing separate waste collection facilities. As a result, many of dangerous items (such as broken glass, razor blades, hypodermic needles and other healthcare wastes, aerosol cans and potentially explosive containers and chemicals from industries) may cause risks of injury or poisoning, particularly to scavengers and school going children.

11	Open body trucks are being used for the collection of solid wastes in Rawalpindi City without covers. This practice is unhygienic.
12	Heavy solid waste collection vehicles are causing significant damage to the road.
13	Different segregated solid waste materials, such as plastic bottles and medical supplies, are not being properly cleaned or sterilized by local scavengers.
14	During rainy seasons, produced leachate from the open dumped sites is causing serious pollution to water bodies in Rawalpindi City.
15	A high percentage of collected solid waste from Rawalpindi City is being treated or disposed of in an unsatisfactory way, causing a severe aesthetic nuisance regarding smell and manifestation.
16	Liquids and fumes are escaping from deposits of chemical wastes and creating fatal or other serious effects to the community.
17	Illegal burning of collected solid waste in Rawalpindi City is creating serious negative impacts on outdoor air quality. Furthermore, it is also causing illnesses which is more likely to result on increasing amount of deaths in the city.

MSW if not manage properly, gives negative impact not only in our environment but also to public health. The study of Galarpe et al. (2014) presents the summary results for the health responses among community adjacent to disposal sites in the Philippines. Prevalent diseases were gastrointestinal, upper respiratory and skin diseases. Potentially, the use of contaminated tube and deep wells may likely be attributed to cause gastrointestinal diseases (Su, 2005). The occurrence of respiratory diseases among neighboring population to waste/ disposal site was relevant (Heller & Catapreta, 2003). Present review is in agreement with past studies on prevalence of respiratory symptoms among municipal solid waste workers (Makyrynos & Dounias, 2010) and waste-picking children (Romero et al., 2010) which can be attributed to potential high levels of particulate matter. Overall, the underserviced and poor environmental condition impacts the health of slums and increasing vulnerabilities to diseases. Table 1.3 presents the summary of health responses from community adjacent to disposal sites.

Table 1.3
Summary of Health Responses from Community Adjacent to Disposal Sites in the Philippines in year 2017

Disposal Site and Location	Findings	Reference Studies
Cebu City Sanitary Landfill, Cebu, Region 7	Gastrointestinal Upper Respiratory Skin Diseases and Dengue	(Galarpe and Parilla, 2014), (Nazareno and Flavier, 2011)
Umapad dumpsite, Mandaue City, Region 7	Upper Respiratory and Skin Diseases	(Ejares and Aguilar, 2014)
Lapu-lapu City dumpsite, Region 7	Gastrointestinal and Upper Respiratory Health Response	(Galarpe et al., 2014)
Zayas landfill, Cagayan de Oro Region 10	Dengue Cases	(Dimaampao et al., 2014)
Payatas dumpsite, Quezon City	Prevalence of Diarrhea and Water Borne Illnesses	(Su, 2005), (Su, 2007)

In the Philippines, the Ecological Solid Waste Management (ESWM) Act of 2000 (Republic Act 9003) was approved in January 26, 2001 and came into effect on February 16, 2001. Republic Act 9003, in section 2, paragraph (a) “ensure the protection of the public health and environment”, and paragraph (e) “promote national research and development programs for improved solid waste management and resource conservation techniques, more effective institutional arrangement and indigenous and improved methods of waste reduction, collection, separation and recovery” (Philippines Laws and Jurisprudence Databank, 2017). This provides the mandate and framework for solid waste management in the country. The implementation however on the local government units (LGUs) reflects the lack of institutional arrangements for waste management. Also, this has been reflected through the utilization of unregulated dumpsites and landfills exhaustively although other alternatives can be considered. Primary reasons were drawn from inadequate technical and financial resources, lack of political will, unwillingness of stakeholders, and minimal local awareness which poses great threats to the country’s environment, public health, and Economic opportunities (Gallarpe, 2017).

Many studies (Neogy et al., 2017; Karadimas et al., 2007; Manoharan, 2017; Karadimas and Loumus, 2007; Nguyen et al., 2017; Kamde et al., 2016; Nemade et al., 2015; Hareesh et al., 2015; Hareesh et al., 2015; Ansari et al., 2015; Verma and Bhonde, 2014; Son, 2014; O’Connor, 2013; Bhambulkar and Khedikar, 2011; Jovičić et al., 2011; Bhambulkar, 2011; Kanchanabhan et al., 2010; Chalkias and Lasaridi, 2009; Minghua et al., 2009; Chalkias and Lasaridi, 2009; Apaydin and Gonullu, 2008; Karadimas et al., 2007; Apaydin, 2007; Sahoo et al., 2005) were conducted to contribute solution to address the problem of solid waste management. Several were using Geographic Information System analytics (GIS) to help solving many factors, including the location of waste bins, type of waste, collection details, number of workers, operational hours, driving direction, type of vehicle, travel impedances, and integrity of road network being traversed. This is for optimized route plan in different countries, developed a simulation model Design on weekly optimum route (DOWOR) to determine optimized refuse collection vehicle routes for individual vehicles, and to analyze the optimal route between a given origin and destination in a waste collection network.

IoT solution (Internet of Things) was adopted by several studies (Al Mamun et al., 2014; Johansson, 2006; Meghana and Nataraj, 2016; Navghane et al., 2016; Dev et al., 2016; Parkash and Prabu, 2016; Amrutha et al., 2017; Hong et al., 2014; Sandeep et al., 2017; Dhaya et al., 2016) which is the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data. This system provides the information when the bin gets completely filled with garbage and reduces the number of times the arrival of the vehicle which collects the garbage. This concept concluded to help in keeping the environment clean. Also, applied solution approach was considered as a solution to the SWM particularly in collection problem (Manliguez et al., 2017; Salleh et al., 2016; Marković et al., 2010; Nuortio et al., 2006). It develops a routing algorithm and will use scheduling methodology to optimize the routing plan.

All approaches/solutions mentioned above really contributed in addressing the SWM problem. However, strategic deployment plan of garbage bin placement was out of sight. Also, most of the study on collection optimization is focused on routing plan but the idea of grouping/clustering garbage bins for dividing collection route plan was not considered. Where the total of garbage to be collected in a group will at least equal to the capacity of the garbage truck for optimal collection, cutting the total time traveled and saving of gas to consume.
In Iligan City, as per the interview of the City Environmental Management Office (CEMO) headed by Mr. Virgilio B. Encabo, a Senior Environmental Management Specialist, the current system of garbage collection in the city is based on time schedule. Also, the management of CEMO discourages the deployment of garbage bins in the city for the reason that it encourages even to people not from the city. Furthermore, each barangay is required to have their own Barangay Materials Recovery Facility (BMRF) where people from their barangay can left their garbage during the scheduled time. During the time when the barangay has not yet constructed its BMRF, they are required to designate a pick-up point/area in the absence of BMRF.

As to the problem encountered of the present system in the city, as per the interview of one of barangay councilor in Poblacion, Iligan City, in the person of Ms. Lorelie Yabut, there are people who are not from their barangay throwing their garbage anywhere, in volume, and unsegregated which causes a bad smell in the area.

2 METHODOLOGY

To accomplish the outcome of the research plan, interviewing will be used as a technique in gathering the needed data. Also, this section presents the sequence of tasks to be undertaken to fulfill the outcome of the research plan.

Phase 1 – *Preparation of Survey Questionnaire*

This step involves the preparation of questionnaire to use during interview.

Phase 2 - *Conduct an Interview and Collect Data*

This step involves meeting (face-to-face) and interviewing the representative from the offices of Solid Waste Management, Philippines Statistics Authority, and the City Engineering of Iligan City in order to collect the needed data.

Phase 3 - *Generate Information*

This step involves fusing the numerous amount of data being collected to generate information.

2.1. Develop the Graph-Theoretic Model for Optimal Collection using Clustering Technique.

2.1.1. Research Plan

Figure 4.2 shows the research plan to develop the model incorporating map conversion into a two-dimensional undirected graph, strategic deployment of smart bin using graph-theoretic techniques, and optimal collection of municipal solid waste using clustering techniques.

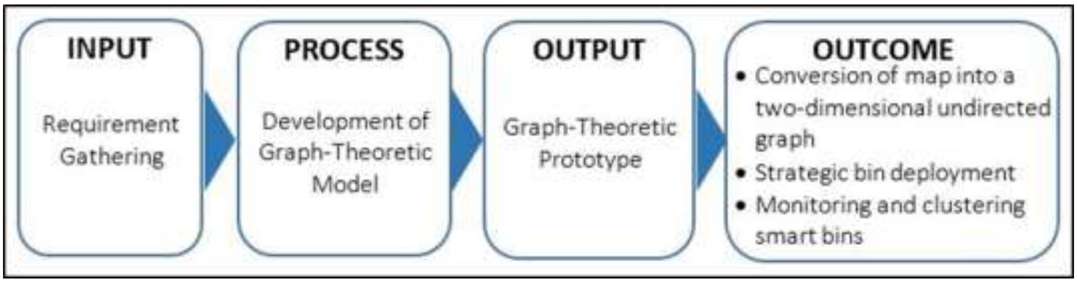


Figure 4.2 Plan for Developing the Graph-Theoretic Model

2.1.2. Methodology

To develop the model and fulfill the outcome of the research plan, prototype model (*see Figure 4.3*) will be used in developing the prototype with 3 iterations only. Also, this section presents the sequence of tasks to be undertaken to fulfill the outcome of the research plan.

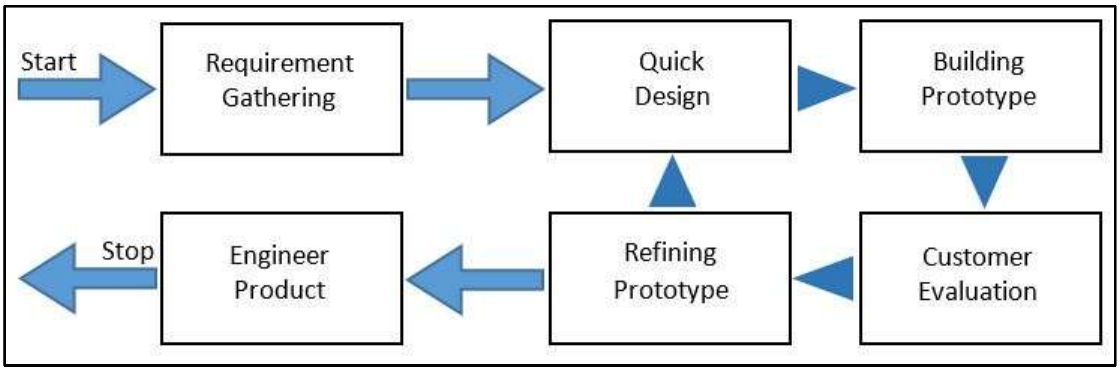


Figure 4.3 The Prototype Model

2.1.2.1. Phase 1 – *Requirements Gathering*

This step involves preliminary investigation related to the development of the graph-theoretic model and the techniques to incorporate in it for optimal collection of municipal solid waste.

2.1.2.2. Phase 2 - *Quick Design*

This step involves the designing of the model appropriately to what this study wants to produce and suitably to the user for ease of use.

2.1.2.3. Phase 3 - *Building Prototype/Model*

This step involves the building of the model according to the suggested design incorporating the following features: converting the map into a two-dimensional undirected graph; graph-theoretic technique; and the clustering technique.

2.1.2.4. Phase 4 - *Customer Evaluation*

This step involves the evaluation of the model by the representative from the office of Solid Waste Manage of Iligan City.

2.1.2.5. Phase 5 - *Refining Prototype*

This step involves the decision of the user (Solid Waste Management personnel) for acceptance after evaluating it.

2.1.2.6. Phase 6 - *The Product (Graph-Theoretic Model)*

When the model is finally accepted.

2.2. Develop the GSM-enabled Smart Bin for garbage volume sensing and data transmission.

2.2.1. Research Plan

Figure 4.4 shows the research plan to develop the GSM-enable smart bin for garbage volume sensing and data transmission.

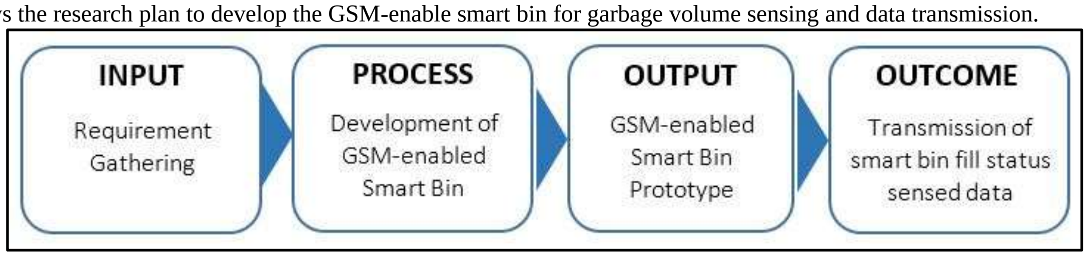


Figure 4.4 Plan for Developing the GSM-enabled Smart Bin

2.2.2. Methodology

To develop the GSM-enabled Smart Bin prototype and fulfill the outcome of the research plan, waterfall model as shown in figure 4.5 will be used in developing the prototype because the requirements are very well known, clear and fixed; Technology is understood; There are no ambiguous requirements; Plenty of resources with required expertise are available freely; and The project is short. However, the development of the model is until prototyping and unit testing only.

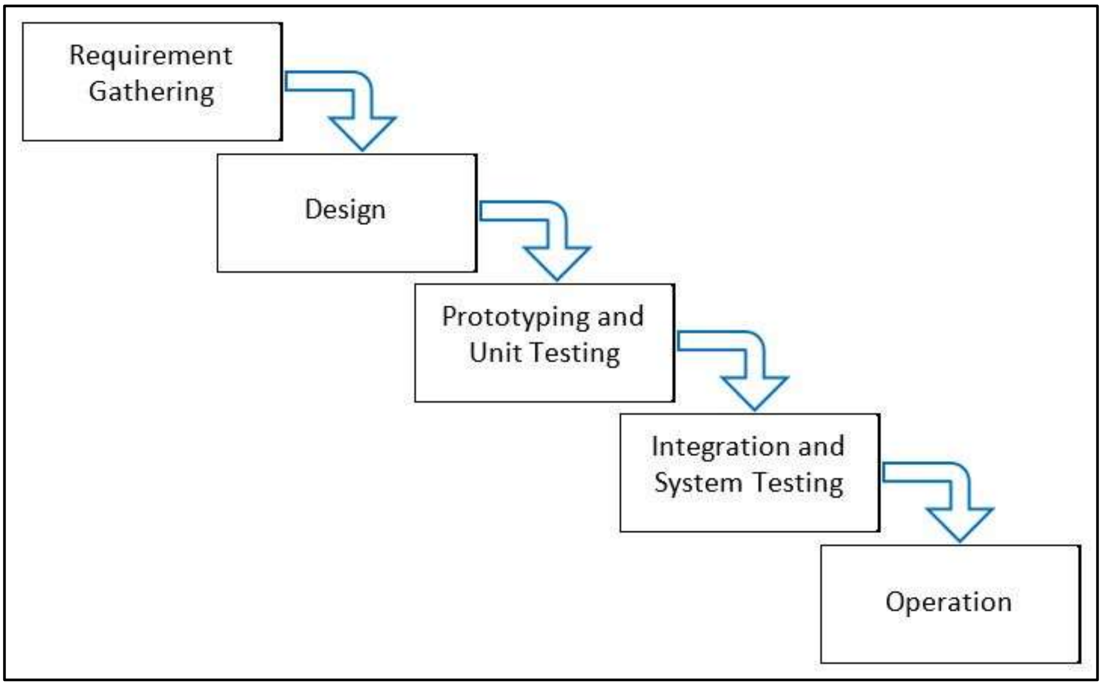


Figure 4.5 The Waterfall Model

2.2.2.1. Phase 1 - *Requirement Gathering*

This step involves preliminary investigation related to the development of the GSM-enabled Smart Bin and the appropriate electronic devices to use to build the prototype.

2.2.2.2. Phase 2 – *Design*

This step involves the designing of the GSM-enabled Smart Bin to make it able to sense the garbage volume of its bin and able to transmit the sensed data to Graph-Theoretic model through telecommunication network. Figure 4.6 shows the block diagram of the whole system. This includes the diagram of the GSM-enabled Smart Bin as selected in the figure.

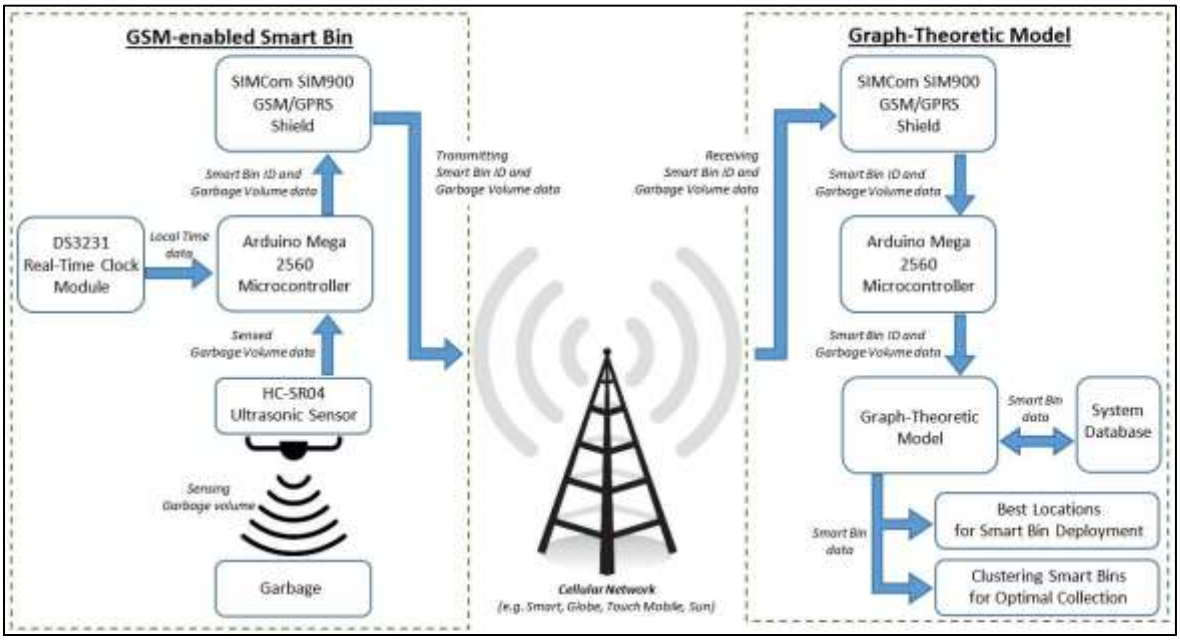


Figure 4.6 Block Diagram of the Whole System

2.2.2.3. Phase 3 - *Prototyping and Unit Testing*

This step involves the building of the smart bin prototype according to the suggested design. Also, incorporating the appropriate electronic devices to do the sensing of the garbage volume and data transmission.

2.3. Simulation of the Prototypes.

2.3.1. Research Plan

Figure 4.7 shows the research plan for the simulation of the Graph-Theoretic Model and GSM-enabled Smart Bin prototype.

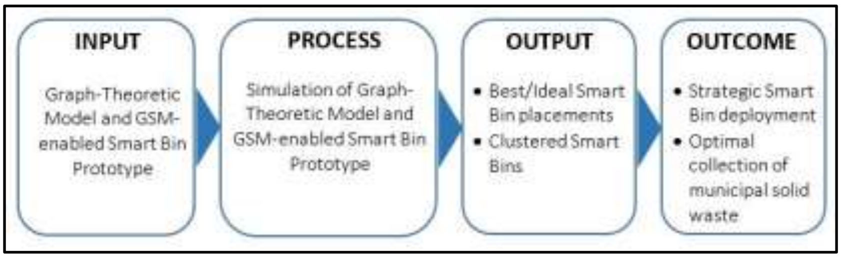


Figure 4.7 Plan for Simulation of the Prototypes

2.3.2. Methodology

To simulate the prototypes and fulfill the outcome of the research plan, the signal-flow model as shown in figure 4.8 will be used in simulating the prototypes.

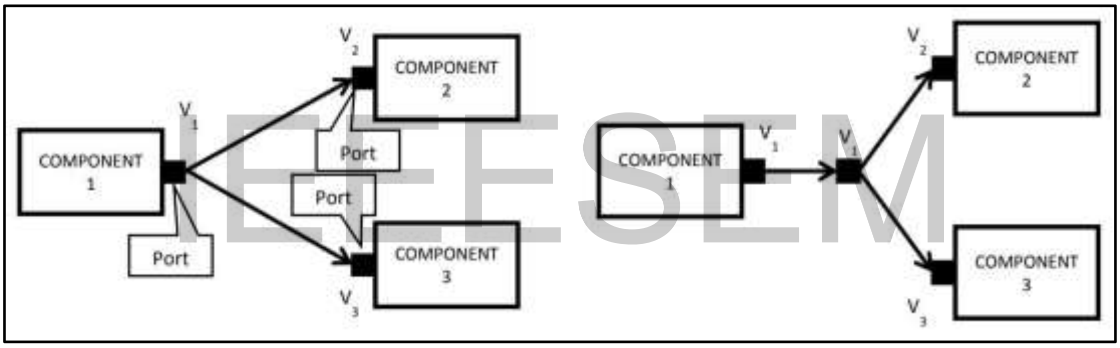


Figure 4.8 Equivalent Graphical Depictions of Two Links in Signal-Flow Modeling

2.3.2.1. Phase 1 - *Determine and link the input and output components*.

This step involves in determining and linking the input and output components of the whole system. Figure 4.9 shows the components for simulation and the classification of its port as an input or an output. Telecommunication network however, is included as component but not part of the study to develop.

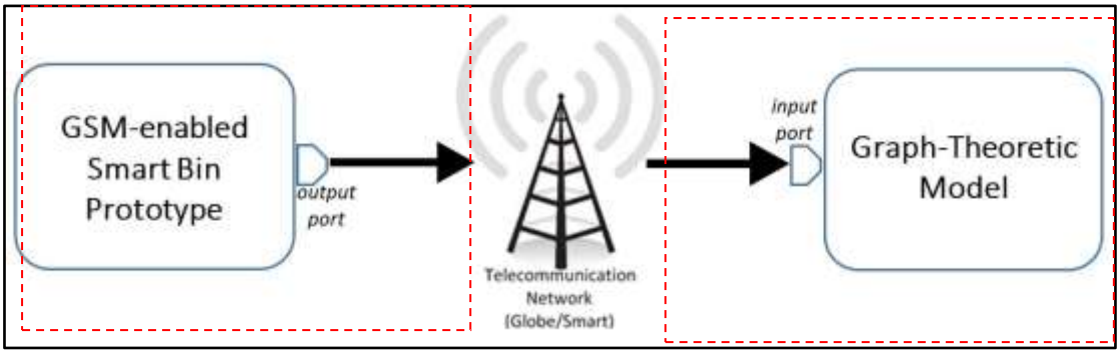


Figure 4.9 Components for Simulation

2.3.2.2. Phase 2 - *Perform simulation runs*

This step involves the actual simulation of the components (the GSM-enabled Smart Bin and the Graph-Theoretic Model).

2.3.2.3. Phase 3 - Interpret and present results

This step involves in interpreting and presenting results right after the simulation is done.

3 RESULT AND DISCUSSION

3.1. Map Points and Attributes Data Preparation Results

In preparing the map points and attributes data for the simulation of the prototypes, several interviews were conducted to collect data and fusing them to generate information. Map points refer to the possible locations on the map to be evaluated for best locations in the deployment of smart bins. On the other hand, attributes refer to the properties of each map point and will be used as parameters in determining each point its degree of importance.

Unfortunately, as per the interview of the City Environment Management Office (CEMO) of Iligan who supervise the Iligan City Solid Waste Management System (ICSWMS), they cannot provide the data of current placements/locations of garbage bins already deployed which will have supposed to be the map points to be evaluated for best locations in the deployment. The concept of this study is just not applicable to the current ICSWMS because deploying of garbage bins in the city was discouraged. Consequently, the supposition of the study regarding the map points is to place it on every road intersection on the map of the selected portion of Iligan City as shown in Figure 5.1.

Figure 5.1 Map Points on a Selected Portion of Iligan City

In determining the degree of importance of every point for the best location, parameters such as population, establishment, and road accessibility are considered to be used. As the study of Hoornweg and Bhada-Tata (2012) shows that the higher the economic development and rate of urbanization, the greater the amount of solid waste produced. Furthermore, the process of urbanization according to Dociu and Dunarintu (2012) represents the increase in the proportion of people living in towns and cities as a result of people movements from rural areas to urban.

Fortunately, during the interview conducted in the office of Barangay Poblacion, Iligan City, the Secretary of Barangay Poblacion in the person of Ms. Kisney Orbe, able to evaluate each of the point presented in the map as shown in Figure 5.2 (as possible locations for the evaluation for best locations) and gave its remarks (1-10) regarding to its population, establishment and road accessibility as shown in Table 5.1.

Figure 5.2 Possible Locations to be Evaluated

for Best Locations in the Deployment of Smart Bin

Table 5.1 Data Obtained After the Secretary of Barangay Poblacion Evaluated

Every Possible Location Presented in the Map Regarding Its Remarks
on Population, Establishment, and Road Accessibility

Smart Bin Name	Population (1-10)	Near Establishment (1-10)	Road Accessibility (1-10)
bin1	8	4	8
bin2	2	6	5
bin3	8	8	8
bin4	8	8	8
bin5	8	10	8
bin6	8	4	8
bin7	8	3	8
bin8	8	10	7
bin9	9	10	8
bin10	9	10	8
bin11	3	6	8
bin12	8	5	4
bin13	8	10	8

bin14	8	10	9
bin15	8	10	8
bin16	7	10	8
bin17	8	4	8
bin18	7	2	8
bin19	5	4	8
bin20	8	4	4
bin21	8	10	8
bin22	8	10	9
bin23	8	10	9
bin24	9	10	9
bin25	5	4	8
bin26	6	3	8
bin27	6	10	8
bin28	6	10	8
bin29	7	10	9
bin30	5	3	8
bin31	9	7	8
bin32	5	3	8
bin33	6	10	8
bin34	8	10	8
bin35	8	9	8
bin36	6	10	8
bin37	5	2	8
bin38	3	5	8
bin39	5	3	8
bin40	6	4	8
bin41	6	3	8
bin42	7	3	8
bin43	8	9	8
bin44	9	10	8
bin45	7	8	8
bin46	7	10	7
bin47	5	3	8
bin48	5	2	8
bin49	6	2	8
bin50	6	4	8
bin51	7	3	8
bin52	5	4	8
bin53	7	10	8
bin54	9	10	8
bin55	8	10	8
bin56	5	4	8
bin57	6	2	8
bin58	7	10	8
bin59	5	3	8
bin60	7	7	8
bin61	9	6	8
bin62	8	10	8
bin63	6	4	8
bin64	7	2	8
bin65	9	10	8
bin66	5	3	8
bin67	6	3	8
bin68	5	4	8
bin69	6	2	8
bin70	6	10	8
bin71	8	9	8
bin72	7	10	7

bin73	8	8	8
bin74	5	4	7
bin75	7	2	7
bin76	6	3	7
bin77	6	2	8
bin78	6	3	8
bin79	7	3	8
bin80	6	9	8
bin81	7	10	8
bin82	9	10	8
bin83	9	10	8
bin84	5	4	8
bin85	5	4	8
bin86	7	2	8

3.2. Development of Prototypes Results

Presented in this section are the development of GSM-enabled Smart Bin and Graph-Theoretic model, and its respective functionalities.

3.2.1. System Architecture

The system architecture shown in Figure 5.3 includes the development of two models/prototypes. First, the GSM-enabled Smart Bin which is expected to sense the bin garbage volume and transmit the data to the other model/prototype. Second, the Graph-Theoretic Model which is expected to do the following: (1) Determine the best and unnecessary locations for the deployment of smart bins, and (2) Clustering of smart bins for optimal collection. Each of this model/prototype will be discuss further in the succeeding sections.

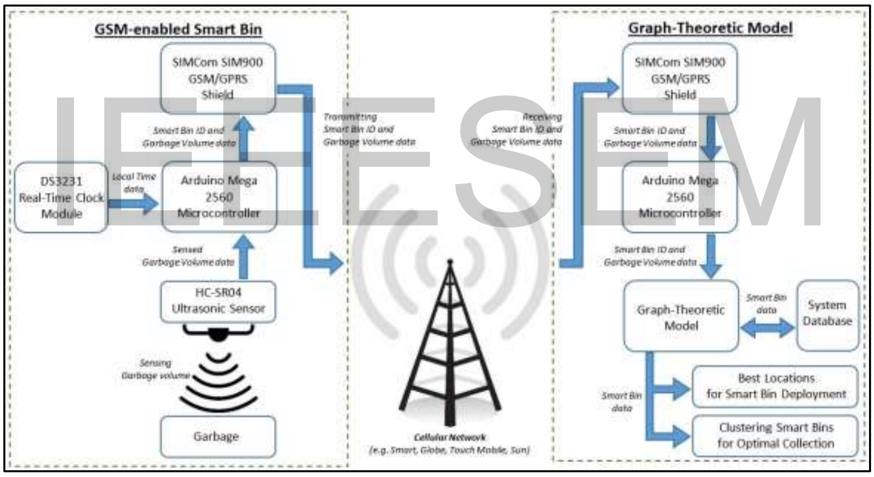
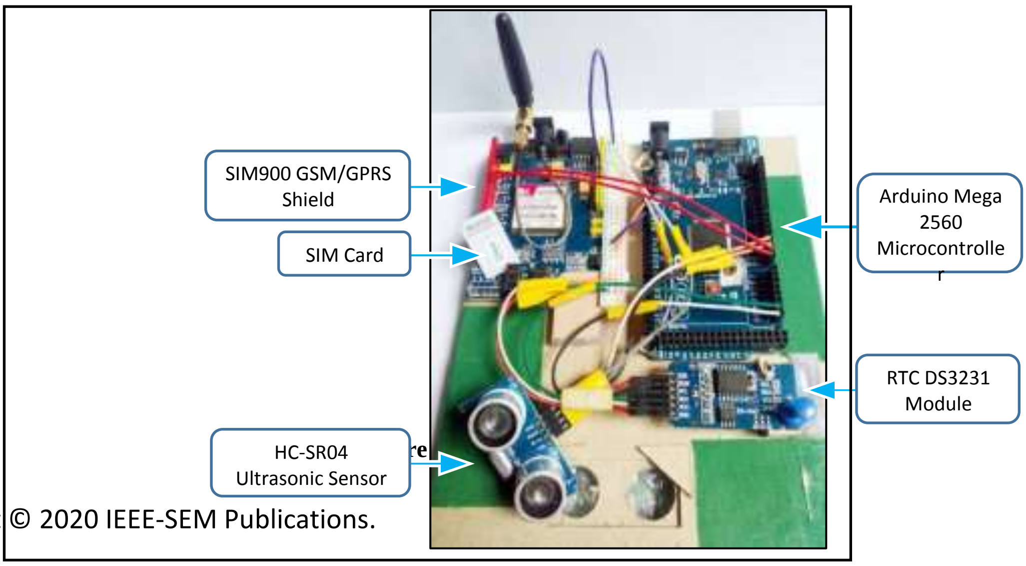


Figure 5.3 Block Diagram of System Architecture

3.2.2. Development of GSM-enabled Smart Bin Prototype



Developing the prototype of GSM-enabled Smart Bin shown in Figure 5.4 comprises the following components:

1. The **Arduino Mega 2560 Microcontroller** shown in Figure 5.5, a small, rugged, low cost, and low-power device. Dedicated to one task and run one specific program. The role of this device in the smart bin prototype shown in Figure 6.5 is to process the sensed data (garbage volume) coming the HC-SR04 ultrasonic sensor (which is connected to it), and give command to SIM900 GSM/GPRS module to transmit the smart bin information to the Graph-Theoretic Model through cellular network. On the other hand, the role of this device in Graph-Theoretic model is to process the data received from the smart bin through GSM module and transmit to the model. This device has been used by Juang and Lum (2013) in designing and controlling a two-wheel self-balancing robot. Also, in designing an automatic temperature control system by Abdullah, Rizman, Dzulkefli, Ismail, Shafie and Jusoh (2016).

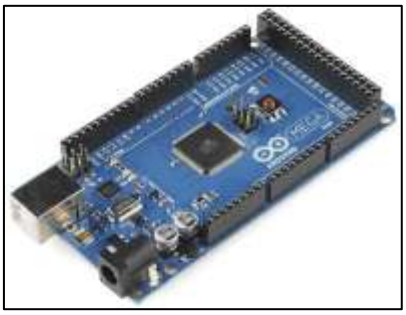


Figure 5.5 Arduino Mega 2560 Microcontroller

2. The **HC-SR04 Ultrasonic sensor** shown in Figure 5.6 has 4 pins, Ground, VCC, Trig and Echo. The Ground and the VCC pins of the module needs to be connected to the Ground and the 5 volts pins on the Arduino Mega Board respectively and the trig and echo pins to any Digital I/O pin on the Arduino Mega Board. It emits an ultrasound at 40000 Hz which travels through the air and if there is an object or obstacle on its path it will bounce back to the module. Considering the travel time and the speed of the sound distance can be calculated. This device operates at a distance of 2 centimeters to 4-5 meters. This has been used in two-wheeled self-balancing robot obstacle avoidance control system by Ruan and Li (2014). Also in early flood alerts using short message service by Kuantama, Setyawan, and Darma (2012).

Figure 5.6 HC-SR04 Ultrasonic Sensor

To illustrate how this device work, an example is shown in Figure 5.7. If the object is 10 cm away from the sensor, and the speed of the sound is 340 m/s or 0.034 cm/µs the sound wave will need to travel about 294 u seconds. But what you will get from the Echo pin will be double that number because the sound waves needs to travel forward and bounce backward. So in order to get the distance in cm we need to multiply the received travel time value from the echo pin by 0.034 and divide it by 2.

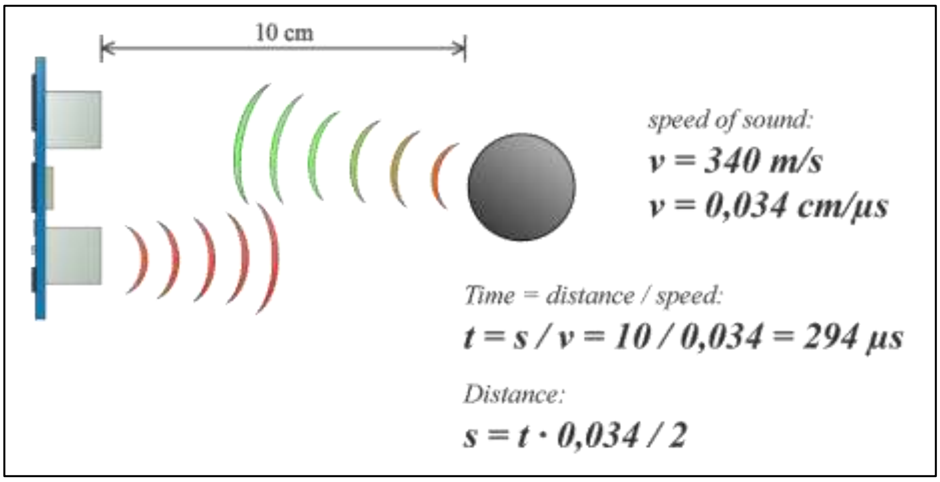


Figure 5.7 Illustration on How HC-SR04 Ultrasonic Sensor Works

The role of this device in the prototype is mainly to sense the distance from its own point down to the topmost of the garbage (in centimeter) and transmit the data to the Arduino Mega microcontroller. Prior to sensing the garbage volume and transmission of data, determining the depth of the bin was taken. Figure 5.8 shows how this device gets the depth of garbage bin.

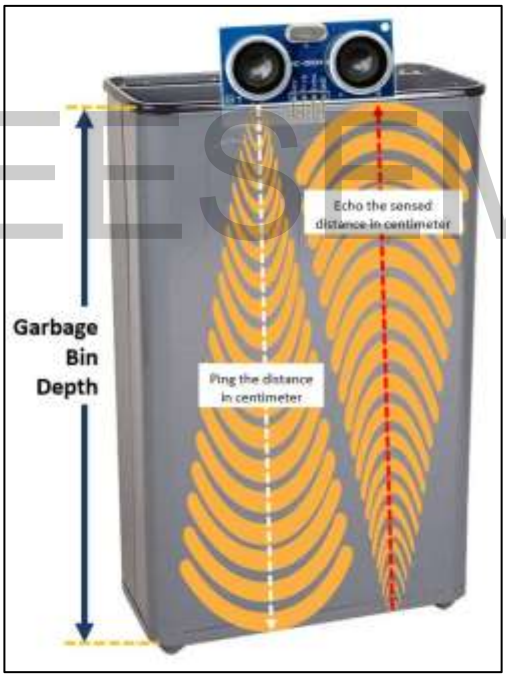


Figure 5.8 Illustration in Getting the Depth of Garbage Bin Using the HC-SR04 Ultrasonic Sensor

In this study, the model of garbage bin used in prototype is rectangular prism in shape as shown in Figure 5.9. In getting the garbage volume of the smart bin right after the transmission of data from Ultrasonic sensor to Arduino Mega Microcontroller, the microcontroller take charge to do the computation. Figure 5.10 shows the computation of getting the volume of a smart bin.

Figure 5.9 Garbage Bin Model and Its Size

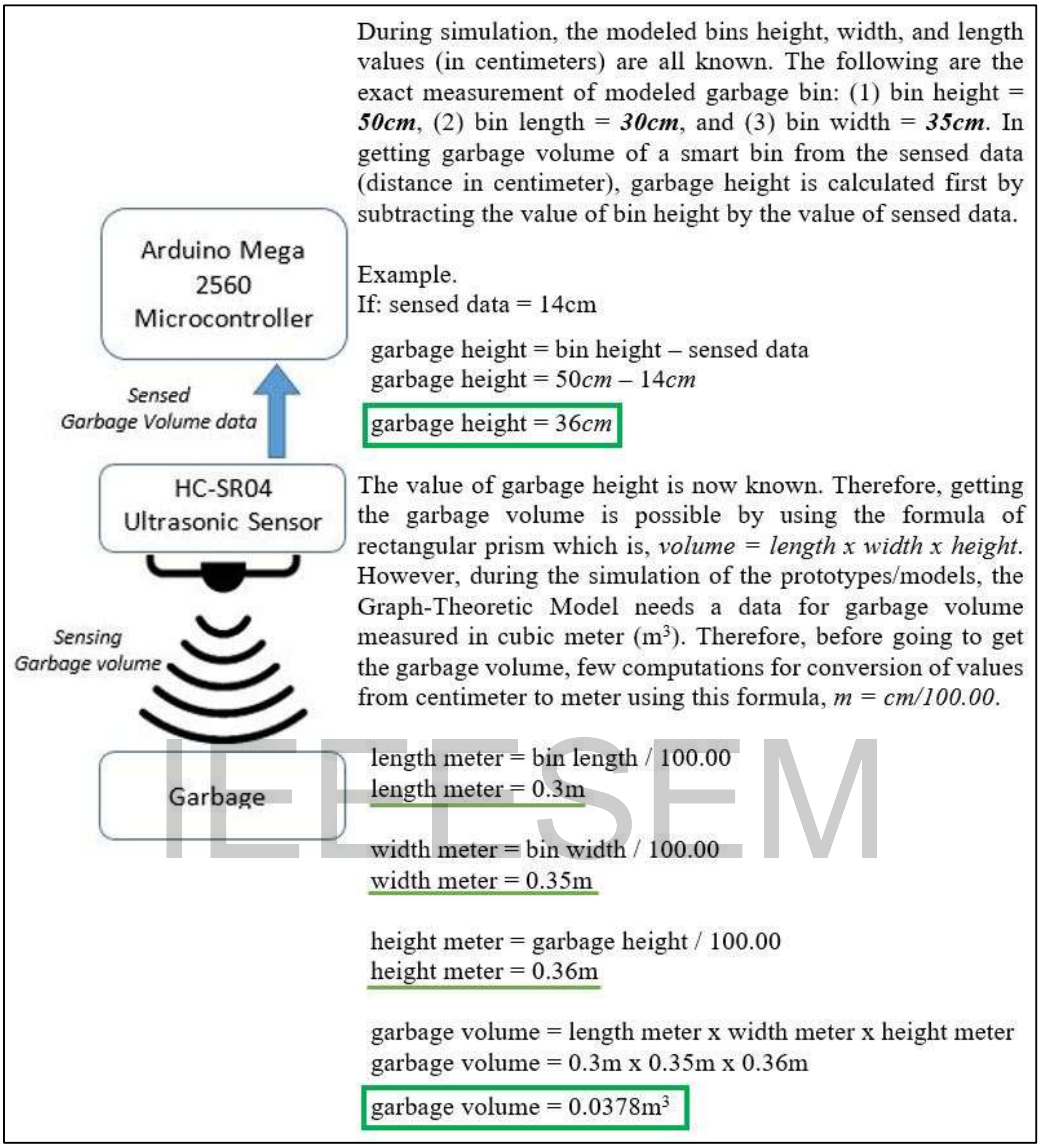


Figure 5.10 Illustration in Getting the Approximate Garbage Volume

1. The **SIM900 GSM/GPRS shield** shown in Figure 5.11 is Quad-band GSM/GPRS engine, works on frequencies 850 MHz, 900 MHz, 1800 MHz and 1900 MHz. It is very compact in size and easy to use as plug in GSM Modem. The Modem is designed with RS232 Level converter circuitry, which allows you to directly interface PC Serial port. The baud rate can be configurable from 9600-115200 through AT command. Initially Modem is in Auto-baud mode. This GSM/GPRS RS232 Modem is having internal TCP/IP stack to enable you to connect with internet via GPRS. It is suitable for SMS as well as DATA transfer application in M2M interface. The modem needed only 3 wires (Tx, Rx, GND) except Power supply to interface with microcontroller/Host PC. The built in Low Dropout Linear voltage regulator allows you to connect wide range of unregulated power supply (4.2V -13V). Using this modem, you will be able to send & Read SMS, connect to internet via GPRS through simple AT commands. The role of this device in the GSM-enabled Smart Bin prototype is to transmit the smart bin information and in Graph-Theoretic model is to receive the transmitted data from the smart bin. This has been used in wireless data transmission system for data acquisition and control of power induction furnace by Zaghloul (2014). Also, in bus safety system for school children with the RFID device by Al-Ismaili, Al-Mahruqi, and Vrindavanam (2015).

Figure 5.11 The SIM900 GSM/GPRS Shield

2. The **Real-Time Clock (RTC) DS3231** shown in Figure 5.12 is a low-cost, extremely accurate I2C real-time clock (RTC) with an integrated temperature compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted. The integration of the crystal resonator enhances the long-term accuracy of the device as well as reduces the piece-part count in a manufacturing line. The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator. The role of this device in a smart bin prototype is to provide accurate time which will be used in comparing against the scheduled time for sending smart bin information to Graph-Theoretic model. This has been used in automatic timer siren by Mankar, Kulkarni, Sukhdeve, Dongre, and Ukey (2017). Also, in the internet of things (IoT) based energy monitoring and control device by Hiremath, Pugari, and Gadway (2017).

Figure 5.12 The Real-Time Clock (RTC) DS3231 Module

3.2.3. Development of Graph-Theoretic Model

Developing the Graph-Theoretic Model includes the integration of Dominant Set technique (explain) for determining the best location for deployment of Smart Bins, and K-Means clustering method for clustering Smart Bins for optimal collection of municipal solid waste.

3.2.4. Simulation of Prototypes

Simulation includes the preparation of GSM-enabled Smart Bin prototype and the Graph-Theoretic Model. There is only one (1) sim card used in the simulation inserted in the GSM module as shown in Figure 5.13.

Figure 5.13 The Sim Card Used in the Simulation

Using a single sim card gives no problem in instantiation of smart bin identification which represents its locations on the map. Sim card was registered to unlimited text to all network which means, unlimited sending of Short Message Service (SMS) to all other cellular network. Styrofoam granules as shown in Figure 5.14 were used to represent as garbage.

Figure 5.14 The Styrofoam Granules Used in the Simulation

In Graph-Theoretic model, the map of the selected portion of Iligan City was added. Also, the points/locations in every intersection on the map which was evaluated by the personnel of the Office of Barangay Poblacion, Iligan City were added. Dominant Set technique able to suggest the best and unnecessary locations for smart bin deployment. At the moment, the Clustering of smart bins feature in Graph-Theoretic model is still in progress but the idea and the expected results will be discussed here. Further results in the simulation will be presented in the proceeding sections.

3.2.5. Adding Points on the Map

Adding of possible points and its attributes on the map as shown in Figure 5.15 is next right after adding the map. This allows the Graph-Theoretic model to determine the best and unnecessary locations for smart bin deployment.

Figure 5.15 Adding the Possible Locations and Its Attribute Remarks to the Map for the Evaluation of Best Locations

After adding all possible locations on the map, Figure 5.16 shows all possible points/location added in the map and will be evaluated for best locations.

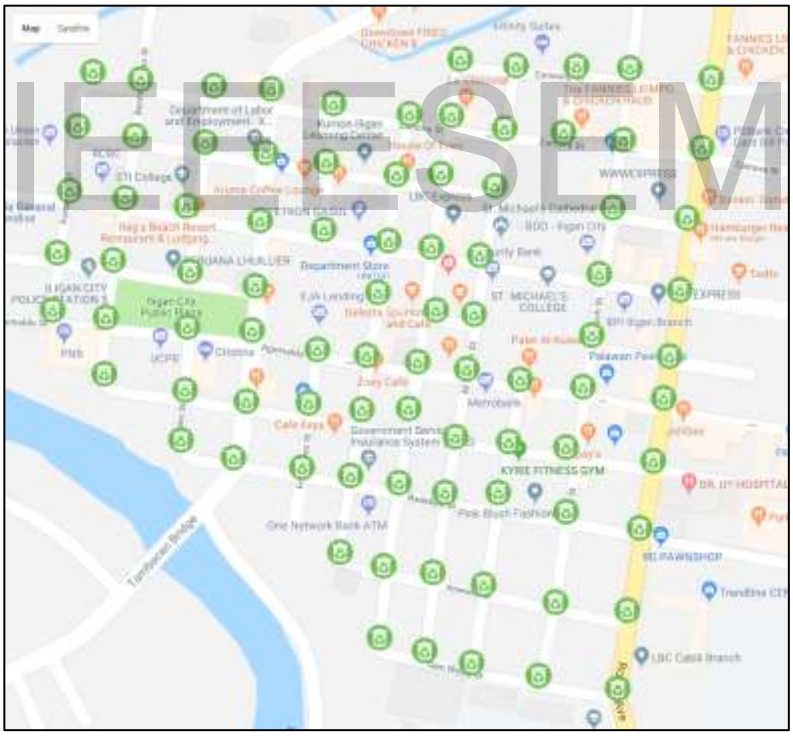


Figure 5.16 Possible Locations Added in the Map

3.2.6. Conversion of the Map to Two-Dimensional Undirected Graph

The conversion of the map containing all possible points/locations to two-dimensional undirected graph as shown in Figure 5.17 is necessary to illustrate the concept of Dominant set in graph theory when executing the algorithm based on it. Each of the point will be evaluated its degree of importance according to its attributes as shown in Table 5.1 for finding the best and unnecessary locations for the deployment of smart bins.

Figure 5.17 Conversion of the Map with the Possible Points to Graph

3.2.7. Dominant Set Algorithms for Determining the Best and Unnecessary Points/Locations

There are two (2) algorithms that were performed in evaluating the possible locations for best location in the deployment of Smart Bin. The first algorithm is shown in Figure 5.18, its main objective is to determine the priority bin locations among all possible locations in the map. This has a linear runtime because the number of operations increases as the number of input size also increases. The runtime is proportional to the input size which is O(n) in Big O notation.


```
FOR each location in the map
     IF population remark is less than five AND
        establishment remark is less than five AND
        road accessibility remark is less than five THEN
               SET location is priority
     OTHERWISE
               SET location is non-priority
     END IF
END FOR
```

Figure 5.18 Dominant Set Algorithm for Determining Priority Bin Locations

As the result of the algorithm presented in Figure 5.18, Figure 5.19 shows the representation of locations identified as priority bin locations (points without ‘X’ mark) and the locations identified as non-priority bin locations (points with ‘X’ mark).

Figure 5.19 Result of the Dominant Set Algorithm in Determining Priority Bin Locations for the Deployment of Smart Bins

However, the result presented in Figure 5.19 does not justify the concept of Personalized Dominant Set inspired by Dominating Set and thus, doesn't suggest the best location for the deployment of smart bins. Thsu, another set of algorithm were executed as shown in Figure 5.20.

```
WHILE there is non-priority location with non-priority neighbors exist

    // Collecting non-priority locations with non-priority neighbors
    SET Location_List as Collection
    FOR each non-priority location in the map
      SET neighbors_count to zero
        IF all of its neighbors are also non-priority THEN
            SET neighbors_count to the number of its neighbors
            Add this non-priority location and
             its neighbors_count to Location_List
        OTHERWISE
            Continue to the next non-priority location
        END IF
    END FOR

    // Determining the non-priority location with highest degree
    SET Location_High_Degree to empty
    SET High_Degree to neighbors_count column[zero] of Location_List
    FOR i = 1 to Location_List length - 1
        IF neighbors_count column[index] > High_Degree THEN
            SET High_Degree to neighbors_count column[index]
            SET Location_High_Degree to non-priority location column [index]
        END IF
    END FOR

    // Updating the status of non-priority locations with highest degree
    // to priority location
    SET Location_High_Degree to Priority Location

END WHILE
```

Figure 5.20 Dominant Set Algorithm for Determining Priority Bin Locations from Among Identified Non-Priority Bin Locations

As the result of the algorithm presented in Figure 5.20, the desired outcome was obtained as shown in Figure 5.21 where all possible locations identified as non-priority bin locations should have at least one neighbor of identified priority bin location.

Figure 5.21 Result of the Dominant Set Algorithm for Determining Priority Bin Locations from Among Identified Non-Priority Bin Locations

The result of the first and second Dominant Set algorithms identified all priority bin locations from among all possible locations for deployment. This is also considered as the best locations for the deployment of Smart Bins.

After best locations were obtained, unnecessary locations or (the identified non-priority bin locations) were removed to show the actual location for the deployment of smart bins as shown in Figure 5.22. In result, among 86 possible locations, there were 36 locations eliminated (which is about 41.86% of the total number of possible locations). Thus, helps to minimize the deployment of garbage bin in the city.

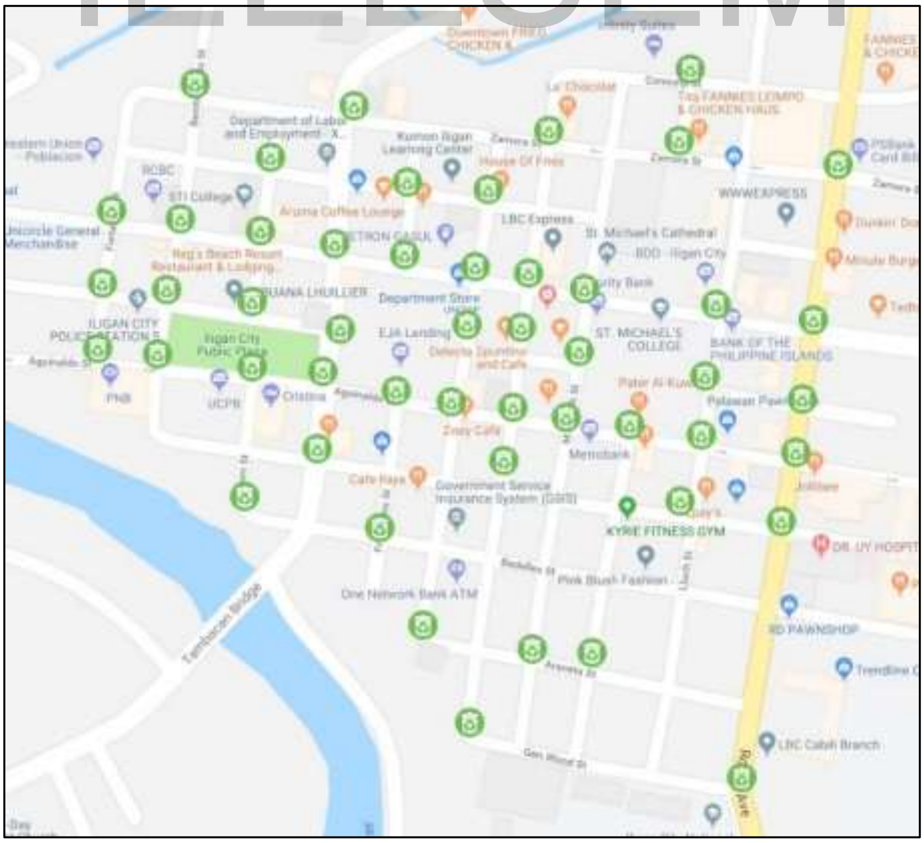


Figure 5.22 The Best Locations for the Deployment of Smart Bins

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3.2.8. Transmission of Data from GSM-enabled Smart Bin prototype to Graph-Theoretic Model

The result presented in Figure 5.23 is the simulation of GSM-enable Smart Bin prototype and Graph-Theoretic model. The smart bin prototype able to sense the garbage volume and transmit the smart bin information to the Graph-Theoretic model. Graph-Theoretic model able also to do its functionality in receiving the smart bin data from the Smart Bin prototype.

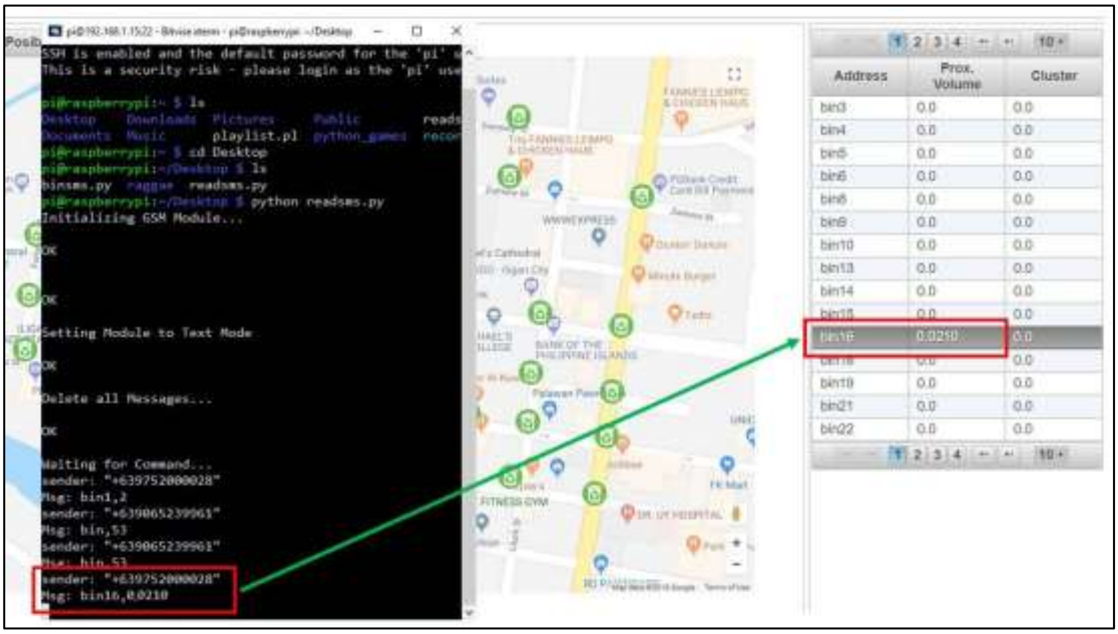

Figure 5.23 The Actual Transmission of Smart Bin Information from the Smart Bin Prototype itself to the Graph-Theoretic Model During the Simulation of Prototypes

As the result of simulation, the data of garbage volume was obtained as shown in Table 5.2.

Table 5.2 Data Obtained During the Simulation of Prototypes

Smart Bin name	Population	Near Establishment	Road Accessibility	Approximate Garbage Volume (in m^3)	Approximate Garbage Volume (in cm^3)
bin3	8	8	8	0.0347	34700.00
bin4	8	8	8	0.0466	46600.00
bin5	8	10	8	0.0397	39700.00
bin6	8	4	8	0.0219	21900.00
bin8	8	10	7	0.0301	30100.00
bin9	9	10	8	0.0337	33700.00
bin10	9	10	8	0.0247	24700.00
bin13	8	10	8	0.0373	37300.00
bin14	8	10	9	0.0317	31700.00
bin15	8	10	8	0.0398	39800.00
bin16	7	10	8	0.0210	21000.00
bin18	7	2	8	0.0421	42100.00
bin19	5	4	8	0.0251	25100.00
bin21	8	10	8	0.0437	43700.00
bin22	8	10	9	0.0379	37900.00
bin23	8	10	9	0.0321	32100.00
bin24	9	10	9	0.0286	28600.00
bin27	6	10	8	0.0387	38700.00
bin28	6	10	8	0.0261	26100.00
bin29	7	10	9	0.0228	22800.00
bin31	9	7	8	0.0227	22700.00
bin33	6	10	8	0.0339	33900.00
bin34	8	10	8	0.0360	36000.00
bin35	8	9	8	0.0447	44700.00

bin36	6	10	8	0.0327	32700.00
bin39	5	3	8	0.0314	31400.00
bin41	6	3	8	0.0305	30500.00
bin43	8	9	8	0.0366	36600.00
bin44	9	10	8	0.0307	30700.00
bin45	7	8	8	0.0528	52800.00
bin46	7	10	7	0.0337	33700.00
bin49	6	2	8	0.0357	35700.00
bin53	7	10	8	0.0267	26700.00
bin54	9	10	8	0.0490	49000.00
bin55	8	10	8	0.0322	32200.00
bin58	7	10	8	0.0512	51200.00
bin60	7	7	8	0.0459	45900.00
bin61	9	6	8	0.0411	41100.00
bin62	8	10	8	0.0279	27900.00
bin65	9	10	8	0.0351	35100.00
bin70	6	10	8	0.0381	38100.00
bin71	8	9	8	0.0412	41200.00
bin72	7	10	7	0.0404	40400.00
bin73	8	8	8	0.0316	31600.00
bin78	6	3	8	0.0437	43700.00
bin80	6	9	8	0.0365	36500.00
bin81	7	10	8	0.0441	44100.00
bin82	9	10	8	0.0452	45200.00
bin83	9	10	8	0.0327	32700.00
bin86	7	2	8	0.0518	51800.00

3.2.9. Executing K-Means Clustering Algorithm for Clustering of Smart Bins

The objective of clustering Smart Bins of the model (using K-Means clustering method) is to obviously group smart bins into several numbers (depends on the number set by the user), and be able to get the total approximate garbage volume of each cluster. Thus, determining the collection status of every cluster is possible by comparing its approximate garbage volume against to the capacity of the available garbage truck.

The study assumed that there is only one garbage truck available with the capacity of 4 cubic meter. In determining the garbage collection status of each cluster, the model uses the algorithm shown in Figure 5.24 where each cluster's approximate
garbage volume is compared against to the capacity of available garbage truck. If it's 80% (which is equal to 3.2 cubic meter) or more of the garbage truck capacity, then the cluster's garbage is ready for collection. Otherwise, it is not ready for collection.

```
FOR each cluster in the map
      // Evaluating the cluster's accumulated garbage volume if it's greater than
      // or equal to 80% of 4 cubic meter as the garbage truck capacity
      IF cluster's accumulated garbage volume is greater the 3.2 THEN
            SET cluster's garbage collection status to ready for collection
      OTHERWISE
            SET cluster's garbage collection status to not ready for collection
      END IF
END FOR
```

Figure 5.24 Condition in Comparing the Accumulated Approximate Garbage Volume of Each Cluster Against the Capacity of the Garbage Truck

As the result of the algorithm presented in Figure 5.24, Figure 5.25 shows the clustered smart bins on the map (defined by its color) into 3 groups and its collection status (if it's ready for collection or not). Clustering Smart Bins uses an algorithm that defines the K-Means clustering method, where the data points being classified doesn't have a label at all. Furthermore, *K* or cluster number is set to determine the number of clusters/groups and K points are randomly place as its initial centroids during the process of classifying each data point. Then, data points are evaluated and assigned to its closest centroid. Next, re-compute the centroid of each cluster. This steps are repeated until convergence (such that centroids do not change, and the number of data points of each cluster do not change). Figure 2.17 of Chapter 2 present the basic of K-Means Algorithm.

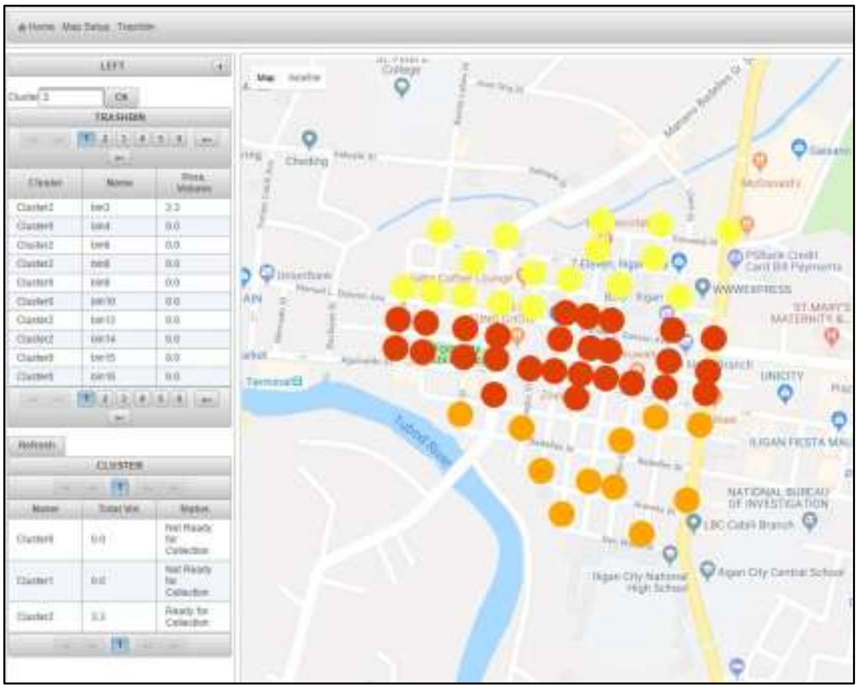

Figure 5.25 Clustered Smart Bins and its Collection Status

Legend:
- Cluster 0
- Cluster 1
- Cluster 2

CONCLUSIONS

Using the Interview Method, identifying the current status of solid waste management and the information of population, infrastructure, and road accessibility of the selected location of Iligan City were gathered.

In the development of Graph-Theoretic model, using the Prototype Model as a framework, the model (a software) was developed on time with the required features and able to performed its expected functions.

In the development of the GSM-enabled Smart Bin prototype, using the Waterfall Model as a framework, the device (a hardware) was also developed on time and able to performed its expected functions.

In the simulation of the prototypes, using the Signal Flow Model as a framework, the study was able to determine the input and output components, and able to performed the expected functions of the prototypes as to which component will produce an output to be transmitted to the other component which will be the receiving components. As a result, the simulation of the prototypes was successful.

As can be seen in the results of the conducted simulation of prototypes, the integration of the Personalized Dominant Set technique inspired by Dominating Set in Graph Theory and the K-Means Clustering method help the deployment of smart bins in a strategic way and able to determine the garbage status of a certain location if it's ready for collection or not. Using the concept of Dominant Set, best locations for deployment of smart bins are identified from several possible locations. Also, the clustering of smart bins using the K-Means Clustering method help in getting the accumulated approximate garbage volume of each cluster which is then evaluated for collection.

Generally speaking, this study concluded that the Dominant Set in Graph Theory and the K-Means Clustering method are the appropriate techniques/methods for this study.

RECOMMENDATIONS

Based from the results and conclusions of this study, the following recommendations were formulated:

1. Integration of the Shortest Path algorithm (such as Dijkstra's algorithm, the algorithm for Travelling Salesman Problem, and other shortest path algorithms) to suggest for the shortest route to the garbage collector when certain clusters are ready for collection.
2. Better sensing of the garbage volume for the enhancement of the Smart Bin prototype.

3. The Graph-Theoretic model should be able to control the time schedule as to when will the smart bins transmit its approximate garbage volume.
4. Better notification of the garbage collection status for the clusters to the user in the developed Graph-Theoretic model.

REFERENCES

Al Mamun, A.A., Hannan, M.A., & Hussain, A. (2014). *Real Time Solid Waste Bin Monitoring System Framework Using Wireless Sensor Network*. ICEIC 2014, Jan. 15 - 18, 2014, Kota Kinabalu, Malaysia.

Ambuhl, C. (2006). *Constant-factor approximation for minimum-weight (connected) dominating sets in unit disk graphs*. Retrieved from http://www.cs.le.ac.uk/people/te17/papers/CS-06-008.pdf

Amrutha, P.V., Chaithra, B.N., Kavyashree, D.R., Kumar, P.S., & Chethan, M.S. (2017*). IoT based Waste Management Using Smart Dustbin.* Recent Advances in Technology and Engineering (RATE-2017): 6th National Conference by TJIT, Bangalore.

Ansari, M., Pakrou, S., Abdol, M.A., & Karbasi, A. (2015). *Optimization of MSW Collection Using GIS (Case Study: Tabriz City)*. Current World Environment Vol. 10 (Special Issue 1), 882-890 (2015).

Apaydin, O., & Gonullu, M. T. (2007). *Route Optimization for Solid Waste Collection: Trabzon (Turkey) Case Study.* Global NEST Journal, Vol 9, No 1, pp 6-11, 2007.

Apaydin, O., & Gonullu, M. T. (2008). *Emission Control with Route Optimization in Solid Waste Collection Process: A case study*. Sadhana Vol. 33, Part 2, April 2008, pp. 71–82.

Bhambulkar, A. V. (2011). *Municipal Solid Waste Collection Route Optimized with ARC GIS Network Analyst.* International Journal of Advanced Engineering Sciences and Technologies: Vol No. 11, Issue No. 1, 202 – 207.

Bhambulkar, A.V., & Khedikar, I.P. (2011). *Municipal Solid Waste (MSW) Collection Route for Laxmi Nagar by Geographical Information System (GIS).* International Journal of Advanced Engineering Technology: E-ISSN 0976-3945.

Castillo, A.L., Otoma, S. (2013). *Status of Solid Waste Management in the Philippines*. Article of Japan Science and Technology Information Aggregator, Electronic.

Chalkias, C., & Lasaridi, K. (2009). *Optimizing Municipal Solid Waste Collection Using GIS*. Energy, Environment, Ecosystems, Development and Landscape Architecture: ISSN: 1790-5095.

Chalkias, C., Lasaridi, K. (2009). *A GIS based Model for the Optimization of Municipal Solid Waste Collection: The case study of Nikea, Athens, Greece*. WSEAS Transactions on Environment and Development: Issue 10, Volume 5, October 2009.

Corneil, D. & Stewart, L. (1990). *Dominating Sets in Perfect Graphs.* Retrieved from http://www.sciencedirect.com/science/article/pii/0012365X9090357N.

Dao-Tuan, A., Nguyen-Thi-Ngoc, A., Nguyen-Trong, K., Bui-Tuan, A., & Dinh-Thi-Hai, V. (2017). *Optimizing vehicle routing with path and carbon dioxide emission for municipal solid waste collection in Ha Giang, Vietnam*. Conference Paper · September 2017.

Dev, A., Jasrotia, M., Nadaf, M., & Shah, R. (2016). *IoT based Smart Garbage Detection System.* International Research Journal of Engineering and Technology (IRJET): Volume: 03 Issue: 12 | Dec -2016.

Dhaya, R., Pattabiraman, P., Shahrukh, S., & Aravindh, J. (2016). *Smart Waste Management Using Internet of Things (IoT).* Middle-East Journal of Scientific Research 24 (10): 3358-3361, 2016: ISSN 1990-9233.

Dimaampao, J., Emata, C., Eppie, J., Lacpacan, R., Po, C.P., & Valmorida, K. (2014). *Environmental Condition and Common Diseases of Children in Zayas Landfill, Carmen, Cagayan de Oro City*. Advancing Medical Technology Research, 2(1): 65-80.

Ejares, J. A., Paler, M.K.O., & Aguilar, M.E.L. (2014). *Socio-Demographic Profile of Scavenging Households in Umapad Dumpsite, Mandaue City Cebu, Philippines*. Journal of Sustainable Development Studies, 6(1): 175-191.

Ejaz, N., Akhtar, N., Nisar, H., & Ali Naeem, U. (2010). *Environmental impacts of improper solid waste management in developing countries: a case study of Rawalpindi City*. WIT Transactions on Ecology and the Environment, Vol 142, © 2010 WIT Press.

Farkas, K., Maurer, F., Ruf, L., & Plattner, B. (2006). *Dominating Set Based Support for Distributed Services in Mobile Ad Hoc Networks*. Computer Engineering and Networks Laboratory (TIK). Swiss Federal Institute of Technology Zurich (ETH Zurich). Gloriastrasse 35, CH-8092 Zurich, Switzerland. Retrieved from http://ieeexplore.ieee.org/xpl/login.jsp

Galarpe, V.R.K.R., & Parilla, R.B. (2014). *Opportunities and Threats to Adjacent Community in a Sanitary Landfill, Philippines.* EnvironmentAsia, 7(1):112-125.

Galarpe, V.R.K.R., Aruta, J. P., Badilla, D., Lawas, M.L., & Velez, M.A. (2014). *Preliminary study on the effects of landfill leachate to tilapia fingerlings*. Journal of Applied Sciences in Environmental Sanitation.

Gibson, M. & Pirwani, I. (2010). *Approximation Algorithms for Dominating Set in Disk Graphs*. Saeedi et al. (2011).

Habibulla, Y., Zhao, J., & Zhou, H. (2015). *The Directed Dominating Set Problem: Generalized Leaf Removal and Belief Propagation*. State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China.

Hareesh, K.B, Manjunath, N.T., & Nagarajappa, D.P. (2015). *Route Optimization Model for Municipal Solid Waste Management by Decentralized System in Davangere City*. International Journal of Emerging Technology and Advanced Engineering Volume 5, Issue 7, July 2015.

Hareesh, K.B, Manjunath, N.T., & Nagarajappa, D.P. (2015). *Route Optimization of Municipal Solid Waste for Davangere City Using GIS*. International Journal of Innovative Research in Science, Engineering and Technology Vol. 4, Issue 6, June 2015.

Hassinen, M., Polishchuk, V., & Suomela, J. (2008). *Local 3-approximation algorithms for weighted dominating set and vertex cover in quasi unit-disk graphs*.

Haxhimusa, Y., Kropatsch, W., & Ion, A. (2006). *Applied Graph Theory in Computer Vision Pattern Recognition.*

Henson, T. & Rajendiran, S. (2014). *Application of Domination Set for Fixing Surveillance Cameras.* PG and Research Department of Mathematics. St. Joseph's College of Arts & Science(Autonomous), Cuddalore, India. Volume: 03, May 2014, Pages: 864-866.

Hong, I., Park, S., Lee, B., Lee, J., Jeong, D., & Park, S. (2014). *IoT-based Smart Garbage System for Efficient Food Waste Management.* The Scientific World Journal Volume 2014, Article ID 646953, 13 pages.

Hoornweg, D. & Bhada-Tata P. (2012). *A Global Review of Solid Waste Management.* Urban Development Series Knowledge Papers, March 2012, No.15.

Johansson, O.M. (2006). *The Effect of Dynamic Scheduling and Routing in a Solid Waste Management System*. Waste Management 26 (2006) 875–885.

Jovičić, N. M., Bošković, G. B., Vujić, G. V., Jovičić, G. R., Despotović, M. Z., Milovanović, D. M., & Gordić, D. R. (2011). *Route Optimization to Increase Energy Efficiency and Reduce Fuel Consumption of Communal Vehicles*. Thermal Science: Year 2011, Vol. 14, Suppl., pp. S67-S78.

Kamde, S.A., Ghosh, P.K., & Gupta, M.K. (2016). *Optimization of Solid Waste Using Geographic Information System (GIS) for Durg City*. Volume No.4, Issue No.1, December-January 2016, 2662-2672.

Kanchanabhan, T. E., Mohaideen, J. A., Srinivasan, S., & Sundaram, V. L. K. (2010). *Optimum Municipal Solid Waste Collection Using Geographical Information System (GIS) and Vehicle Tracking for Pallavapuram Municipality*. Waste Management and Research published online 14 April 2010.

Karadimas, N. V., Kolokathi, M., Defteraiou, G., & Loumos, V. (2007). *Municipal Waste Collection of Large Items Optimized with Arc Gis Network Analyst*. Conference Paper · June 2007.

Karadimas, N. V., Papatzelou, K., & Loumos, V. G. (2007). *Genetic Algorithms for Municipal Solid Waste Collection and Routing Optimization.*

Karadimas, N.V., Papatzelou, K., & Loumos, V.G. (2007). *Optimal Solid Waste Collection Routes Identified by the Ant Colony System Algorithm*. Waste Manage Res 2007: 25: 139–147.

Livingston, M., & Stout, Q. (1994). *Constant Time Computation of Minimum Dominating Sets*.

MacQueen, J. B. (1967). *Some Methods for classification and Analysis of Multivariate Observations, Proceedings of 5-th Berkeley Symposium on Mathematical Statistics and Probability.* Berkeley, University of California Press 1:281-297.

Manliguez, C., Cuabo, P., Gamot, R. M., & Ligue, K. D. (2017). *Solid Waste Collection Routing Optimization using Hybridized Modified Discrete Firefly Algorithm and Simulated Annealing: A Case Study in Davao City, Philippines*. In Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2017), pages 50-61, ISBN: 978-989-758-252-3.

Marković, D., Janošević, D., Jovanović, M., & Nikolić, V. (2010). *Application Method for Optimization in Solid Waste Management System in the City of NIS*. Mechanical Engineering Vol. 8, No 1, 2010, pp. 63 – 76.

Meghana, K.C., & Nataraj, K.R. (2016). *IoT based Intelligent Bin for Smart Cities.* International Journal on Recent and Innovation Trends in Computing and Communication: Volume: 4 Issue: 5.

Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A., & Yi, L. (2009). *Municipal Solid Waste Management in Pudong New Area, China*. Waste Management 29 (2009) 1227–1233.

Navghane, S.S., Killedar, M.S., & Rohokale, V.M. (2016). *IoT based Smart Garbage and Waste Collection Bin*. International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE): Volume 5, Issue 5, May 2016.

Nazareno, P.A. G., Buot, I.E, & Flavier, M.E. (2011). *The plants in a landfill in the Philippines and their behavior towards lead and mercury: their potential use for future remediation of metal-contaminated soils in the country*. Journal of Environmental Science and Management, 14(1):60-70.

Nemade, P. D., Bansode, S. S., Deshmukh, P.S., Lawand, V.B, Kulal, S.S., & Pawar, S.M. (2015). *Solid Waste Management and Route OptimizationBy Using GIS-A Case Study of Indapur City.* International Journal on Recent and Innovation Trends in Computing and Communication. Volume: 3 Issue: 5.

Neogy, B., Shetty, A.R., Singh, S., & Durbha, S.S. (2017). *IoT-enabled Service for Efficient Waste Collection in Smart Cities.* 17th Esri India User Conference 2017.

Nuortio, T., Kytojoki, J., Niska, H., & Braysy, O. (2006). *Improved Route Planning and Scheduling of Waste Collection and Transport.* Expert Systems with Applications, ESWA 1404—4/8/2005—16:24—SHYLAJA—159522—XML MODEL 5 – pp. 1–10.

O'Connor, D. L. (2013). *Solid Waste Collection Vehicle Route Optimization for the City of Redlands, California (Master's thesis, University of Redlands).* Retrieved from http://inspire.redlands.edu/gis_gradproj/201.

Oyelade, O.J., Oladipupo, O.O., & Obagbuwa, I.C. (2010). *Application of k-Means Clustering algorithm for prediction of Students' Academic Performance*. (IJCSIS) International Journal of Computer Science and Information Security, Vol. 7, No. 1, 2010.

Parkash & Prabu, V. (2016). *IoT based Waste Management for Smart City*. International Journal of Innovative Research in Computer and Communication Engineering: Vol. 4, Issue 2, February 2016.

Philippine Laws and Jurisprudence Databank (2017). *An act providing for an ecological solid waste management program, creating the necessary institutional mechanisms and incentives, declaring certain acts prohibited and providing penalties, appropriating funds therefor, and for other purposes*. Retrieved from http://www.lawphil.net/statutes/repacts/ra2001/ra_9003_2001.html#top. October 24, 2017.

Saeedi, R., Nickray, M., & Afzali-Kusha, A. (2011). *A Joint Neural Network Ant Colony Optimization Model for Dominating Set Based Clustering of Wireless Sensor Networks.*

Sahoo, S., Kim, S., & Kim, B. (2005). *Routing Optimization for Waste Management*. Vol. 35, No. 1, January–February 2005, pp. 24–36.

Salleh, A. H., Ahamad, M. S. S., & Yusoff, M. S. (2016). *Applying an Integrated Route Optimization Method as a Solution to the Problem of Waste Collection*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W1, 2016 International Conference on Geomatic and Geospatial Technology (GGT) 2016, 3–5 October 2016, Kuala Lumpur, Malaysia.

Sandeep, M., Chaware, Dighe, S., Joshi, A., Bajare, N., & Korke, R. (2017). *Smart Garbage Monitoring System Using Internet of Things (IoT).* International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering: ISO 3297:2007 Certified: Vol. 5, Issue 1, January 2017.

Son, L.H. (2014). *Optimizing Municipal Solid Waste Collection Using Chaotic Particle Swarm Optimization in GIS based environments: A case study at Danang City, Vietnam*. Article of Expert Systems with Applications: No. of Pages 13, Model 5G 25 July 2014.

Su, G. S. (2005). *Water-borne illness from contaminated drinking water sources in close proximity to a dumpsite in Payatas, the Philippines*. JRTPH, 4: 43-48.

Su, G.L. S. (2007). *Impact on drinking water sources in close proximity to the Payatas dumpsite, Philippines*. Journal of public health, 15(1):51-55.

Thangamani, T., Manoharan, M., Das, A., & Adugna, T. F. (2017). *GIS Based Least Cost Path Routing Model for Municipal Solid Waste: Case Study in Kumbakonam, Tamilnadu*. International Journal of Scientific & Engineering Research Volume 8, Issue 6, June-2017.

The World Bank (2017). *Solid Waste Management*. Retrieved from http://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management. April 2017.

Verma, A., & Bhonde, B.K. (2014). *Optimization of Municipal Solid Waste Management of Indore City Using GIS. International Journal on Emerging Technologies*: 5(1): 194-200(2014).

Zou, F., Wang, Y., Xu, X., Li, X., Du, H., Wang, P., & Wu, W. (2009). *New approximations for minimum-weighted dominating sets and minimum-weighted connected dominating sets on unit disk graphs.*