Faculty of Computing and Information Management

"IoT FOR AFRICAN SMART CITIES: A MODEL FOR A SMART SOLID WASTE MANAGEMENT SYSTEM IN NAIROBI"

By

Emma Muthoni

MSc Data Analytics

Student number: I6/00601

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Declaration

This project is my original work and to the best of my knowledge this research work has not been submitted for any other award in any University

Emma W Muthoni: ______________________________ Date: ________________

16/00601

This project report has been submitted in partial fulfillment of the requirement of the Master of Science Degree in accordance with KCA University with my approval as the University supervisor

Dr. Simon Mwendia: ______________________________ Date: ________________

Mrs Rachel Kibuku: ______________________________ Date: ________________

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DEFINITION OF TERMS

Big data- Big data refers to voluminous data sets that are complex and require modern and novel processing. Traditional data processing is inadequate for big data. Big data include both structured and unstructured data with the 4 V characteristics of volume, variety, veracity and velocity.

Data analytics- Data analytics refers to the method of examining large data sets in order to observe patterns and draw conclusions about the information contained in these data sets.

Internet of Things- IoT refers to the network of physical objects and the communication between these objects. This network is ever growing as technology keeps advancing.

Cloud computing-Cloud computing refers to the hosting of services over the internet.

1.0 CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter entails the background of the study, which includes a close look at the current waste management systems in Nairobi. It also will outline the problem statement, objectives of the study, research questions, and hypotheses, the scope of the study, limitations, and assumptions of the study.

1.2 Background to the Study

The ubiquity of the Internet and the Internet of Things are perhaps the two most disconcerting effects of technological evolution in today's World. Internet availability has ultimately brought with it the era of data explosion and consequently big data. Big data consists of high Volume, Velocity, and Variety (the 3 "Vs") of information demanding cost-effective and innovative data processing for gaining insights and decision making (Kedia, 2016). The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. There is a loud buzz surrounding IoT and in it lies a great opportunity for African cities to take up solutions that can provide efficient services to their residents. A smart city can be defined as a city that uses ICT as an enabler towards a transition to a less material-intensive economy. Caragliu et al. (2011) say: "We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure, fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance." Definition of a smart city from Giffinger et al. (2007) is "a city well performing in a forward-looking way, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens." A smart city is identified with respect to six area domains being economy, people, governance, mobility, environment and living, Lundin, A. Et al., (2017). Cities like Singapore, Barcelona, Oslo, San Francisco and London have invested heavily towards laying the groundwork to achieving their dreams of acquiring smart cities. In fact, Singapore is currently crowned as "having taken the term 'Smart City' to a whole new level." This is after having installed sensors and cameras across the island of Singapore making it possible for authorities to detect even the smallest violators who range from litterbugs to people who smoke in unauthorized zones. Cities that use ICT as an enabler towards this transition are called Smart Cities (Shahrokni, H. et.al, 2014). Waste management, however, remains as a challenge for these cities as they incorporate ICT towards their transition into smart cities. A recommendation done by UNRCD on solid waste management methods in Nairobi was to think outside the conventional and traditional way of managing waste in Nairobi.This in their view would unlock untapped potential in solid waste management. "New approaches and technology can change the way we handle our waste. This is good news not only for us but for the whole planet. Many methods of municipal solid waste management have been developed and many of them have potentially significant adverse impacts," Kedia (2016). Monyoncho (2013) notes that 'In developing countries, it is not uncommon for authorities to spend 20-50 percent of their available recurrent budget on solid waste management. Yet, it is also common that 30-60 percent of all the urban solid waste in developing countries is uncollected and less than 50 percent of the population is served. In some cases, as much as 80 percent of the collection and transport equipment isout of service and in need of repair or maintenance.'

1.3 Problem Statement

Nairobi is East and Central Africa's leading capital and perhaps also one of the most promising cities in Africa. Nairobi sits on an area of 690 km2 and according to the 2009 census; the city hosts a population of 3.5 million people. According to Njoroge et al. (2014) solid waste generated in Nairobi on a daily basis amount to 4,016 tonnes in line with an earlier prediction by Allison (2010). In the County development plan for 2018-2019, solid waste management is listed as one of the major social-economic challenges facing Nairobi County. Nairobi continues to experience rapid growth in its population as well as uncontrolled urbanization and industrial growth. This has a direct correlation with the rate of waste generation within the city. Major challenges facing Nairobi County with respect to Solid Waste Management include management of waste collection and disposal (CADP, 2018-2019). According to (JICA, 2010) only 33% of solid waste in Nairobi is collected which leaves 2,690 tons of daily uncollected waste in Nairobi. Collected solid waste in Nairobi finds itself at the infamous Dandora dumping site having been disposed in an environmentally unsustainable manner. Most of the uncollected solid wastes are disposed of in open dumps and on the ground, contaminating the land and posing serious environmental problems such as littering and ingestion by animals, breeding grounds for mosquitoes and blocking storm water drains (Mukui, 2015). Two thirds of the waste generated in Nairobi cannot be accounted for (Integrated Solid Waste Management Plan for the City of Nairobi, 2010). Nairobi's solid waste situation, which could be taken to generally represent Kenya's status, is largely characterized by low coverage of solid waste collection, pollution from uncontrolled dumping of waste, inefficient public services, unregulated and uncoordinated private sector and lack of key solid waste management infrastructure (Njoroge et al., 2014). Studies have shown that poor solid waste management is associated with childhood morbidity and mortality (Oloruntuba et al., 2014, Reed and Mberu, 2014). Rapid urbanization, industrialization, population growth and increased waste generation have transformed solid waste into a major public health and environmental concern in Nairobi city (Njoroge et al., 2014). 'Waste collection today is inefficiently performed using static routes and schedules. Some bins are overflowing with waste causing unnecessary clean-up costs. This type of inefficiency wastes both time and money and is harmful for the environment but what if there is a better way. Integrated hardware and software solution optimizes waste collection, saving time, money and the environment,' Saha et.al.,(2017). CGN is solely charged with the responsibility of managing the capital's solid waste. According to NEMA (2015), a study done in Nairobi indicates that about 30-40% of the waste generated is not collected and less than fifty percent of the population is served. This is evident that not all of the solid waste is collected and more than 50% of the county's population are not served. According to Njoroge et al. (2014), 63% of solid waste in Nairobi goes uncollected. NEMA also accredits slow or lack of adoption of modern technology in solid waste management as a challenge in waste management in Kenya. Solid waste management, therefore, remains a complex and dynamic aspect of the Nairobi County Government and other county governments due to lack of prioritizing the establishment of proper systems for solid waste management. Among the recommended policy interventions by CGN include research and adoption of technology based waste management interventions (CADP, 2018-2019). Current waste collection efforts utilize static route planning with fixed scheduling, which indicates there still exists areas for continued development and improvement in this field. Such an approach is costly and generates a high-carbon footprint (Aleyadeh & Taha ,2018). ‘To overcome this information barrier, we propose the big data approach. The value typically shows up as a result of a combination of IOT applications with new process introduction and accumulates over time. It is difficult to quantify value due to complex processes and multiple interactions. Fact is that value is the key element finally asked by the project stakeholders or owners. Therefore, by applying data analytics we can analyze that as more waste is generated within the same area, it will require more waste pickup vehicles for dumping,’ Kedia (2016). According to Aleyadeh & Taha(2018), the use of emerging technology may lead to significant improvement in the waste management process.

Fig 1: Photo shows garbage dumped by the roadside in Nairobi city. (Photo downloaded from Google)

1.4 Research Objectives

1.4.1 Main Objective

The purpose of this study is to review the efficiency or inefficiency of the existing solid waste management processes and explore the application of the adoption of IoT towards achieving efficient solid waste disposal systems in Nairobi.

1.4.2 Specific objectives

i) To establish the various types of solid wastes, waste generation rates and waste collection methods in Nairobi.
ii) To evaluate IoT architectures applicable in solid waste management
iii) To design and simulate an IoT architecture applicable for efficient solid waste management in Nairobi
iv) To evaluate the simulation

1.5 Research Questions

1.4.1 What are the types of solid waste in Nairobi?

1.4.2 What IoT architecture and IoT Technologies can be leveraged for solid waste management?
1.4.3 How can IoT be used in solving solid waste management challenges in Nairobi?

1.6 Motivation for the study

My motivation for this study comes from my passion for technology and innovation as well as the desire for a cleaner environment. While driving or walking around Nairobi, one is most likely to find uncollected or illegally dumped waste in most streets and estates of the city. Improper handling of solid waste as evidenced in Nairobi County has potential environmental and health risks. Beyond the economic challenges, inadequate waste management in urban cities can also represent a vast annoyance for the citizens Lundin, A Et al., (2017). Mismanagement of solid waste has also contributed to the massive pollution of our environment. It poses as a great threat not only to the economy by scaring away tourists and foreign investors, but it also creates a great health risk to the residents of Nairobi. Exposure of solid waste to the general public has direct and indirect risks to the health of the population, especially due to the breeding of disease vectors like rats and flies in the latter. Some of the health risks of dwellers within the city and county of Nairobi are; chemical inhalation that results in chemical poisoning, degradation of soil and water quality, flooding in the city during heavy rainfall as a result of obstruction of runoff water from uncollected waste, neurological diseases and the spreading of infectious diseases among others. Waste management if approached with the right strategies can be turned into a resourceful venture that would not only create jobs, but also turn waste into a great resource for recycling and upcycling. This study will provide some insights and information on how to incorporate ICT in cities in the developing world in order to improve governance and fuel economic growth.

1.7 Significance of the study

The findings of this study will be vital to the growth of Nairobi and also to its residents since waste management is a critical problem that needs solving. As the city continues to experience significant growth in its population, there is a great need in improving its infrastructure as well as the way in which services to the residents are delivered. This study will therefore help expose the critical areas that need improvement in solid waste management systems, hence may lead to a better and a more efficient method for waste management in Nairobi. Listed below are the various benefits with their respective beneficiaries;

- County government of Nairobi- Reduced cost in garbage collection within the CBD, Identification garbage collection defaulters in other parts of the county,
- Nairobi residents- The residents will generally enjoy living in a cleaner environment, reduced risk of infections emanating from pollution
- Garbage collectors-Improved efficiency in terms of time and cost cutting
- Environment- Less pollution from uncollected waste and less greenhouse gas emissions from garbage trucks during transportation

1.8 Scope of the Study

The study will focus on waste management systems within the city of Nairobi. The study will target three major stakeholders being the County government of Nairobi, Nairobi residents and garbage collectors in the city. The study will entail collecting data from the stakeholders in order to identify various inefficiencies in the status quo and to establish ways in which this can be improved. The study will also derive requirements for a smart, solid waste management system

2.0 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter covers the theoretical and empirical literature review that is relevant to the topic under study. The review is based on the research objectives highlighted above this is with the aim of ensuring that through the objectives formulated in the previous chapter can be represented in more measurable terms.

2.1 Theoretical review

2.1.1. Overview of Solid Waste

a) Types of solid waste

Composition of waste is determined by various factors which include population, level of income, sources, social behavior, climate, industrial production and the market for waste materials (Baldisimo, 1988). Solid waste is generally categorized as municipal waste and non-municipal waste. Municipal solid waste refers to waste that is non-liquid and that is created due to consumption activities by an individual, business, household or institution. In most cases this is commonly referred to as garbage. Non-municipal waste is defined as non-liquid waste that emanates from the production of goods. Industrial waste is classified as a type of non-municipal waste.

Type of waste	Classification
Household	Municipal waste
Industrial	Hazardous non-municipal waste
Commercial	Municipal waste
Biomedical/ hospital	Infectious non-municipal waste

Table 1: Classification of solid waste

b) Solid waste generation rates

According to a World Bank (2012) report, current global MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025. Solid waste generation rates are largely influenced by climate, economic development as well as the level of industrialization in a country. The waste generation in Africa is 62 million tonnes per year.

Region	Waste Generation Per Capita (kg/capita/day)		
	Lower Boundary	Upper Boundary	Average
AFRICA (AFR)	0.09	3.0	0.65
East Asia and Pacific region (EAP)	0.44	4.3	0.95
Europe and Central Asia region (ECA)	0.29	2.1	1.1
Latin America & the Caribbean (LAC)	0.11	5.5	1.1
Middle East & North Africa (MENA)	0.16	5.7	1.1
Organization for Economic Co-operation and Development (OECD)	1.10	3.7	2.2
South Asia (SAR)	0.12	5.1	0.45

Table 2: Current waste generation Per Capita by Region(Table from the World Bank 'What a Waste' final report, 2012)

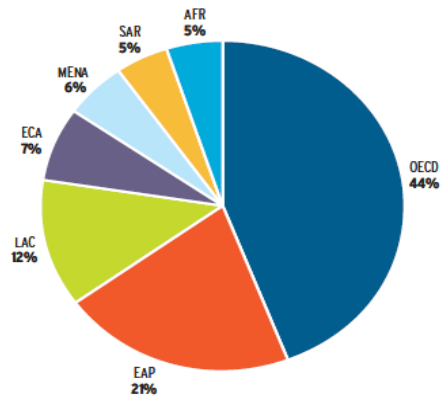


Fig 2: Waste generation by region (Pie chart from the World Bank 'What a Waste ' final report, 2012)

c) Solid waste collection methods

Waste collection refers to the transfer of solid waste from the point of use and disposal to the point of treatment or landfill Mayank, A. Et al. (2016).

- House-to-House: Waste collectors visit each individual house to collect garbage. The user generally pays a fee for this service.
- Public bin /Community bin: Users bring their garbage to community bins that are placed at fixed points in a neighborhood or locality. MSW is picked up by the municipality, or its designate, according to a set schedule.
- Curb side Pick-Up: Users leave their garbage directly outside their homes, according to a garbage pick-up schedule set by local authorities (secondary house-to-house collectors not typical).

- Self Delivered: Generators deliver the waste directly to disposal sites or transfer stations, or hire third-party operators (or the municipality).

Collection method	Type of waste
Public bin/community bin	Household waste
House to house collection	Household waste
Self-delivered	Industrial waste
Contracted service	Household waste/Industrial waste
Curbside pick-up	Household waste

Table 3: Traditional solid waste management methods

2.2 Empirical review

2.2. 1 Overview of solid waste management in Nairobi County

a) Types of solid waste in Nairobi

JICA Final report (2010) describes solid waste in Nairobi as mainly constituted of residential waste at more than 50% of the total waste. Commercial waste, road waste and market waste constitute the rest of solid waste generated in the city.

Type of waste	Classification
Residential	Municipal waste
Commercial	Municipal waste
Road	Municipal waste
Market	Municipal waste

Table 4: Types of solid wastes in Nairobi

b) Solid waste generation rates in Nairobi

Solid waste generation has a direct relationship with the population growth of an area. According to a report done by JICA for the ISWM Nairobi master plan, by the year 2009 solid waste in Nairobi mainly constituted of residential waste at a generation rate 1,318 tons per day while commercial, road and market wastes were generated at a rate of 439 tons, 60 tons and 90 tons per day respectively. The prediction for solid waste generated in Nairobi in the year 2030 is at 3990 tons per day. It is also predicted that 2,830 tons of the waste generated by the year 2030 will be from residential waste while 953 tons of waste will be from commercial sources. This places the expected rate of residential waste generation at 71.7% of the total waste generated.

Year	**2009**	**2010**	**2015**	**2020**	**2025**	**2030**
Nairobi Population ('000)	3,040	3,150	3,760	4,420	5,150	5,940
Waste Generation (ton/day)	1,848	1,924	2,353	2,831	3,378	3,990

Table 5:Baseline Projection of Population and Solid Waste Generation in Nairobi (JICA,2010)

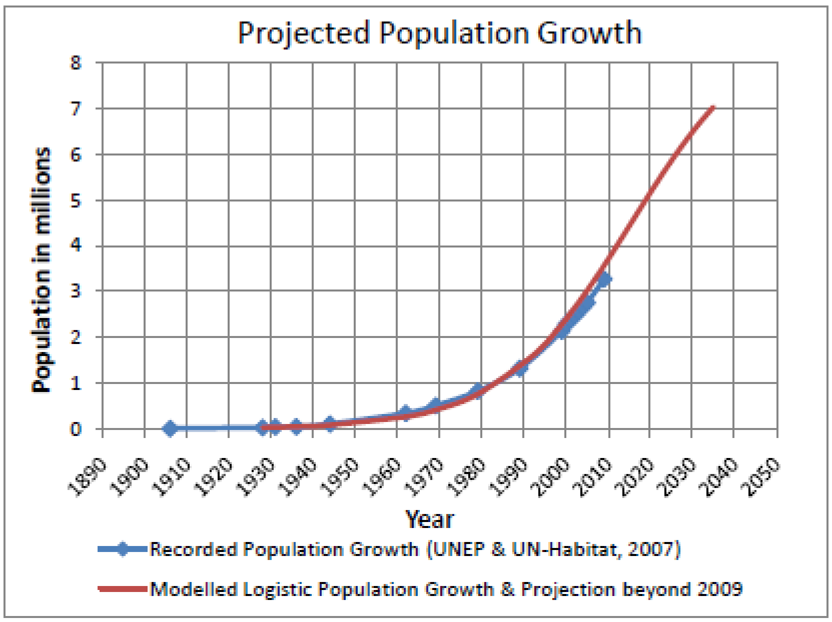


Fig 3:Projected population growth in Nairobi pre and post 2009 (Source:Kasozi .A & Blottniz,2010)

Unit: ton/day

Year	**2009**	**2015**	**2020**	**2025**	**2030**
Residential	1,318	1,747	2,025	2,419	2,860
Commercial	439	538	675	806	953
Road	(60)	60	60	60	60
Market	90	111	131	152	176
Total	1,848	2,352	2,831	3,378	3990

Table 6: Projection of Waste Generation in Nairobi City (JICA, 2010)

Sources: Central Bureau of Statistics Kenya (CBSK) and "World Economic Outlook", 2010, IMF, and the JICA Survey Team

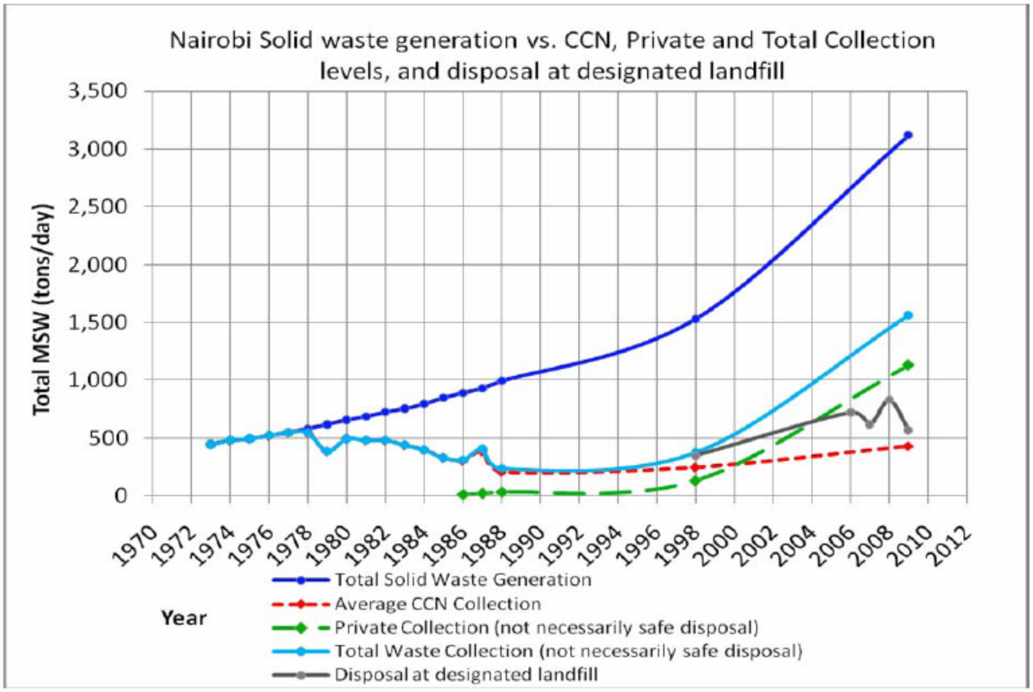


Fig 4: Solid waste generation and management trends in Nairobi (ISWP for Nairobi, 2010)

a) Solid waste collection methods in Nairobi

The County Government of Nairobi is solely mandated with the responsibility of managing solid waste in the city. The county government has, however, privately contracted stakeholders in the private sector to collect solid waste on behalf of CGN. This comprises of private companies, community based organizations (CBOs) as well as youth organizations. Monitoring of the private stakeholders in their waste collection routines has also been a major challenge for the county government.

Collection method	**Type of waste**
Public bin/community bin	Residential waste
House to house collection	Residential waste
Contracted service	Residential waste and Commercial waste
Curbside pick-up	Residential waste

Table 7: Solid waste collection methods used by various stakeholders in Nairobi

In its final report on a master plan for integrated solid waste management in Nairobi(JICA, 2010), put down the below strategies with the long term goal of achieving 100% waste collection in Nairobi by 2030 especially in low income areas where waste collection is observed to be the lowest:

(a) Technical alternatives of the collection and transportation system shall be studied to determine if they can bring the most efficient effect in terms of collection and transportation of solid waste from generation source to final disposal, as well as evaluated from the viewpoint of less impact on society and the environment.

(b) The development plan for collection and transportation vehicles or equipment shall be studied to determine if it corresponds to the most optimum system of collection and transportation including transfer system.

(c) The reformation of private sectors shall be required to enhance the administrative leadership of CCN in controlling the current disorder of their collection and transportation services. The administrative control of their services by zone or district could be one of the solutions. A more detailed approach towards better management of private sectors shall be discussed in the planning in parallel with the establishment of its organization and institutional framework.

(d) As for the solid waste management in low income and slum areas, the key issues shall be identified in terms of waste generation, collection and transportation through the problem analysis approach such as group discussions for CBOs who are the main actors in these areas. Based on the results of identification, the optimum system of discharge and collection shall be studied in combination with the improvement of the transportation system to be provided by CCN or its subcontractors to eliminate the factors causing illegal dumping at these areas.

(e) An action plan shall be prepared in a time frame of short, mid and long term to implement the most suitable development option of collection and transportation.

(f) The capital, operation and maintenance costs of collection and transportation in the above time frame shall be studied to examine the economical and financial viability of the solid waste management project.

(Source, Final JICA Report on solid waste management in Nairobi, 2010)

As noted in the report, one of the major challenges facing the effective management of solid waste in Nairobi is in the collection and the transportation of solid waste. There are, however, no recommendations or attempts to adopt technology as a way of improving of the solid waste management processes.

2.2. 1 IoT Technologies

IoT is not a stand alone technology but it is instead complemented by other technologies . Below are technologies that support IoT. They include, but are not limited to:

a) Wireless Sensor Network

A wireless sensor network refers to a network of dedicated sensors used in the monitoring as well as recording of any environmental or physical conditions. The recorded data is is transported wirelessly and stored in a central location or in a central database. Wireless sensor networks are applied across a variety of domains, including :military applications, health applications, environmental applications, home applications, commercial applications, area monitoring, health care monitoring, environmental/earth sensings, air pollution monitoring, forest fire detection, landslide detection, water quality monitoring and industrial monitoring.

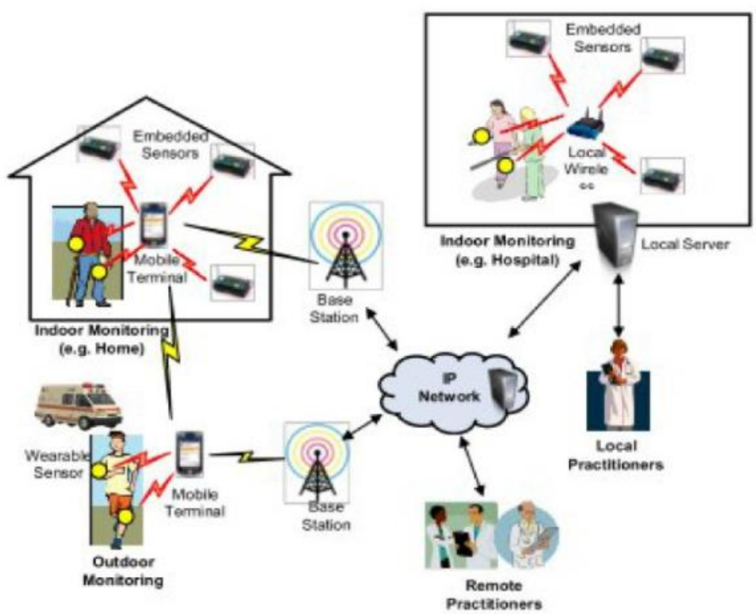


Fig 5: Scenario of a wireless sensor network (Source:Wireless Sensor Networks - Technology and Protocols)

b) Radio Frequency Identification (RFID)

Radio frequency identification refers to a wireless communication technology which uses radio waves to read and identify a unique object. The object can be a non-living or living thing.

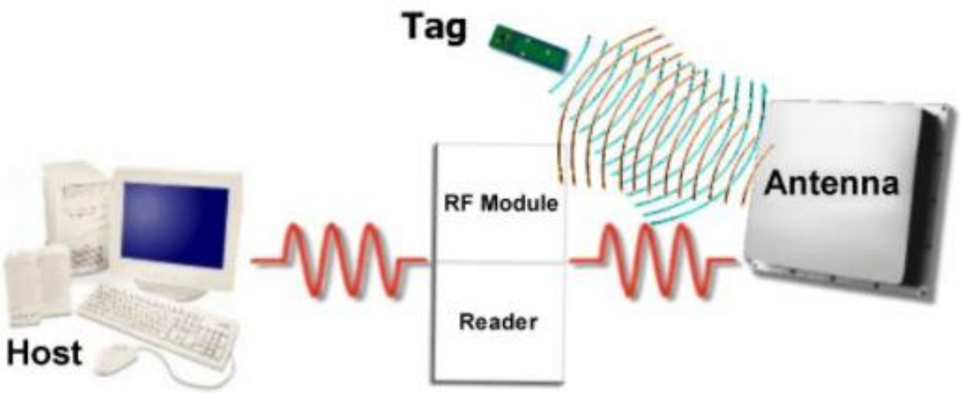


Fig 6: A general RFID architecture

c) Micro-ElectroMechanicalSystems (MEMS)

A micro-electro mechanical system refers to a miniature machine which incorporates both mechanical and electrical components.

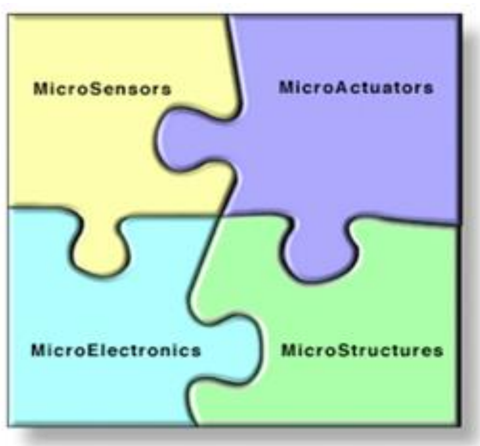


Fig7: Components of a micro-electro mechanical system

d) Cloud computing

Cloud computing refers to the hosting of services over the internet.The Internet of Things will be the biggest consumer of cloud computing because it is the future of Internet, Khalid .A, (2016).

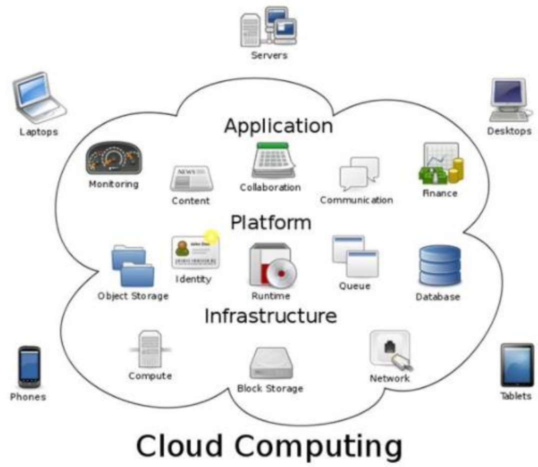


Fig 8: Cloud computing architecture

2.2. 2 Basic IoT Architecture

According to Khalid.A, (2016), the IoT Architecture can be divided into three layers Perception, Network and Application. Some architectures if the IoT model also incorporates a Support layer which is placed between the Network layer and the Application layer. Perception layer (also called as recognition layer) gathers data or information and identifies the physical world. Network layer is the middle one (also called as wireless sensor networks), which accounted for the initial processing of data, broadcasting of data, assortment and polymerization. The topmost application layer offers these overhauls for all industries.

'According to most of the researcher's opinions about conventional IoT architecture, it is considered as three layers: -

- Perception Layer
- Network Layer
- Application Layer

In other aspects, some researchers analyzed one more layer which is also included in IoT's latest architecture that is a support layer that lies between the application layer and network layer,' Muhammad (2017).

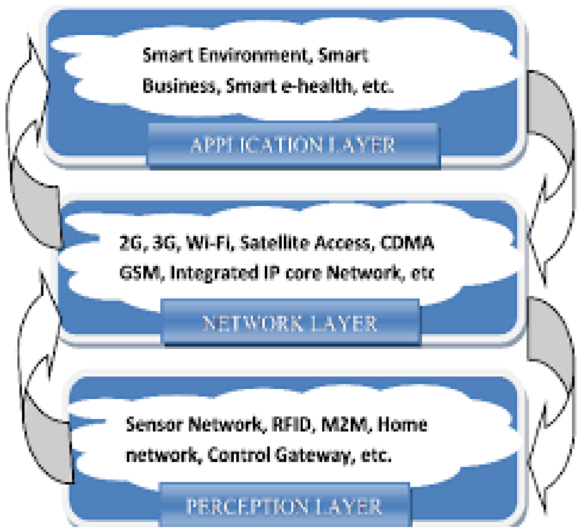


Fig9: IoT architecture model

According to Muhammad (2017), the upper layer of IoT architecture, the application layer, is further divided into three sub-layers due to different functionalities. The service management layer's main responsibilities are facilitating information processing, decision-making, and control of pairing requestor information processing for relevant tasks

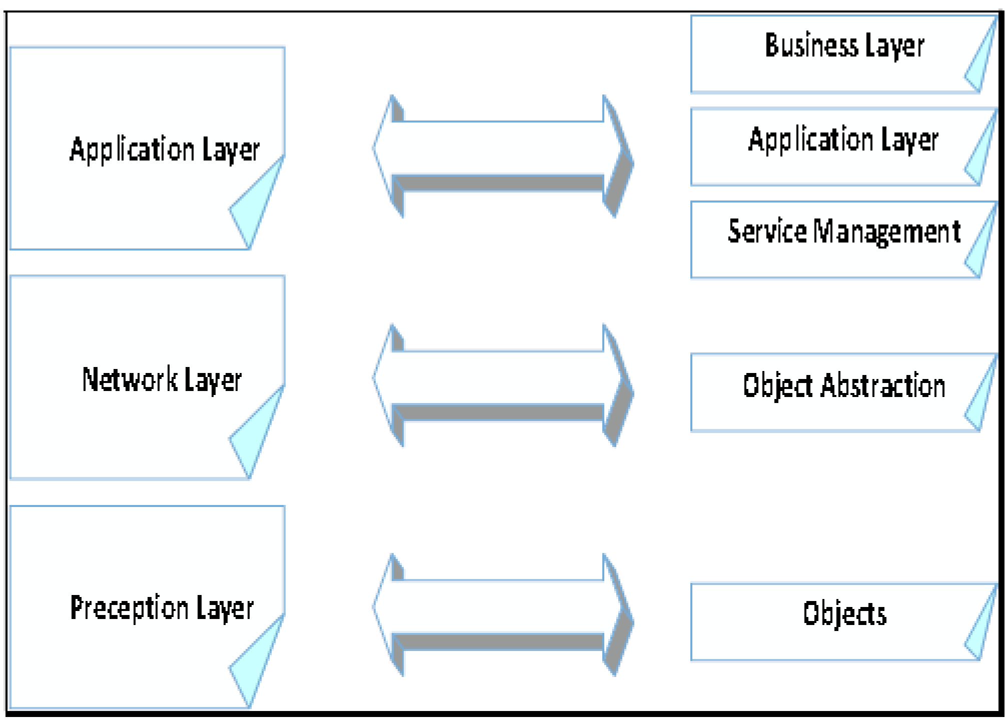


Fig 10: Enhanced 5 layer IoT architecture model

2.2. 3 IoT architectures for solid waste management

From the literature reviewed during this study the researcher adopted a 4-layer archictecture (Muhammad, 2017) , for the smart solid waste management system. The architecture comprised of the perception layer, network layer, support layer and application layer.

Perception layer/ recognition layer

This comprises of the the coding or identification of objects as well as the devices themselves. Objects are given unique IDs that are used to distinguish them. The perception layer is also known as the recognition layer/ IoT device layer. It gives a physical meaning to the objects which have been embedded with sensors used for data collection. Information collected by the sensors is turned into digital signals which are then passed onto the network layer.

Network layer

This layer is tasked with receiving data and transmitting the data for processing in the middleware layer. Mediums used in this layer for data transfer are Bluetooth, GSM, 3G, 4G with various protocols like IPv4, IPv6, MQTT among others. For this study, GSM was used for data transfer.

Support layer

This layer is used for processing data that is received via the network layer from the sensors. Data in this layer is then processed into useful information that can be used for data driven decision making. The middle layer consists of technologies like cloud computing which was used in this study. Since cloud computing is ubiquitous, it gives room for data storage and data access from the DB at any time and from anywhere via an internet connection.

Application layer

This is the layer that all IoT applications depending on the data processed lie on. In this study this comprise of the web view page and a mobile app for smart solid waste management.

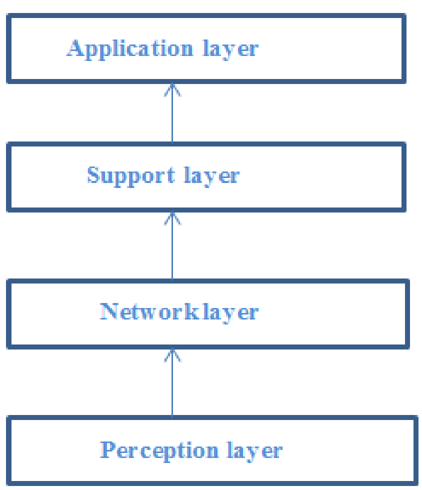


Fig11: Proposed IoT architecture for the Nairobi smart waste management system

2.2.4 Review of IoT architectures for managing solid waste management

2.2.4.1. IoT architectures for solid waste management in Europe

In Lundin, A Et al., (2017), the authors opt to design an IoT system to be used in the monitoring and management of solid waste. They propose the placing of a network of small sensors which are battery powered and wireless on already existing garbage bins. The proposed system also encompasses cloud computing at the back end for data aggregation from sensors and a front end for visualization of bin levels. For optimal wireless communication the authors decide to use LoRaWAN which has a longer range when compared to WiFi as well as low consumption in power as compared to GSM. LoRaWan is also relatively inexpensive and allows for scalability. In their pilot study (in Denmark) of the smart waste management system, the authors were able to collect data that allowed for better real time decision making in terms of efficient waste collection using predictive analytics, better user experience by the public while using the public bins as well as bin placement optimization. The model, however, lacked citizen and municipal authority involvement. Citizen involvement is viewed as a vital requirement while building smart systems for smart cities. To be “smart” is not about size, but about how the city or municipality facilitates dialog, interaction and collaboration with its citizens, Berntzen et. al. (2016).

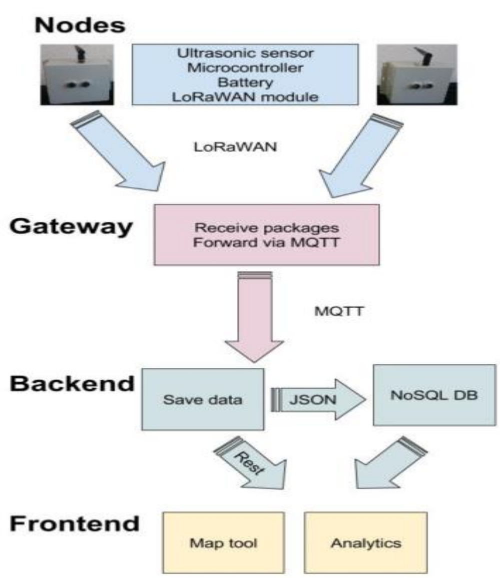


Fig 12: Proposed system architecture for a smart waste management system (Lundin, A. Et al. ,2017)

2.2.4.2. IoT architectures for solid waste management in Asia (India)

"'ICT allows city officials to interact directly with the community and to tell what the situation of city is, how the city is evolving, and how to enable a better life. Through the use of advance technology, system and sensors, data are collected from peoples and objects - then processed in real-time. The data, information and knowledge gathered are keys to tackle inefficiency," Agarwal et.al. (2016). According the authors, India continues to struggle with the challenges in solid waste management a menace attributed to the break out of a plaque in Surat in the year 1994. The authors also indicate that there needs to be better solid waste control mechanisms with a more enhanced participation from the community.

In Kedia (2016), the author mainly focuses on the role of data analytics in the improvement of efficiency of solid waste management. The author also proposes the below diagram that shows the role of IoT and analytics towards improving the efficiency of solid waste management.

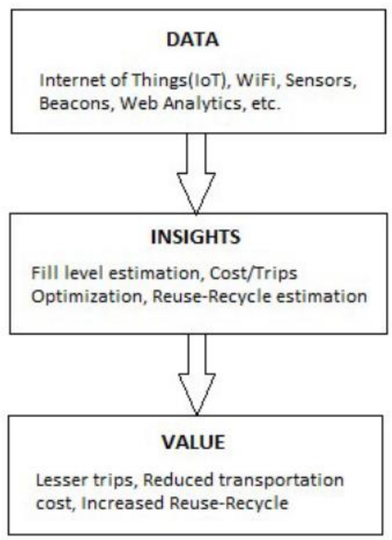
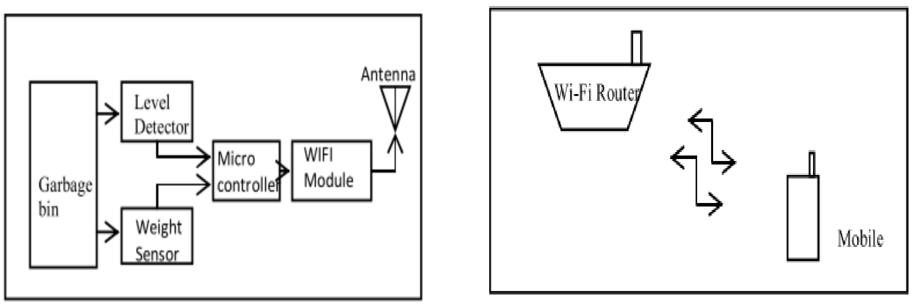


Fig13: IoT architecture by Kedia (2016)

In this study, emphasy is laid to the use of data in the planning of solid waste management strategies . The author collects sensor data from waste bins located in different locations and applies machine learning algorithms for prediction purposes. By applying these algorithms the author was able to identify areas where waste is found in large quantities, information that can be used in the reduction f transportation cost as well as the time spent in solid waste collection.

In Navghane, S. Et al, (2016), the authors propose a smart waste management system whose system architecture comprises of a microcontroller, an IR sensor, a weight sensor and a WiFi module. The microcontroller is a mini computer comprising of a mini CPU and has an embedded high flash memory. The IR sensor and the weight sensor are used in indicating the waste level of the bin and the amount of waste in the bin respectively. The WiFi module is used for data transmission from the garbage bins and is displayed on an HTML in a PDA web browser. The garbage management system ensures timely collection of waste by the garbage collector failure to which data on uncollected waste is sent to a person in higher authority who can take action against the garbage collector. Data on garbage bins is also used for route optimization. The authors, however, also did not take into account the role of citizen involvement in the smart waste management system in order to achieve optimal effectiveness. The authors also did not explore more efficient technology for long range wireless communication and low power consumption.



Transmitter *Receiver*

Fig 11: A system architecture for the transmitter and the receiver of a waste management system (Navghane, S. Et al.,2016)

2.2.4.3. IoT architectures for solid waste management in Africa

Researchers from the Nelson Mandela African Institution of Science and Technology in Tanzania propose the application of multi-agent based IoT system for smart waste management. Using Netlogo Multi-agent platform the authors simulate real time, data-driven decision making for the monitoring and collecting of waste. In Likotiko, E. Et al. (2017), the authors lay emphasis on citizen involvement in the design and implementation of a multi-agent based IoT smart waste management system. The authors highlight the functional requirements of the smart waste management system as a waste bin level indication per unit time, continuous update of waste levels of individual bins, cost of unit waste collection incurred by the citizen and route optimization for waste collection by the garbage collectors. In their proposed general system architecture, a public bin is fitted with a level sensor that does real time monitoring of bin levels. An Arduino Wi-Fi shield is used as a gateway for data transmission to a central system database. The central system comprises of three tier architectures namely lower, middle and upper tiers. The upper tier contains a central DB used for storing waste bin status coupled with an optimization model used to determine the optimal path for waste collection. The middle tier comprises of the gateway while the lower tier contains the sensor nodes. The authors also did not include municipal authority in their architecture and they also used technology for shorter range wireless communication and higher power consumption.

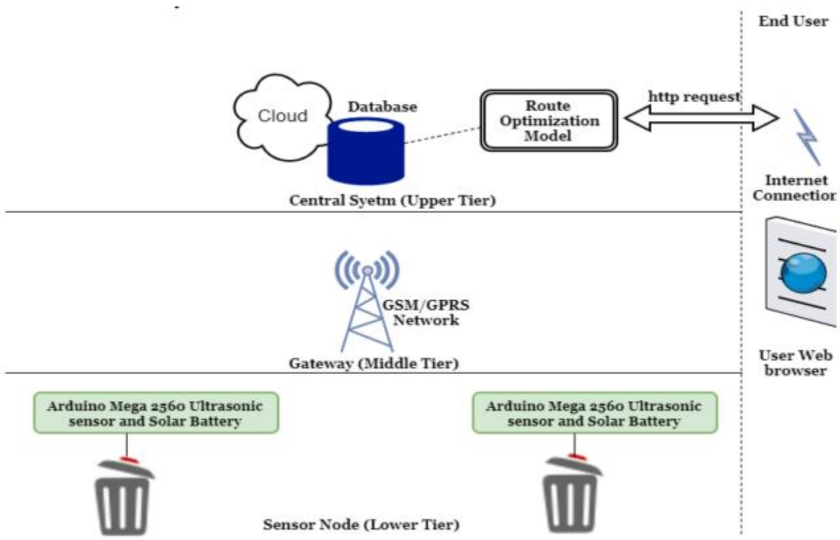


Fig 12: A central system architecture for a multi-agent based IoT system for smart waste management (Likotiko, E Et al. , 2017)

s/n	Related literature	IoT analytics/ Dashboard	Citizen involvement	Municipal involvement
1	Lundin, A Et al., (2017)	YES	NO	NO
2	Navghane, S. Et al, (2016)	NO	NO	YES
3	Likotiko, E Et al. , 2017	YES	YES	NO

Table 8: A summary of previous studies showing application of IoT for solid waste management

2.2. 4 General adoption of IoT in Africa/ Kenya

Internet of Things, though relatively new in Kenya has been adopted in various industries in order to improve the livelihoods of Kenyans. M-KOPA is a popular Safaricom service that uses connected devices in order to provide cheap, clean and affordable energy to Kenyans. IoT has also been used in the monitoring of wildlife to not only reduce poaching, but to also monitor the health of the wild animals. Omollo, L. (2014), also suggests the application of IoT to reduce traffic congestion in the city of Nairobi. However, there is scanty literature on the application of technology to improve on solid waste management in Nairobi and Africa in general.

IBM researchers in their project, dubbed the IBM Research Africa project, have also made attempts in automating the waste management processes in Nairobi. In their approach, however, the researchers fitted garbage collection trucks with smart devices used in tracking and collecting data on the vehicles. Using an app, the researchers were able to track the location of the garbage trucks, monitor their movement, including how long it takes for the truck to move from one collection zone to another, check dumpsites and verifies if they are full as well as monitoring fuel usage by the garbage trucks. One of the objectives of the IBM researchers was to map garbage collection routes in Nairobi after collecting data from the garbage trucks. This data would be used in the monitoring of the garbage collectors to ensure that they are actually carrying out duties as intended.

2.2 Conceptual framework

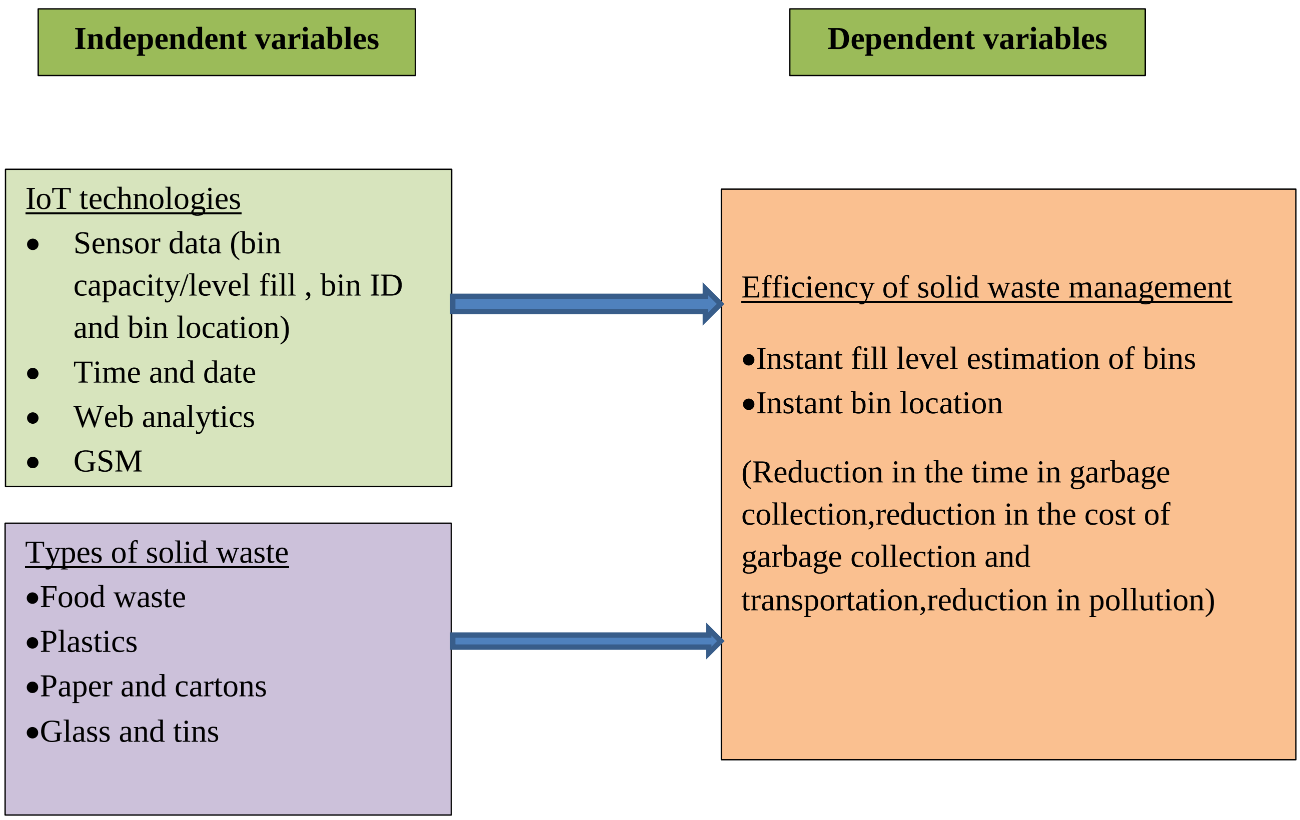


Fig 14: Conceptual framework

2.3 Operationalization of variables

Involves defining and specifying how variables will be measured. It entails having variables into measurable factors.

Variable	**Indicators**	**Values**
IoT and supporting technologies	Connectivity	IoT analytics Device management
Types of solid wastes	Source	Residential Commercial
Efficiency	Change of efficiency metrics	Change in time taken during waste collection Change in time taken during the monitoring of garbage collectors Change of cost incurred during waste collection

Table 9: Operationalization of variables

3.0 CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter comprises of the research design, research population, population frame, data sampling, data collection tools, data processing and analysis. The research methodology was guided by the objectives of the research. It involved the research design, data collection methods, analysis of the data as well as the presentation methods.

3.2 Research design for objective 1

Research design refers to the procedures and methods that are used in the collection and analysis of measures of the variables used in the research study. According to Kothari (2008), research design is the arrangement of conditions for the collection and analysis of data in a stated manner that aims to combine relevance to the research purport with economy in procedure. Research design can also be defined as a framework that is created to discover the answers given to research questions in a research study. It defines the type of study, the study sub-type as well as the data collection methods and the statistical analysis plan. The researcher employed survey method by administering questionnaires to Nairobi residents. The researcher then analyzed and described the responses given by the respondents.

3.2.1. Problem analysis task

The study was carried out in Nairobi county. A combination of data from a survey and the existing literature review of solid waste management in Nairobi was used to identify the types of waste in Nairobi. Data collected from the survey was used in determining the effectiveness of the current solid waste management. Secondary data was also collected from county reports and other stakeholders like NEMA and JICA.

3.2.2. Target Population

Population refers to the focus group of a scientific study. Individuals of a population are known to have similar traits or persona. In the current study, the population refers to the source of relevant to the research questions. The target of this population was households living in Nairobi.

3.2.3. Data collection method

The researcher used both secondary and primary data. Research instruments for data collection were questionnaires for the primary data.Both structured and unstructured questions will be used for the interviews.

3.2.4. Validity

According to Validity is the degree to which an instrument measures what it purports to measure. The research concentrated on content validity by performing a pre-test so as to adjust the research tool to meet the required standards, (Mugenda &Mugenda, 1999). To check on the validity of the instrument, the researcher conducted a pilot study with 10 respondents was carried out. The respondents used in the pilot study were excluded from the actual study in order to reduce potential biases. In an auxiliary attempt to improve the validity of the research instrument, the researcher also took suggestions from experts in the area of study. The supervisor’s guidance in the development of the questionnaire was also highly put into consideration to ensure that the tool collected relavant data to answer the research questions.

3.2.5. Reliability

This is a measure of the degree to which a research instrument would yield the same results after repeated trials (Mugenda & Mugenda, 1999).

3.2.6. Sampling Procedure

The researcher used Kasarani ward as a representative population for Nairobi and made this the target population. According to Arleck and Settle(1995),it is seldom necessary to sample more than 10% of the population provided that the resulting sample is not less than 30 and not more than 1000 units. The population of Kasarani ward is set at 30, 658 people according to the 2009 census by KNBS. It also gives the average number of persons living in a household in Nairobi as 3.3 . The target population was hence taken as the total population divided by the average number of households.

Total population (N) =30,658
Ave population size=3.3
Target population for the study= 30658/3.3 = 9,290.30

The appropriate sample size was determined by the population size, the level of precision (sampling error), the level of confidence and the degree of variability in the attributes measured (Kumar, 2005). A simplified formula was provided by Yamane (1967) which uses the three provided indicators to calculate the sample sizes.

$$n = N/(1 + Ne^2)$$

N= Target Population
n= Sample size
e= margin of error

Assuming a confidence level of 95% (Ngulube,2009), a degree of variability of 0.5 and 0.05 sampling error the above formula was used to target a sample size of:

$$n = 9290/(1 + 9290*0.05^2)$$

$$n = 383.48$$

The sample size,n, was used as the unit of analysis for this study. The unit of observation was a member of each household. In order to collect information from respondents the researcher handed out questionnaires to residents of Kasarani ward and also sent out a link to the survey to residents via email and social media contacts.

3.2.7. Survey response rate

The response rate to questionnaires is highly dependent on the willingness of the respondents to give their responses in a timely manner. Research studies that employ the use of questionnaires will more often than not expect to receive a high response rate which will subsequently give a large data sample and statistical power as well as smaller confidence intervals around sample statistics.

According to (Rogelberg & Stanton, 2007), even if the questionnaires are administered to the target population and incentives such as reminders used, a response rate of 100% is rarely achieved.Cook et al. (2000) have argued that the response representativeness is more important than response rate in survey research but only if it bears on representativeness of the population being studied. During the study, the researcher collected data from 102 respondents. The primary data in this study was supplemented with secondary data which was sourced from various reliable sources.

3.2.8. Data analysis method

Quantitative data analysis was done with the aid of the RapidMiner, Google suite and SPSS statistics software. Quantitative data was described and summarized using descriptive statistics. The research tool consisted mainly of items with nominal variables,one item had ordinal variables and two items had continuous variables. The questionnaire data was coded which provided a way to represent data consistently for all the participants.

3.2.9. Ethical Considerations

Before any data collection exercise, the respondents were informed about the purpose of the data being collected and explained about the objectives of the research. All data collected was used for the intended purposes only and was kept confidential.

3.3 Research design for objectives 2 and 3

To achieve objectives 2 and 3, the researcher adopted an interpretivist approach in the research. This was done so as to assimilate human consideration and interest into the study. The research design adopted was a creative process that involved problem analysis,ideation, implementation, analysis and communication.The research design, methodology entailed problem analysis, suggestion, simulation development, evaluation and conclusion. "Moreover, interpretivism studies usually focus on meaning and may employ multiple methods in order to reflect different aspects of the issue. This approach suited this study because Interviews and observations which are the most popular primary data collection methods in interpretivism studies, are crucial to the type of data that will be collected," Omollo (2014). The researcher employed a research strategy that was maily descriptive. This was done because the aim of the study was to simulate a solid waste management architecture which leveraged the use of IoT and other supporting technologies in order to improve the effictiveness of the solid waste management processes. "A descriptive research intends to present facts concerning the nature and status of a situation, as it exists at the time of the study. It is also concerned with the relationships and practices that exist, beliefs and processes that are ongoing, effects that are being felt, or trends that are developing. Also, such approach tries to describe present conditions, events or systems based on the impressions or reactions of the respondents of the research," (Omollo, 2014).

3.3.1 Problem analysis

This was achieved by qualitative content analysis of the existing literature and publications that focused on IoT models used in the types of solid wastes identified in the first objective. Content analysis was used in identifying any shortcomings on the already existing models.

3.3.2 Ideation and suggestion

Suggestion or proposal of a architecture that can be used to efficiently manage solid waste in Nairobi was done at this stage. The researcher suggested an IoT model that is apllicable in Nairobi using concept combination method. This was done by review of previous suggested models in published articles. The researcher then integrated ideas to design an IoT model for the same.

3.3.3 Creative process and architecture design

Design and the development of a localized an applicable architecture that uses IoT for solid waste management in Nairobi.

3.3.4 Architecture presentation, evaluation and Conclusion

The proposed architecture was presented and simulated and a concluding statement was arrived at based on the suggested and designed architecture. Other than resource contraints resulting to the choice of a simulation of the architecture over a prototype, previous studies have shown that a good simulation study provides data which can be used in the improvement of a prototype.

Phase	Research activity	Research techniques	Research Objectives
1	Data collection by survey method and analyzing data	• Quantitative analysis • Descriptive statistics • Checking the measures of central tendencies and measures of relation	1 & 2
	Literature review	• Qualitative analysis	
2	Problem analysis	• Qualitative content analysis • Summative content analysis	3
	Ideation and Suggestion	• Concept combination method • Integration of ideas • Propose model	
	Creativity process and architecture design	• Developing of the proposed architecture	
	Architecture presentation, evaluation and conclusion	• Presenting of the designed model for critiquing	

Table10: A summary table of the research methodology

4.0 CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter includes findings of my study of the solid waste management systems in Nairobi county and that are relative to my research objectives. Questionnaires were administered to residents in Nairobi and used for data collection purposes.

4.1 Socio-demographic characteristics of the respondents

Total number of respondents = 102

From the survey, the researcher collected data from 102 respondents, 42 of whom were male and 60 of whom were female.

[DataSet1]

Statistics

		Gender	Age	School
N	Valid	102	102	102
	Missing	0	0	0

Characteristics	Categories	Frequency	% (n=102)
Gender	Male	42	41.2%
	Female	60	58.8%
Age	< 20	0	
	20-29	35	34.3%
	30-39	42	41.2%
	40-49	18	17.6%
	50-59	7	6.9%
	<= 60	0	0
Education level	University	47	46.1%
	Certficate/Diploma	40	39.2%
	High School	15	14.7%
	Primary	0	0%
	Never schooled	0	0%

Table 10: Frequency table showing the respondents demographics

Gender

There was a 58.8% and 41.2% representation of the female and male genders respectively from the .

Frequency Table

Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	60	58.8	58.8	58.8
	Male	42	41.2	41.2	100.0
	Total	102	100.0	100.0	

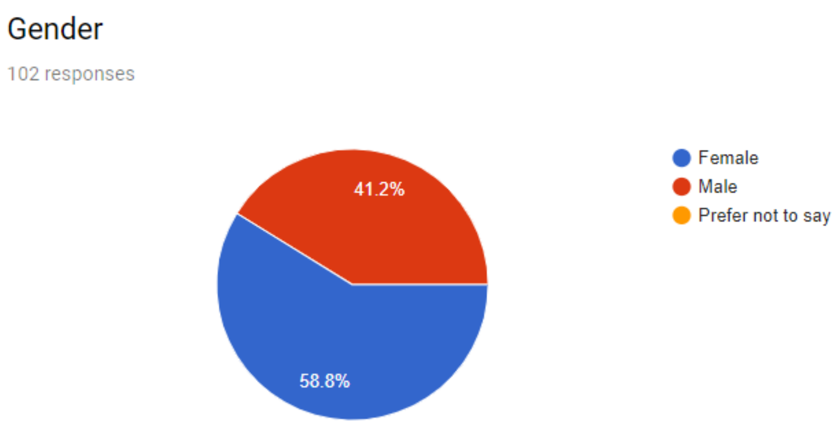


Fig15: A pie chart showing the gender distribution of the respondents

Education level of respondents

Respondents were also educated with majority of them having undertaken at least a degree course. 46.1% of the respondents had university education while 14.7% of the respondents has acquired high school education.

School

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Certificate/Diploma	40	39.2	39.2	39.2
	High school	15	14.7	14.7	53.9
	University	47	46.1	46.1	100.0
	Total	102	100.0	100.0	

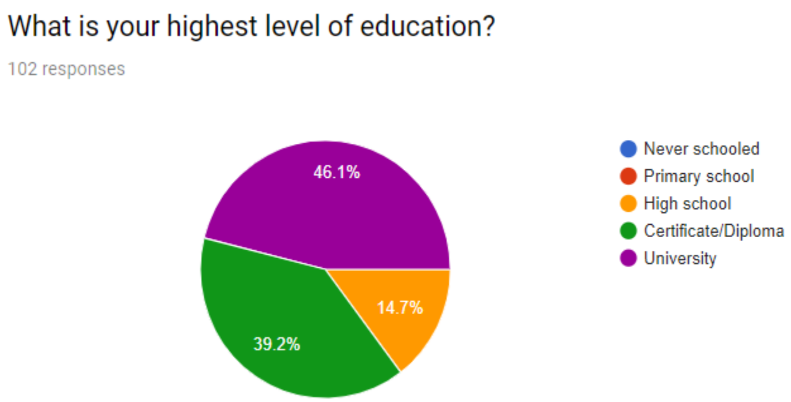


Fig16: A pie chart showing the level of educationof the respondents

Age

41.2% of the respondents belonged to the 30-39 age group making it the mode age group with 42 respondents being categorized here. Only 6.9% of the respondents were in the 50-59 age group.

Age

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-29	35	34.3	34.3	34.3
	30-39	42	41.2	41.2	75.5
	40-49	18	17.6	17.6	93.1
	50-59	7	6.9	6.9	100.0
	Total	102	100.0	100.0	

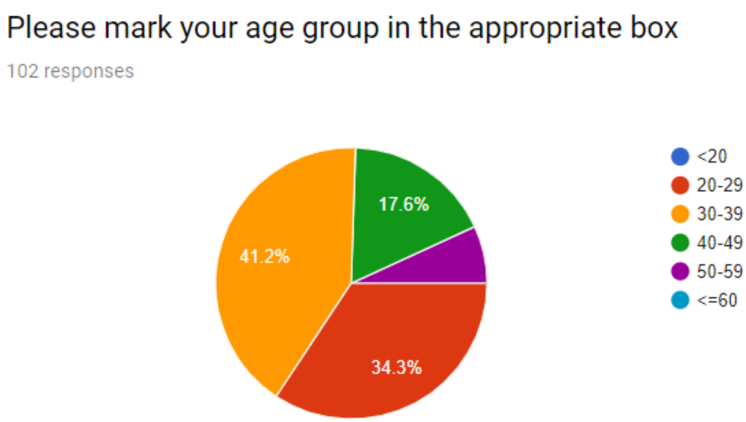


Fig17 :A pie chart showing the age group distribution of the respondents.

4.2 Types of wastes in Nairobi

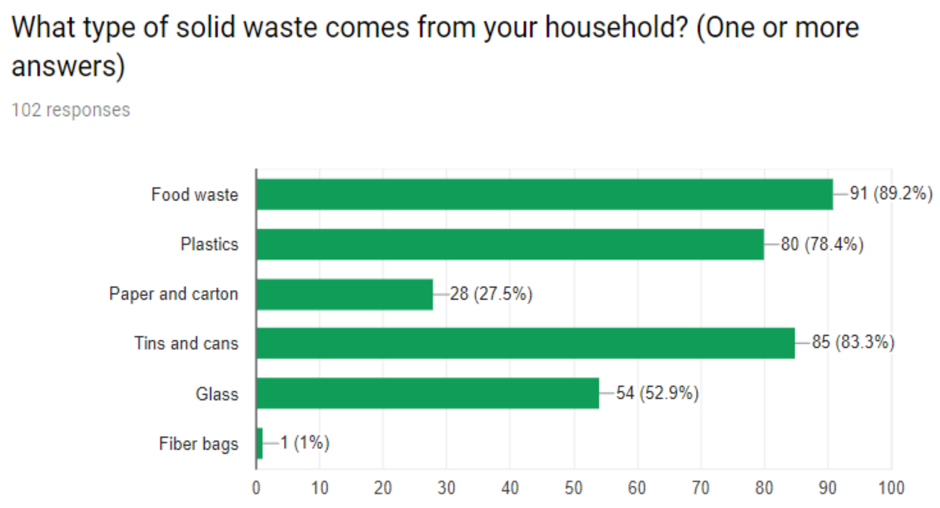


Fig 19:Solid waste types in Nairobi households

JICA Final report (2010) describes solid waste in Nairobi as mainly constituted of residential waste at more than 50% of the total waste. Commercial waste, road waste and market waste constitute the rest of solid waste generated in the city

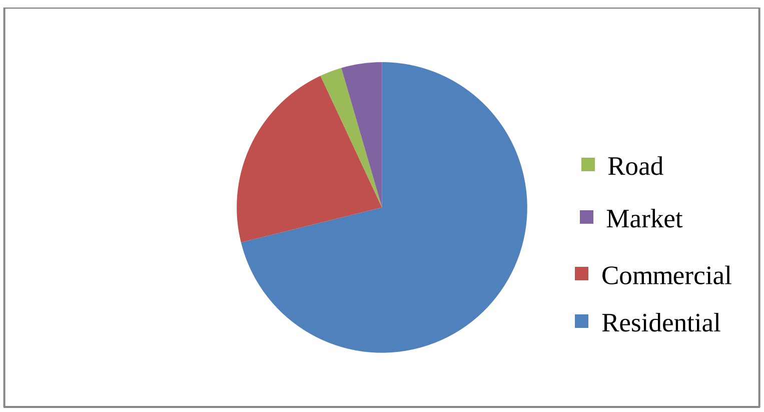
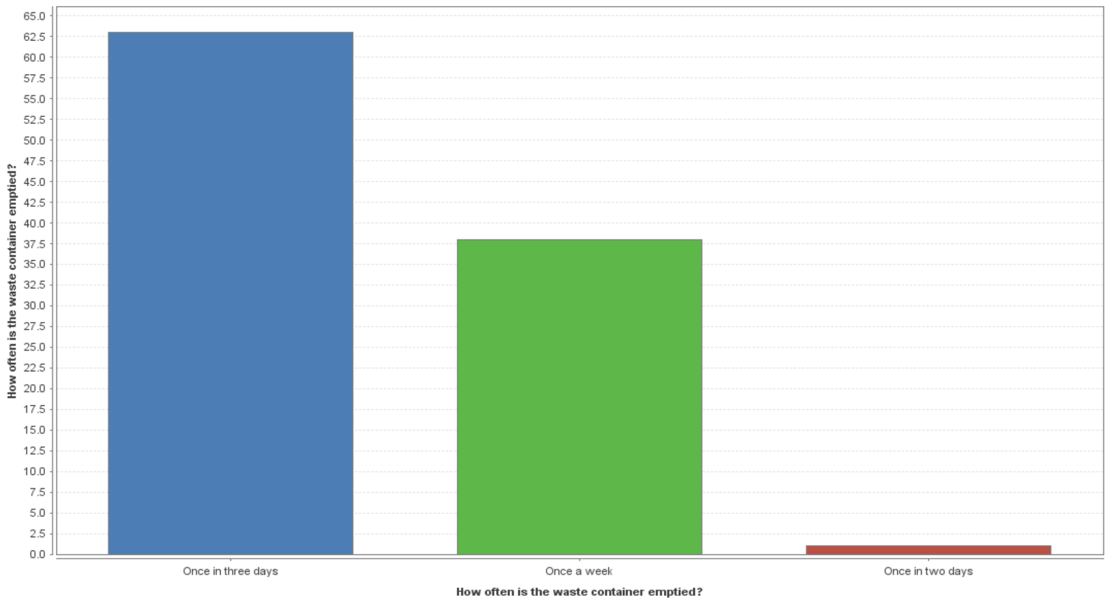


Fig20: Pie chart showing types of waste in Nairobi

4.3 Waste generation rates in Nairobi

The researcher established that 61.8 % of the respondents emptied their waste bins at least once every 3 days while 37.3% of the respondents emptied their waste bins at least once a week. Majority of the respondents also had larger disposal containers with 35% having a capacity of 7 liters,30% had 10 liters while 22% had 12 liters capacity for their waste baskets.



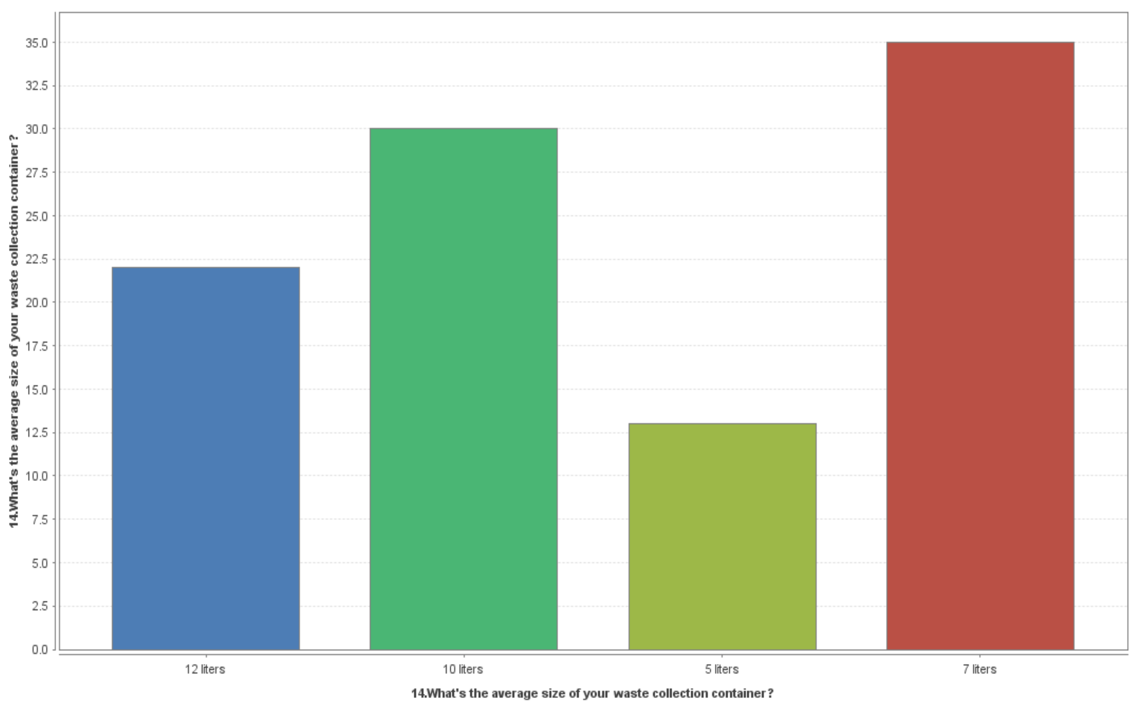


Fig21: Bar graphs showing weekly rate of waste disposal by households

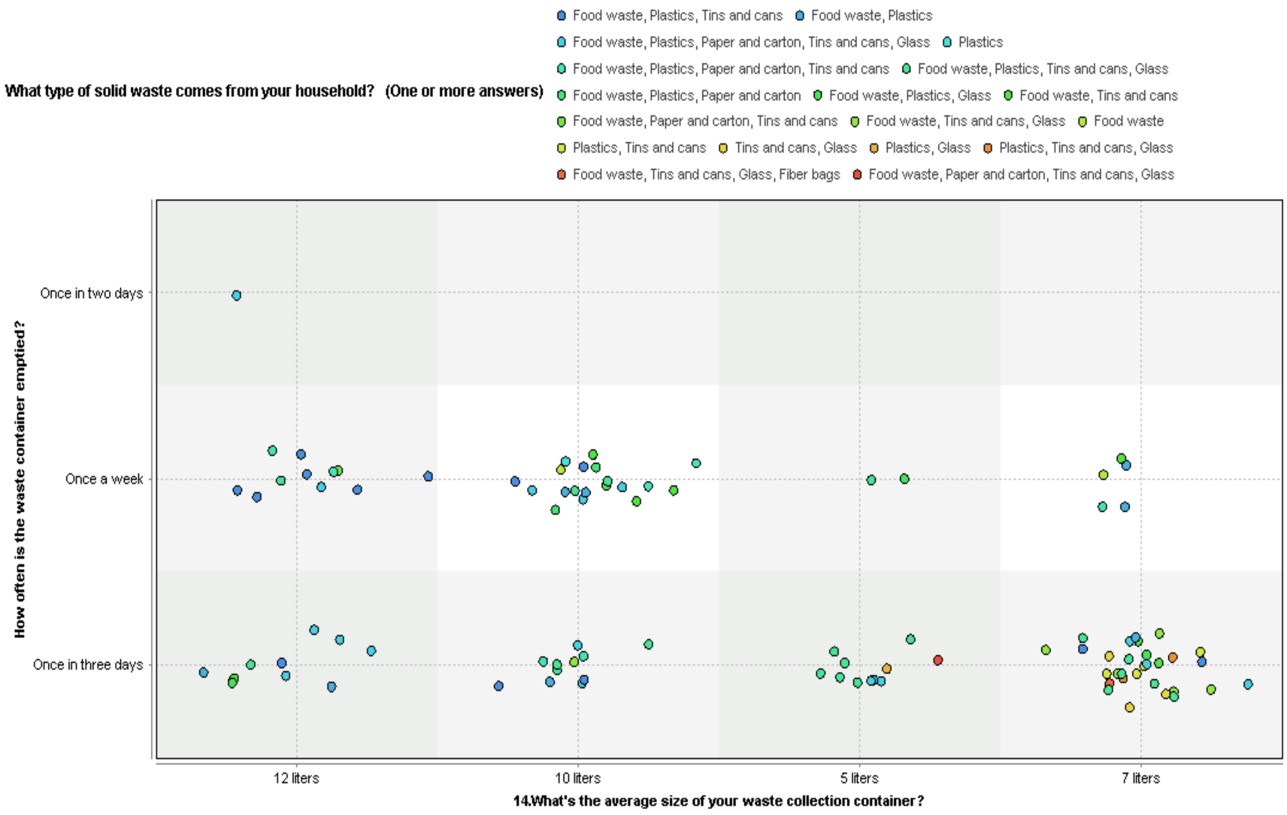


Fig22: Scatter plot showing rates of waste disposal by households in Nairobi

These findings were supported by a report done by JICA for the ISWM Nairobi master plan that showed that showed high increases in the rates of waste generation by households. According to JICA, by the year 2009 solid waste in Nairobi mainly constituted of residential waste at a generation rate 1,318 tons per day while commercial, road and market wastes were generated at a rate of 439 tons, 60 tons and 90 tons per day respectively. The prediction for solid waste generated in Nairobi in the year 2030 is at 3990 tons per day. It is also predicted that 2,830 tons of the waste generated by the year 2030 will be from residential waste while 953 tons of waste will be from commercial sources. This places the expected rate of residential waste generation at 71.7% of the total waste generated.

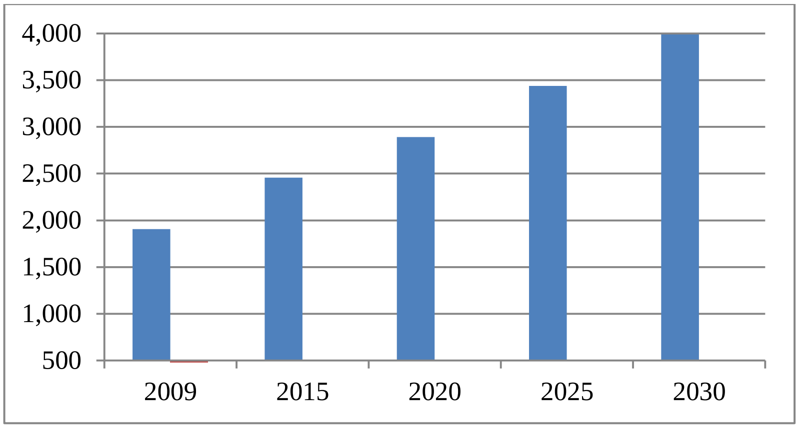


Fig23: Bar graph showing past and expected waste generation in Nairobi

4.4 Waste disposal and collection methods in Nairobi

58.9% of the households had their waste collected by an itirenant waste truck while 42.2% of the households placed their waste in a private bin within their residential buildings.

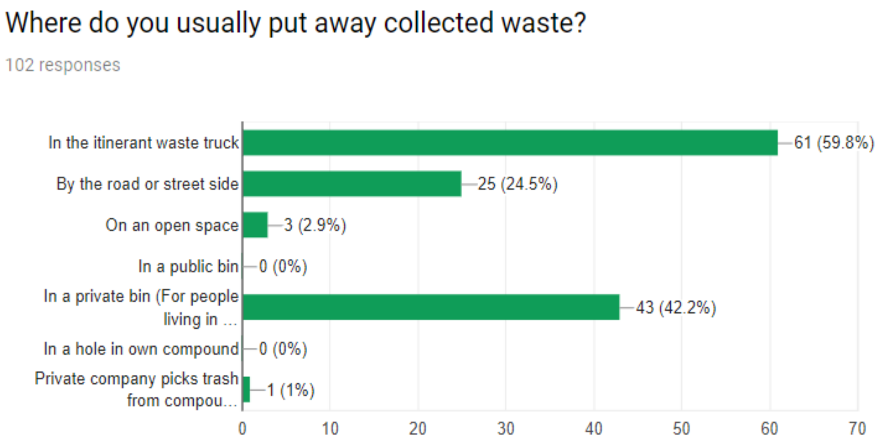


Fig24: A bar graph showing waste disposal methods by households

The County Government of Nairobi is solely mandated with the responsibility of managing solid waste in the city. The county government has, however, privately contracted stakeholders in the private sector to collect solid waste on behalf of CGN. This comprises of private companies, community based organizations (CBOs) as well as youth organizations. Monitoring of the private stakeholders in their waste collection routines has also been a major challenge for the county government.

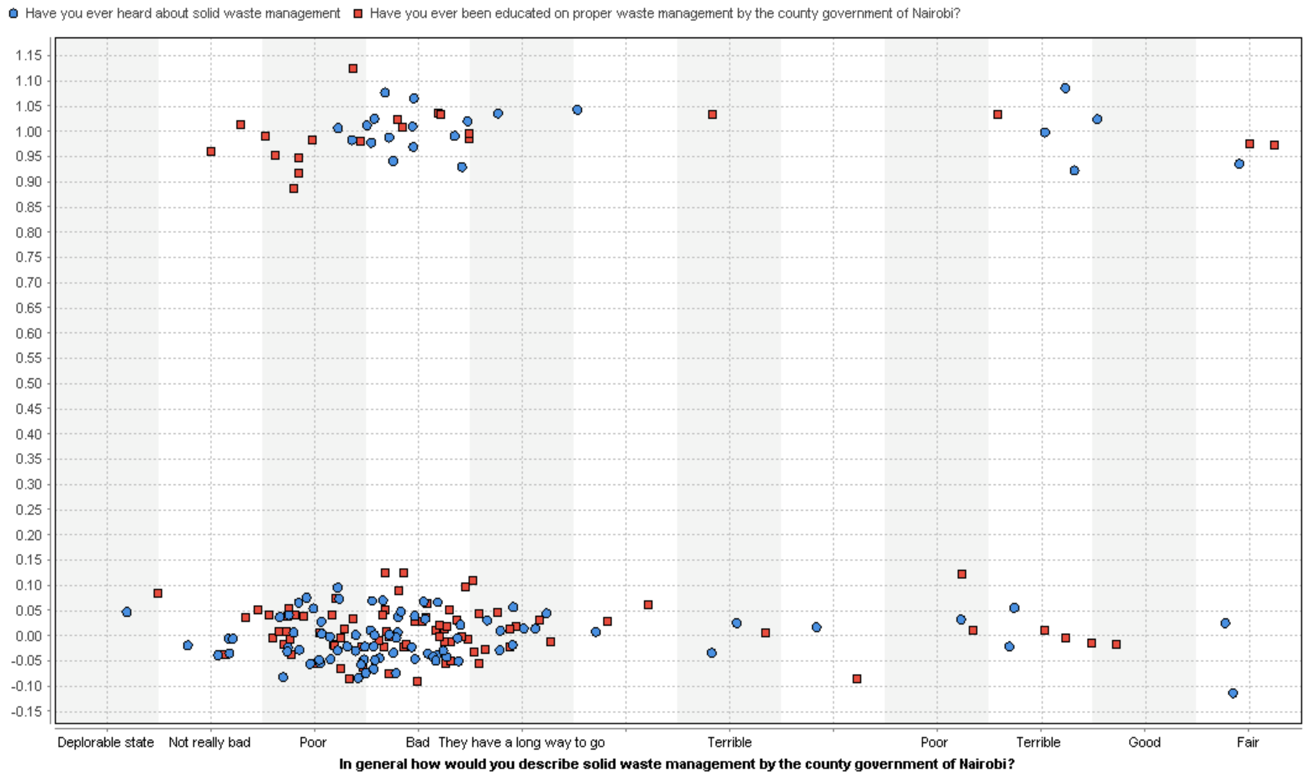


Fig 25: Scatter plot showing the opinion of Nairobi residents with regard to waste management in the city

4.5 Current IoT architectures applicable in solid waste management for Nairobi

Perception layer recognition layer comprised of the the coding or identification of objects as well as the devices themselves. Information collected by the sensors was turned into digital signals which are then passed onto the network layer. The **Network layer** was tasked with receiving data and transmitting the data for processing in the middleware layer. Mediums used in this layer for data transfer was GSM with an MQTT protocols. The **Support layer** was used for processing data that is received via the network layer from the sensors. Data in this layer was then processed into useful information that can be used for data driven decision making. This layer consisted of technologies like cloud computing. The **Application layer** was the layer that all IoT applications depending on the data processed lay on. In this study this comprise of the web view page.

4.6 An architecture for the smart solid waste management system

According to the data collected and analysed in previous sections, it was evident that there were significant challenges in the waste management system in Nairobi. The researcher hence recommended the application of IoT in order to make the waste management systems more efficient. The researcher recommended the model below for solid waste management in the city. Due to complexity of the architecture, the researcher suggested an applicable model and only demonstrated the web view of the simulation of the waste management system and not the entire infrastructure

4.6.1. Proposed architecture

4.6.1.1. Problem

The feasibility study conducted (for objective 1) established that Nairobi residents found that solid waste management methods were inadequate which resulted in pollution of the environment and was also a nuisance to the residents.

4.6.1.2. Solution

After content analysis of solid waste management methods in Kenya as well as other solutions in solid waste management methods in other parts of the world, the research established a gap in the waste management methods in Kenya. The researcher hence recommended the application of IoT where sensors are embedded on public bins and the data collected from these sensors will be used by managers to make data driven decisions. This will ensure that solid waste collection is timely hence reducing pollution. It will also ensure that drivers are only sent to collect waste in the routes where the trash needs to be collected hence avoiding time and fuel wastage by coming up with a route optimization model. The system would also help the Nairobi county government in establishing areas where residents are not getting services required.

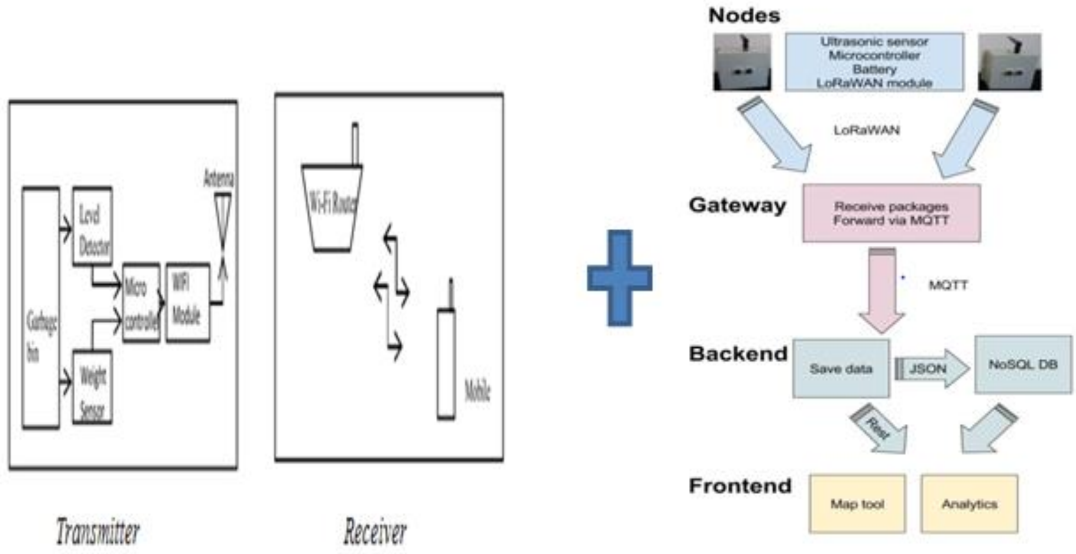


Fig27:Previously suggested architectures used to derive the model for the Nairobi smart waste management system

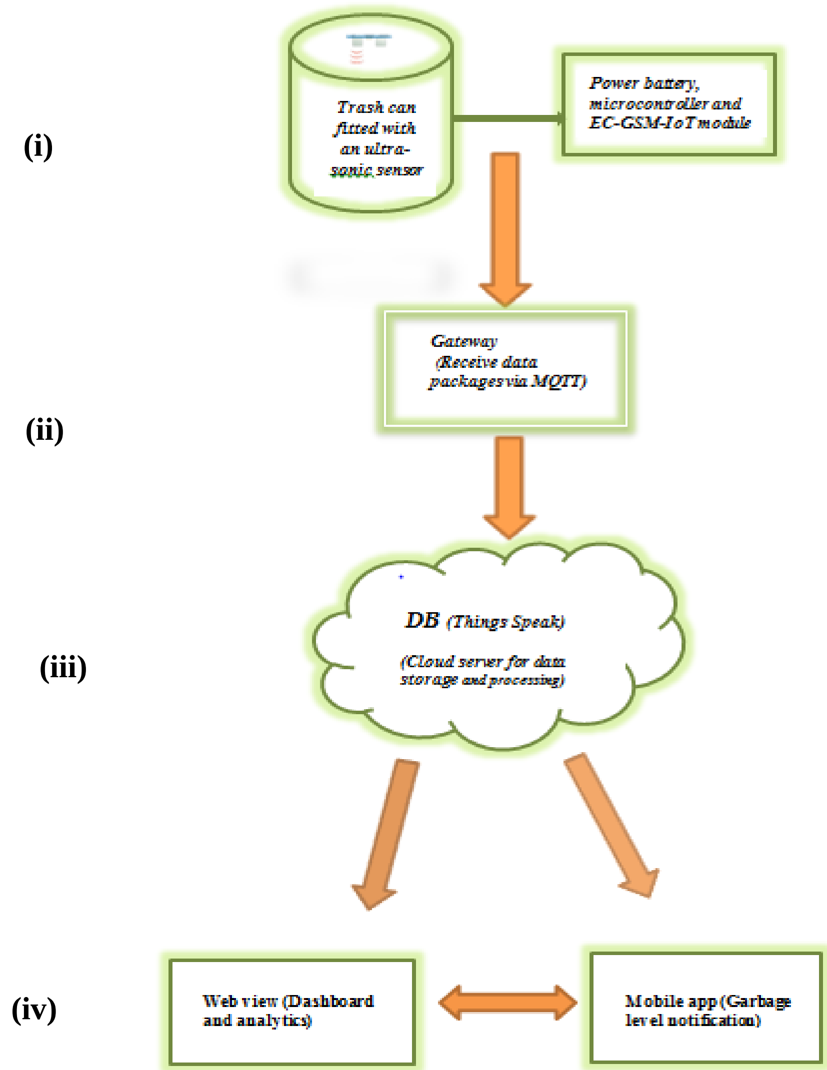


Fig28: Proposed architecture for the Nairobi smart bin system

i) Bin and Sensor (Coding and perception layer)

A trash can is fitted with an ultrasonic sensor, a battery, a microcontroller and an EC-GSM-IoT module. The microcontroller controls the system operation. The ultrasonic sensor is used for waste/trash level detection of the bin. An ultrasonic sensor is used to determine the level of the bin by sending sound waves generated and calculating time spent by the sound wave to be generated and bounced back. Use of an ultrasonic sensor to measure the level of waste is recommended over the use of a weight sensor because the fullness of metric is not necessarily defined by weight rather than by volume. For example, some solid waste may be heavier than other hence determining the fullness of the bin by weight becomes deceiving. The market also has readily available low cost ultrasonic sensors and it also possible to get sensors which are robust to harsh conditions. The trash can is also fitted with a microcontroller which is responsible for reading sensor data and also controlling the EC-GSM-IoT module. The EC-GSM-IoT is an extended coverage GSM IoT module is used for data transfer. The module is a low powe and wide area technology. It is specially designed for IoT commnunications and it is based on eGPRS and it has a low power consumption but still with a high capacity and long range to create efficiency in IoT commnunications. The EC-GSM-IoT module was chosen over wifi modules or bluetoooth. This is because bluetooth has a limitation of proximity for connectivity. To use a bluetooth connetion, the user would need to be at a close enough range with the trash can. Wifi accessibility in Nairobi would also be a challenge in some areas unlike GSM which widely spread. The EC-GSM-IoT module is used for communicating to a cloud server and it is also used for location tracking of the trash can. The smart device is powerd by either a rechargabe Lithion Ion battery or a Nickel Metal – Hydride battery.

i) Gateway (Network layer)

This is an external gateway which is used for aggregating the data and pushing it to the cloud server.This gateway is an Ethernet gateway fitted with modified software hence making it like an MQTT client. This is the network layer of the model.

ii) Backend (Support layer)

A database is needed for collecton and storage of information. A ThingSpeak database is recommended. This is a type of cloud storage for IoT. Data in a smart bin system is mainly sensor and bin location data. Bin are allocated their respective identification name or number. The ThingsSpeak db is used to store the values of the bins and their respective it level information for further processing.

iii) Frontend (Application layer)

Comprises of a webpage and a mobile app.The web page is fitted with a dashboard for visualization and analytics purposes by the end user. The mobile app is a simple application that is used in for communication about the level of the bin.

4.7 Simulation of the smart waste management system

4.7.1. Simulation platform

The researcher used Losant to build a simulation for this study. "Losant is an enterprise IoT platform that makes it easy to build connected solutions that produce real-time results." According to Kodali (2017), 'Losant is an easy-to-use and powerful enterprise IoT platform designed to help you quickly and securely build complex connected solutions. Losant uses open communication standards like REST and MQTT to provide connectivity from one to millions of devices. Losant provides powerful data collection, aggregation, and visualization features to helpunderstand and quantify vast amounts of sensor data.'

4.7.2. Simulation development

Using Losant, the researcher built the application which was named as Nairobi smart bin. The application had 3 devices (three trash cans) which were coded as Trashcan01, Trashcan02 and Trashcan03. For this simulation, the researcher decided to add three devices only but it was possible to add more or less. The devices had two main attributes which were the device location and device level.

<u>Backend</u>

Fig29: Set up of Nairobi smartbin simulation using a virtual environment

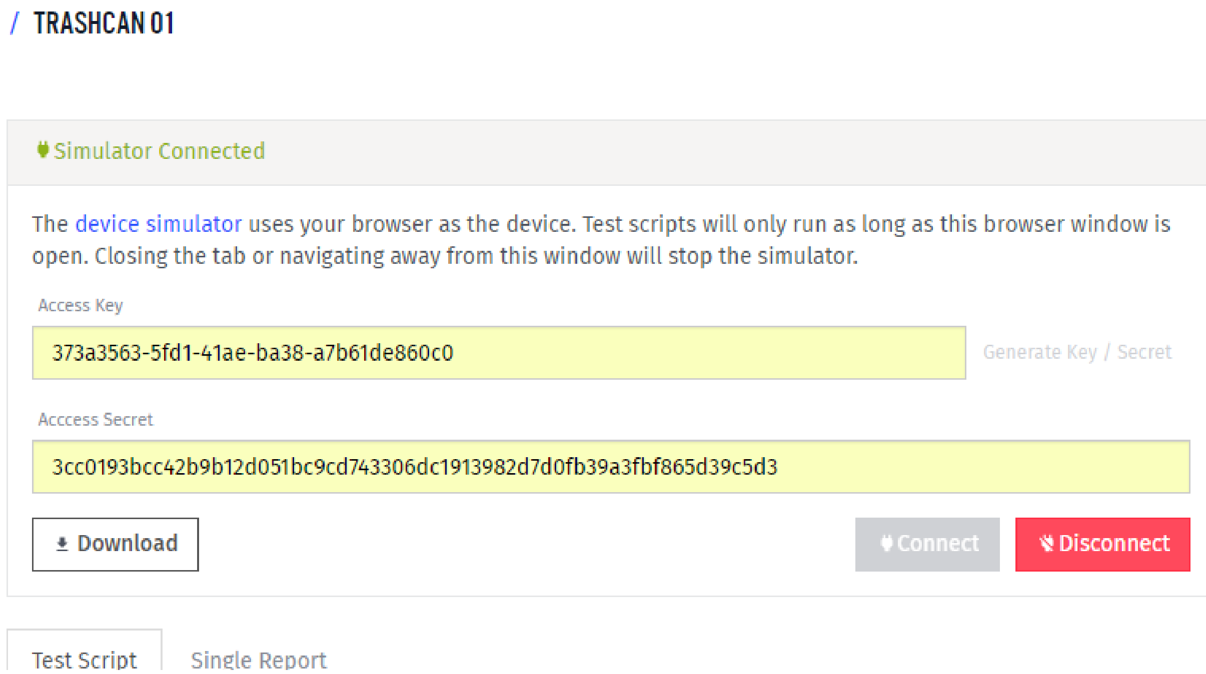


Fig30: Simulation of trashcan01

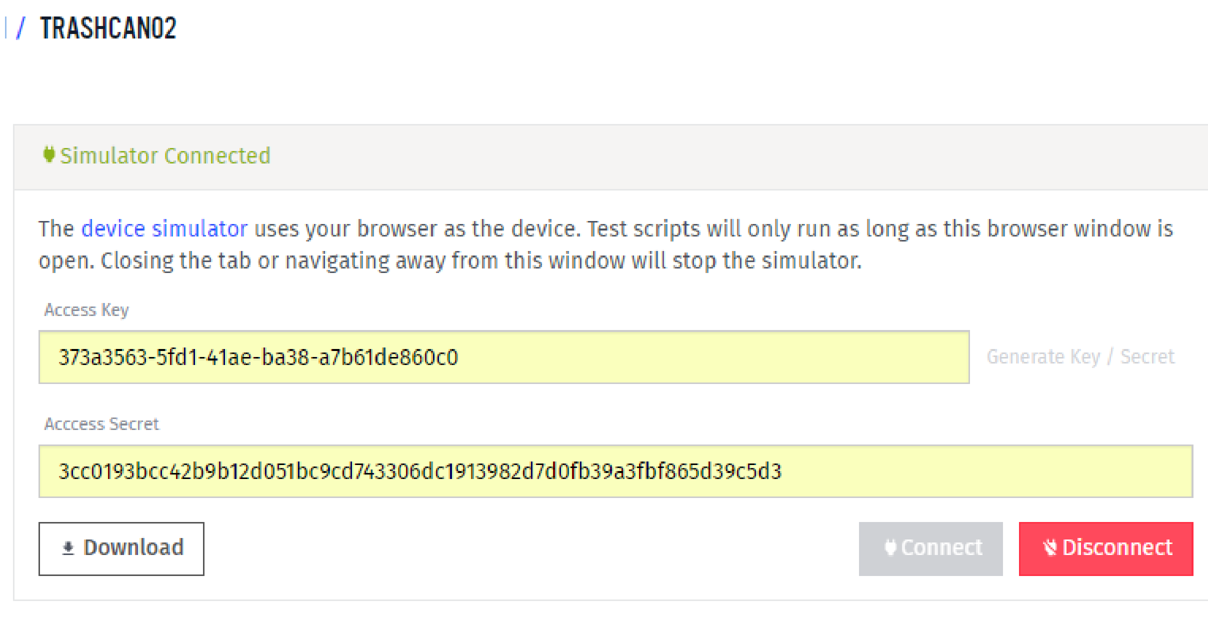


Fig31: Simulation of trashcan02

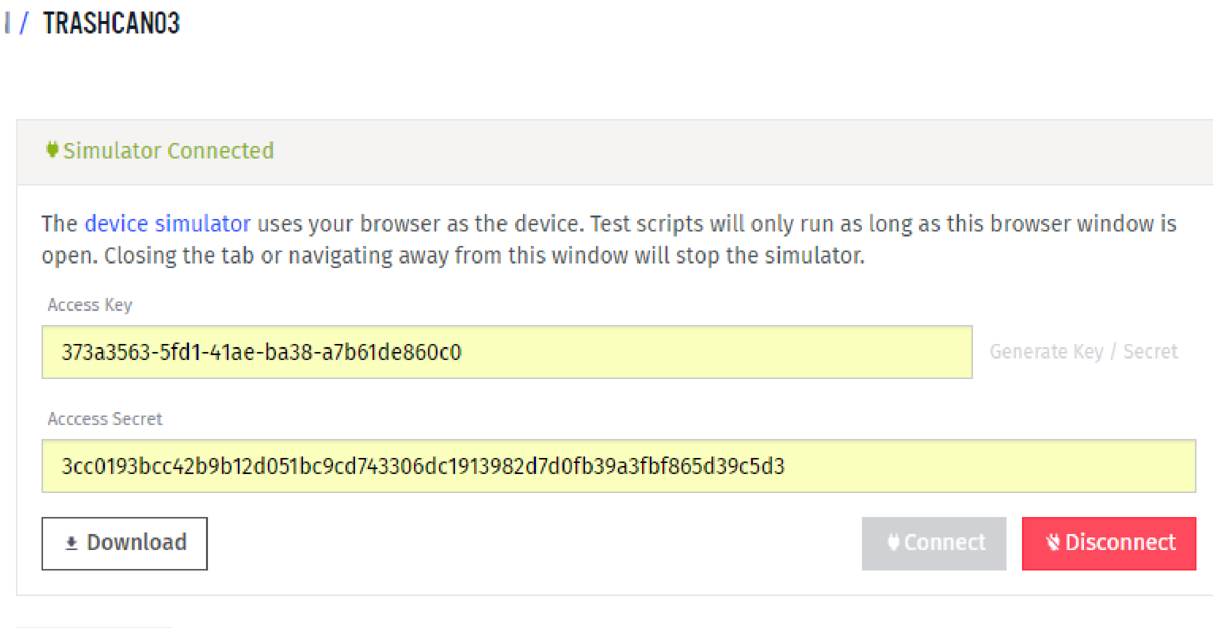


Fig32: Simulation of trashcan03

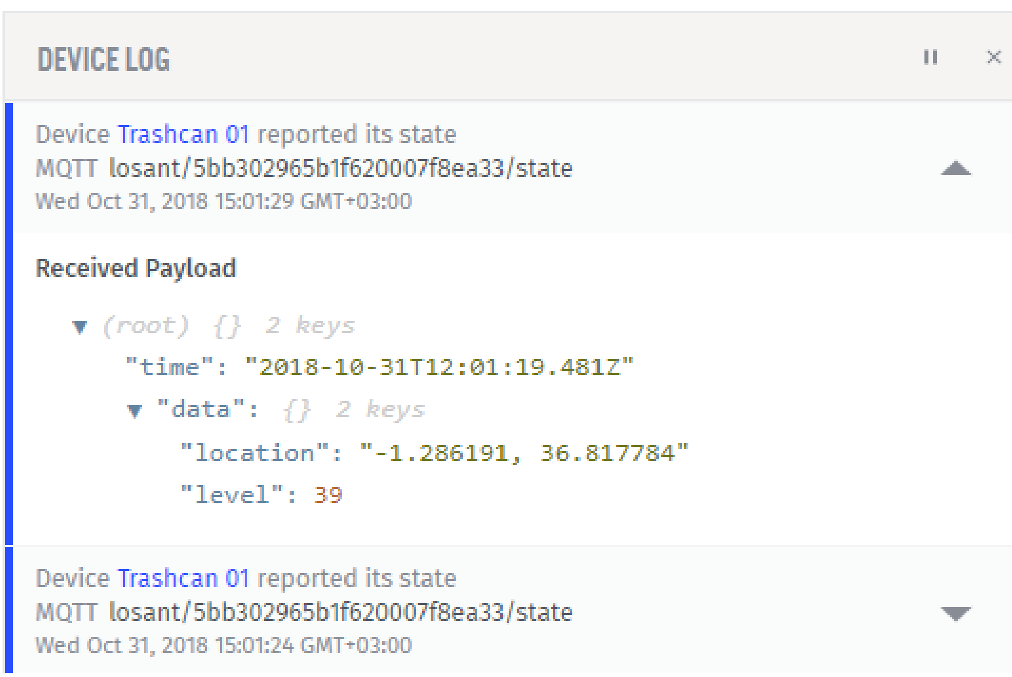


Fig33: Backend view of the devices

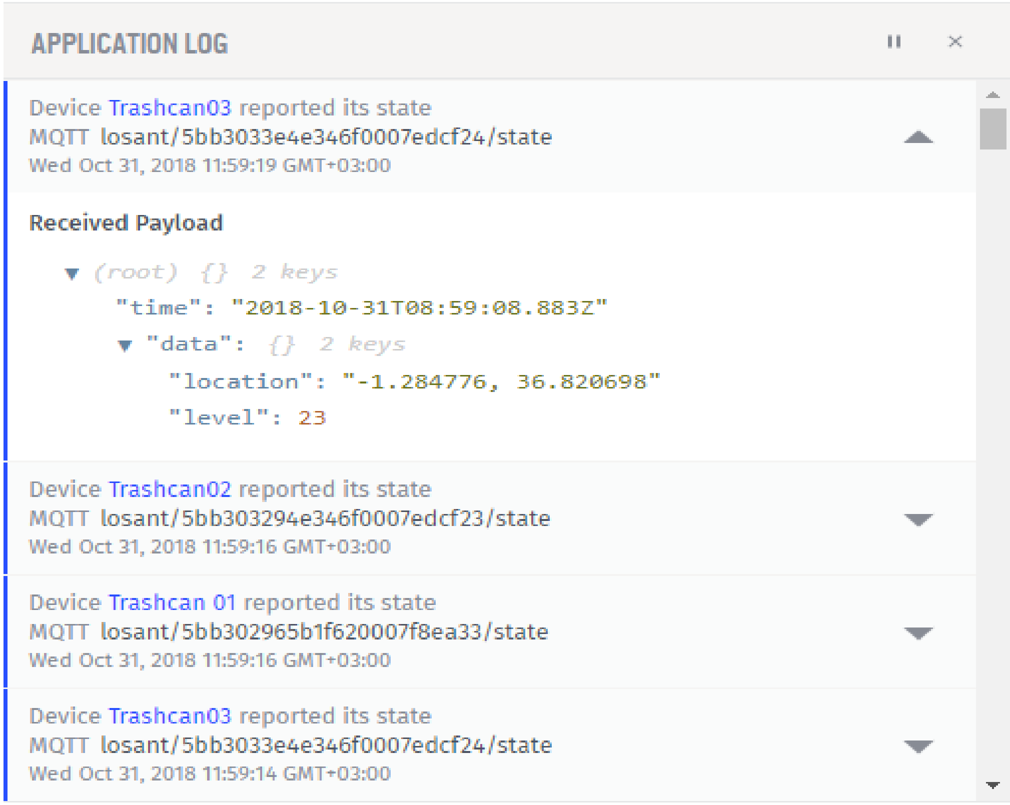


Fig34: Backend view shows data from trashcan03

Fig35: Backend view shows data from trashcan04

Dashboard

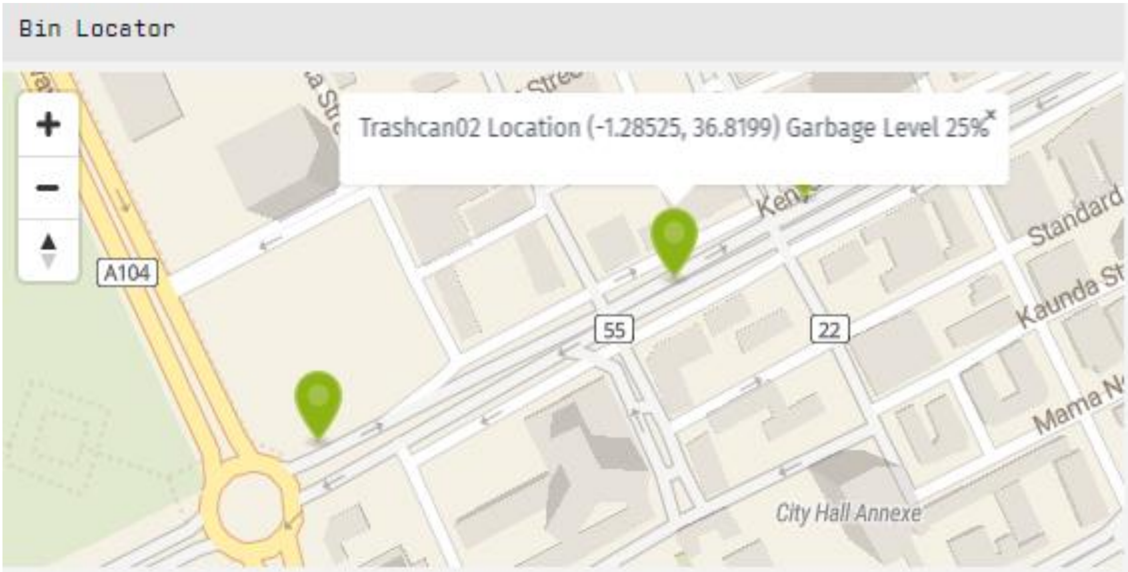


Fig37: A map showing the locations of the simulated trash cans

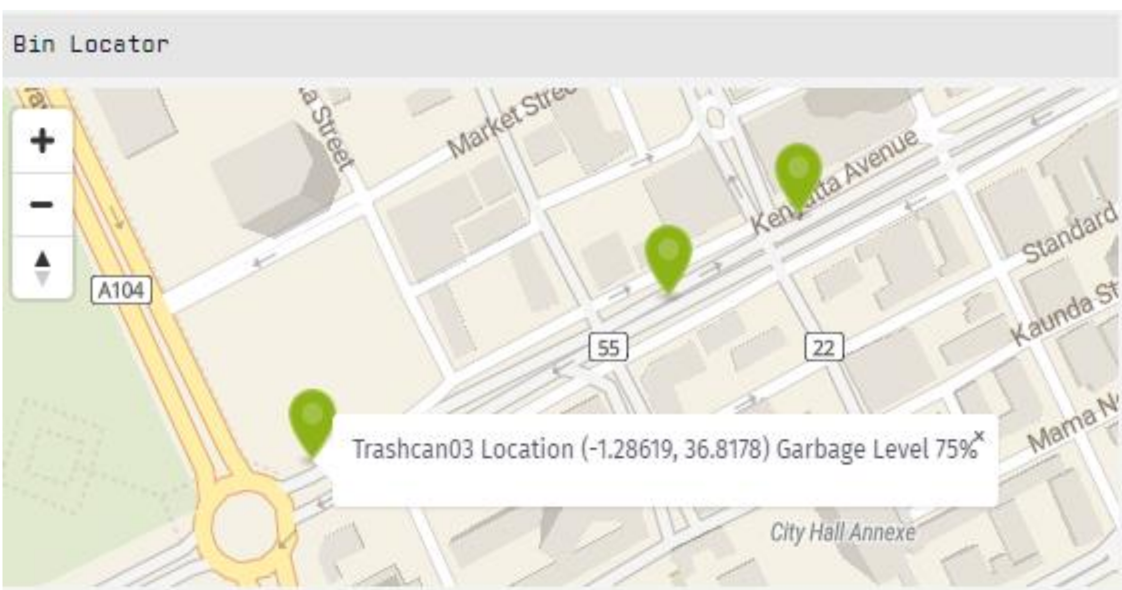


Fig38: A second map showing the locations of the simulated trash cans

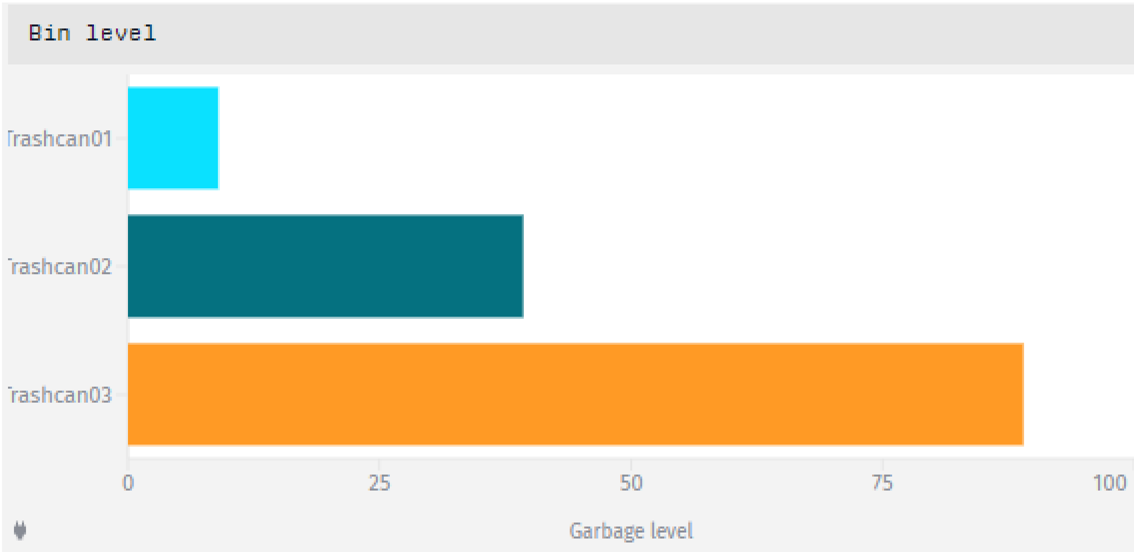


Fig39: Visualization of the trash can fill levels

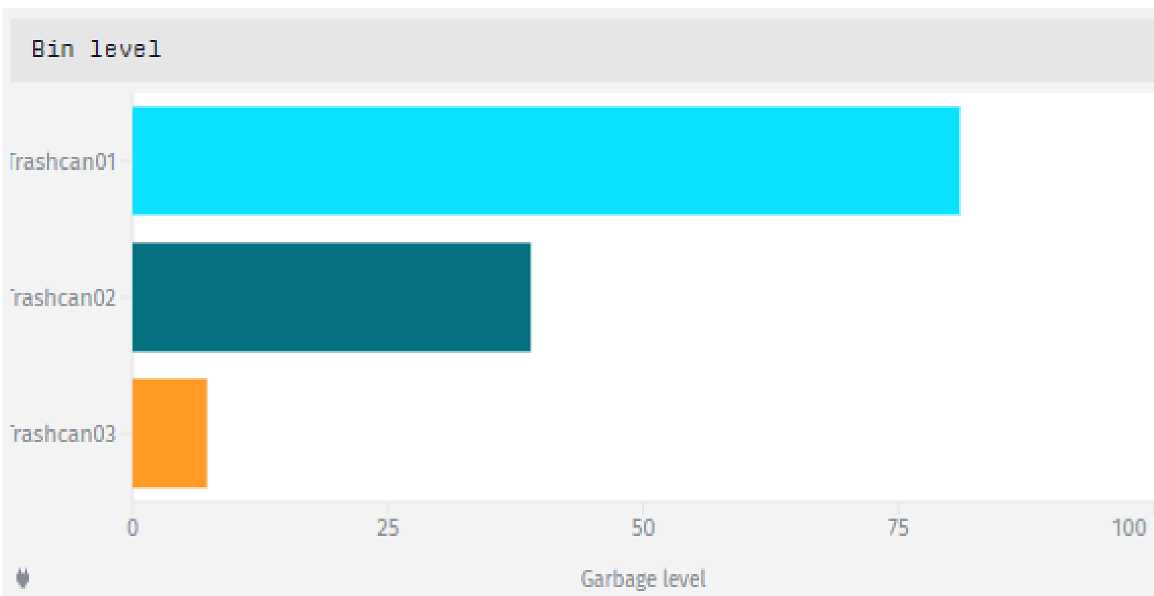


Fig40: A second visualization of the trash can fill levels

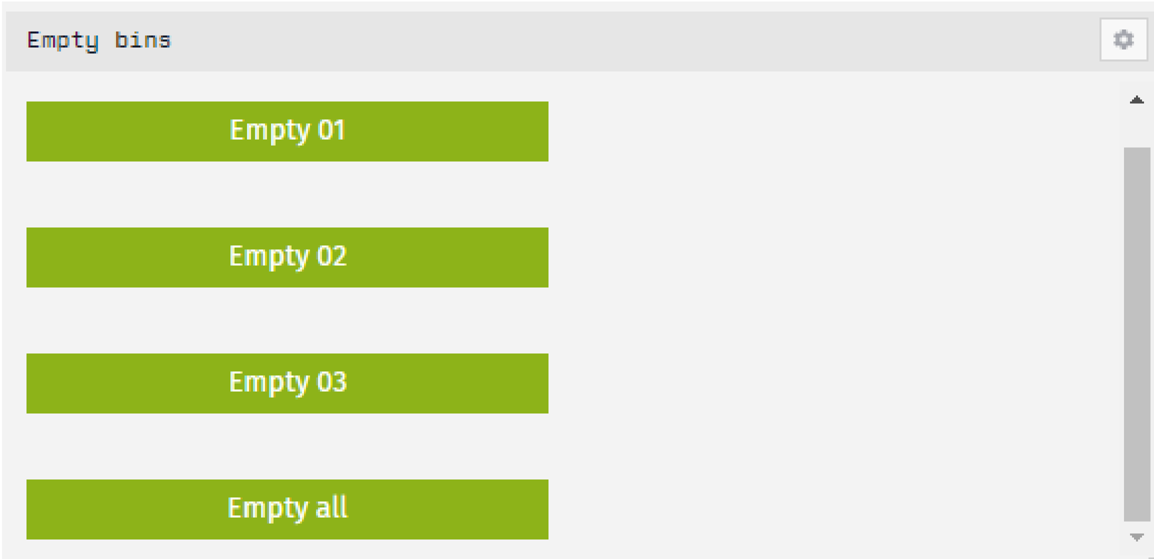


Fig41: Trashcans management console on the dashboard

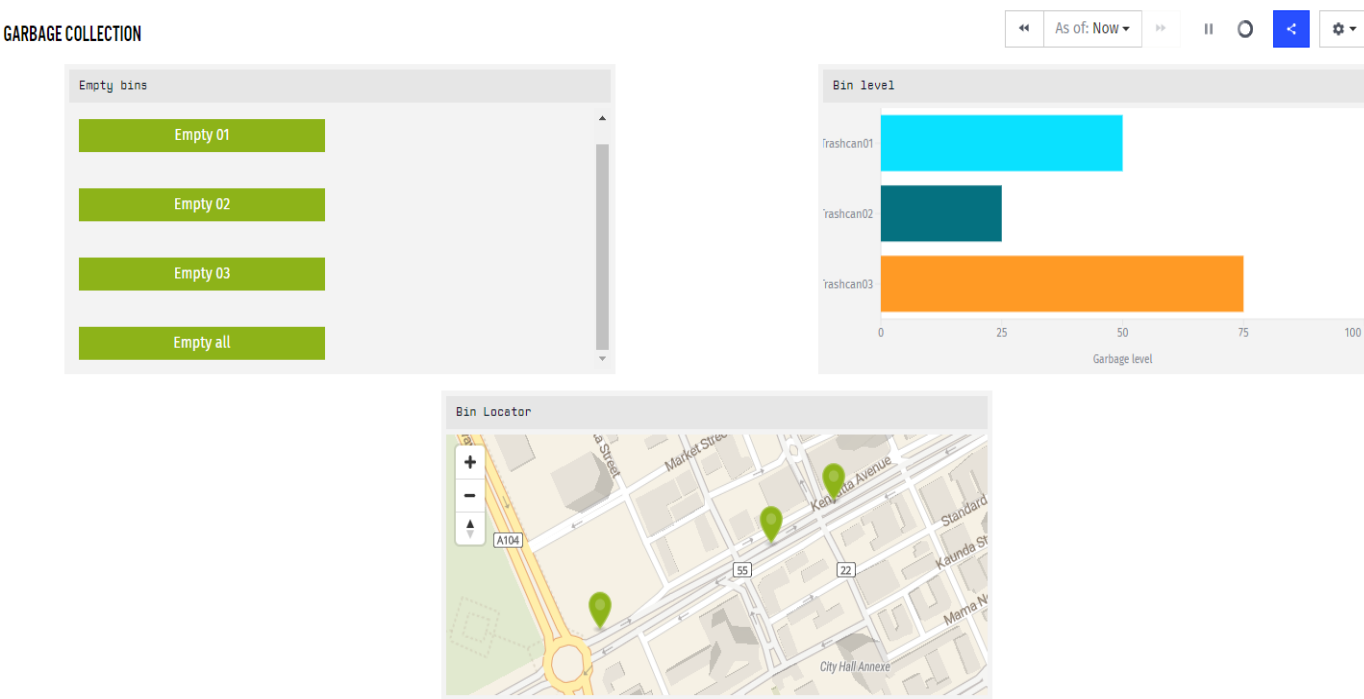


Fig42:Losant dashboard

Discussion of results

The researcher demonstrated the simulation of two layers of the IoT solid waste management and not the the entire IoT infrastructure due to resource contraints. The layers simulated included the part of the perception layer, the network layer and part of the application layer. After running the simulation,the researcher collected the data below of the simulated trashcans. The table shows corresponding fill levels of the trashcans per unit time. The trash can fill levels were given by percentage fill between 0-100.

	Unit time				
	1	***2***	***3***	***4***	***5***
Trashcan01	13	16	54	91	5
Trashcan02	11	84	5	40	25
Trashcan03	25	59	95	5	14

Table 11:Table showing fill levels of the trash cans at unit time

1) Bin level values were recorded at unit time intervals
2) The different trashcans were observed to have different fill level rates
3) The simulation dashboard indicated instantaneous fill levels of all the trashcans bring time taken to collect this information to zero
4) The simulation dashboard also indicated the location of the trashcans instantly reducing the the time take to locate full trashcans to almost zero
5) Data collected on the trashcan levels was representated on a graph that showed the fill level rates of the trash cans with time.
6) Bin was taken to be almost full and was ready for emptying after getting to 95% fill level.

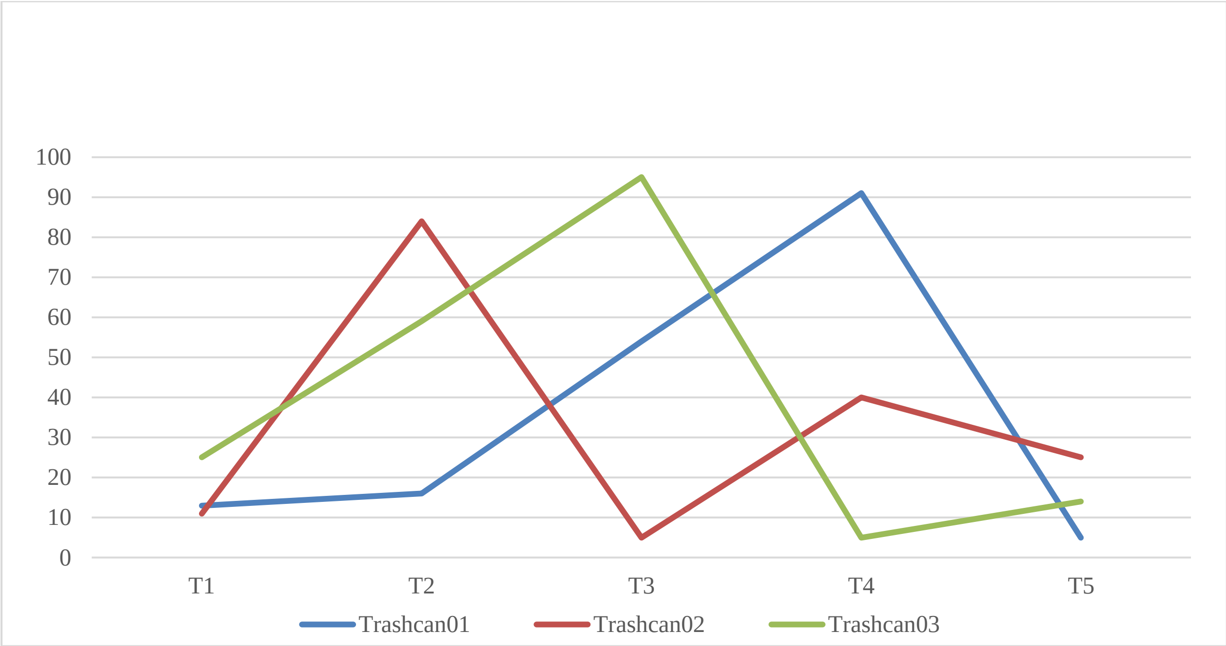


Fig43: A graph showing percentage fill levels of the trash cans vs unit time

5.0 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the research findings made in the study in form of study conclusion while also presenting the recommendations made.

5.1 Achievements

Based on the study findings the researcher concludes as follows:

1. Using both primary and secondary data collected the researcher designed an empirical and localized model for smart solid waste management in Nairobi. Results from the study had shown that 52% of Nairobi residents were of the opinion that solid waste was badly managed and an additional 31.4% felt it was poorly managed. In areas where residents made use of public bins, 60% of the residents noted that the bins are not in a good state due to waste going uncollected longer than necessary.

2. IoT is a relatively new technology in Kenya and has only been adopted in few sectors in the country which include a proposed smart waste collection trucks by IBM. The researcher's model would well applicable for use together with the smart trucks in order to help waste managers not only in the in monitoring of garbage collection trucks but also in the monitoring of waste levels in public bins

3. Adoption of a fully smart waste management system would involve embedding of sensors on public bins and also embedding of sensors on waste collection trucks, a wireless network for data transmission, cloud computing for data storage as well as data processing and analysis.

5.2 Challenges

Challeges encountered by the researcher when exploring the use of IoT as a solution to waste management in Nairobi include:

1. Designing a prototype proved to be extremely expensive and time consuming since the componenets were not only expensive but some of them were also not locally available. The researcher hence was not is a position to affirm on the adoption of IoT due to these prohibitions in cost.

2. The county did not have designated public bins especially in residential estates where most production of waste seems to emanate from.
3. The county also did not have substancial data on their waste management process incuding their efficiency rates and cost of waste management. This data would have been useful in the determination of the efficiency of the county in waste management.

5.3 Conclusions and recommendations

From this study, it was evident that solid waste management was a major problem not only in Nairobi but also in most major cities in the World. Lack of innovation in urban planning continues to haunt Nairobi in its delivery of services to the residents hence limiting efficiency. Increase in consumption as well as increase in the rural-urban migration will continue to increase pressure in the solid waste management systems of the Kenyan capital. The proposed model and the simulation showed a smart waste management system which leverages IoT and which can be used in improving the process in waste management by enhancing data driven decision making.

Based on this study, the researcher recommends areas for future studies in IoT and solid waste management as follows:

1) Prototyping of the smart solid waste model
2) Design of the best route optimization model using data collected in the use of a smart waste management system in Nairobi
3) Application of the IOT smart waste management systems in the monitoring of CO2 emissions
4) Risks involved in the use of IoT smartsolid waste management solution

5.4 Contribution to knowledge

The researcher combined previously suggested models to come up with robust model applicable in solid waste management in Nairobi. The researcher’s model utilizes new technology for a more efficient IoT architecture e.g. use of ultrasonic sensors to detect the level of the waste due, use of MQTT protocol for data. Simulated model showed that incorporation of technology in solid waste management can improve the effectiveness in the processes by cutting cost and time

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APPENDICES

APPENDIX 1: QUESTIONNAIRE INTRODUCTION LETTER

Emma Muthoni,
P.O. Box 43844-00100,
Nairobi, Kenya.

Dear Respondent,

<u>RE:RESEARCH SURVEY ON THE SOLID WASTE MANAGEMENT SYSTEMS IN NAIROBI.</u>

I am an MSc Data Analytics candidate from KCA University and as part of the requirements of the award of the degree, I am required to undertake research on the above mentioned topic.

I wish to request you to facilitate my research by participating in this survey. Kindly fill the attached questionnaire and note that this information will be handled with confidentiality and used to serve the purpose of this research only. Partcipation in the survey is voluntary.

I sincerely appreciate you for making time to fill out the questionnaire .

Sincerely,

Emma Muthoni.

APPENDIX 2: RECOMMENDATION LETTER FROM GRADUATE SCHOOL

KCA UNIVERSITY
1989

Thika Road, Ruaraka
P.O. Box 56808-00200 Nairobi Kenya
Pilot Line: +254 20 8070408/9

Tel: +254 20 3537842
Fax: +254 20 8561077
Mobile: +254 734 888022, 710 888022
Email: kca@kca.ac.ke
Website: www.kca.ac.ke

KCAU/SGS/MSc/February .18/6 *February 13, 2018*

To whom it may concern,

Dear Sir/Madam,

RE: EMMA WAMBUI MUTHONI REG. NO. 16/00601

It is my distinct pleasure to introduce to you Ms. Emma Muthoni_who is a student in our institution pursuing a Master of Science in Data Analytics in the Faculty of Computing and Information Management. Her research proposal has been successfully presented and approved.

Emma is conducting research on a topic titled: "***Smart solid waste management: A case study for turning Nairobi into an African smart city by leveraging IoT technologies'*** which is part of the requirements of the program she is pursuing. The research as well as the data procured thereof shall be used for academic purposes only.

Any assistance accorded to her is highly appreciated.

In case of further inquiry, do not hesitate tc contact the undersigned.

Yours faithfully,

KCA UNIVERSITY SCHOOL OF GRADUATE STUDIES 13 FEB 2018 P.O. Box 56808 – 00200, NAIROBI

Dr. Nyaribo Misuko
Dean, School of Graduate Studies & Research

APPENDIX 3:QUESTIONNAIRE

URL to my google survey form https://goo.gl/forms/rrmmWIHaqOiCBw3Q2

Household questionnaire

Study on the effectiveness of solid waste management systems in Nairobi county

Emma Wambui. MSc Data Analytics, KCA UNIVERSITY, Nairobi Kenya.

The goal of this survey is to gather data on the effectiveness of the solid waste management systems in Nairobi County,for a feasibility study and to subsequently design an automated solid waste management system for the county. Participation in this study is completely voluntary. The information collected is purely for academic purpose and will be treated confidentially.

URL to my google survey form https://goo.gl/forms/rrmmWIHaqOiCBw3Q2

(Questions marked with * are required)

Section A (Demographics)

1. Name of the area of residence* ________________________
2. Gender ☐Male ☐Female ☐Prefer not to say
3. Please mark your age group in the appropriate box*

   ☐ <20

   ☐20-29

   ☐30-39

   ☐40-49

   ☐50-59

   ☐ <=60
4. How many people are currently living in this house? * _________________
5. How many people are less than 16 years? * ___________________
6. How long have you lived in Nairobi? *

   ☐Less than 1 year

   ☐ 1-2 years

   ☐3-4 years

   ☐5-9 years

   ☐10-19 years

   ☐20 years and above
7. What is your highest level of education? *

☐Never schooled
☐Primary school
☐High school
☐University/ college
Other_______________________________

8. What is your occupation? *
   ☐ Employed by a private company
   ☐ Employed by a government body
   ☐ Self employed
   Other _______________________________

Section B (Indicator for types of waste)

9. Have you ever heard about solid waste management? *
   ☐Yes
   ☐No

10. If yes, in what way? (One or more answers)
    ☐Radio
    ☐Tv
    ☐In school
    ☐Posters
    ☐Public meeting
    Other __________________________________

11. Have you ever been educated on proper solid waste management by the county government of Nairobi? *
    ☐ Yes
    ☐ No

12. What type of waste comes from your household? (One or more answers) *
    ☐ Food waste
    ☐ Plastics
    ☐ Paper and carton
    ☐ Tins and cans
    ☐ Glass
    ☐ Fiber bags

Other ____

Section C (Indicator for rates of waste generation)

13. In what container do you collect your waste? (One or more answers) *

☐ Carton

☐ Waste bin

☐ Tin/Can

☐ Plastic bag

Other_________________________________

14. How often is the container emptied? *

☐Once a day

☐ Once in two days

☐Once in three days

☐ Once a week

Other_________________________________

15. What's the average size of your waste collection container? *

☐ 3 liters

☐ 5 liters

☐7 liters

☐10 liters

☐12 liters

Section D (Indicator for waste disposal methods)

16. Where do you usually put away collected waste? *

☐ In the itinerant waste truck

☐ By the road or street side

☐ On an open space

☐ In a public bin

☐ In a private bin (For people living in flat buildings)

Other______________________________________

17. Are there any public bins near your house? *

☐ Yes

☐ No

18. If yes, how long does it take to get there?

☐ 5-10 min

☐ 11-15 min

☐ 16-20 min

☐ 21-25 min

19. If there are public bins, how often are they emptied?

☐ Once a week

☐ Twice a week

☐ Thrice a week

☐ Everyday

☐ Don't know

Other_____________________________________

20. How can you describe the state of the public bin near your house? (One or more answers)

☐ Rusting/Rotting

☐ In a good state

☐ Adequate size

☐Not in a good condition

☐ Inadequate

☐Don't know

Other____

21. Do you think the waste disposal method is a problem in your neighborhood? *

☐Yes

☐No

22. What problems do you think exist in your area as for waste management? *

23. How do you evaluate the state of solid waste disposal in your house area? *

☐ Terrible

☐ Bad

☐ Fair

☐ Good

☐ Great

☐ Don't have

Other____________________________________

24. In general how would you describe solid waste management by the county government of Nairobi? *

APPENDIX 3: BUDGET

#	Item	Qty	Unit Cost (Ksh)	Total Cost (Ksh)
1	Software		10,000	10,000
2	Virtual lab hours	20	1,000	20,000
3	Printing and binding documents			25,000
4	Data and talktime			10,000
5	Transport and miscalleanous			10,000
	Total			**75,000**