FACULTY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF SURVEYING AND GEOMATICS

SOLID WASTE COLLECTION MANAGEMENT INFORMATION SYSTEM FOR GWERU CITY COUNCIL

BY

TITUS MUNODA CHAPUKIRA

R143422Z

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN SURVEYING AND GEOMATICS

2018

Declaration by the student

I, **Titus Munoda Chapukira**, the undersigned do hereby declare that this dissertation is a product of my original work and where appropriate I have acknowledged the work of others.

Signature……………………………….. **Date**……../………/ 2**019**

Approval form

The undersigned certify that they have supervised the student **Titus Munoda Chapukira's** dissertation entitled **"Solid Waste Collection Management Information System for Gweru City Council",** submitted in partial fulfilment of the requirements of the Bachelor of Science Honours degree in Surveying and Geomatics at Midlands State University.

Supervisor: Dr. C. Paradzayi

Signature……………………………….. **Date**……../………/ 2**019**

Supervisor: Mrs. M. Machingauta

Signature……………………………….. **Date**……../………/ 2**019**

Chairperson: Mr. D. Njike

Signature……………………………….. **Date**……../………/ 2**019**

Release form

NAME OF STUDENT:	TITUS MUNODA CHAPUKIRA
REGISTRATION NUMBER:	R143422Z
DISSERTATION TITLE:	Solid Waste Collection Management Information System for Gweru City Council
DEGREE TITLE:	Bachelor of Science Honours Degree in Surveying and Geomatics.
YEAR THIS DEGREE GRANTED:	**2018**

SIGNATURE OF AUTHOR: **…………………………………………...**

DATE SIGNED: **……………………………………………**

PERMAMENT ADDRESS: 365 Jacha Road

Senga Area 1

Gweru

Zimbabwe

Dedication

This work is dedicated to my sister Theresa Chapukira who is my pillar of strength and source of motivation.

Acknowledgements

I would like to thank the Almighty God for his divine grace that ensured me to reach this far. Without his grace this achievement would have been null and void. Special gratitude goes to my father Mr J Chapukira for his support both financially and spiritually. He scarified to see me through the 5years of my education at Midlands State University regardless of the harsh economic conditions that prevailed during the beginning and end of my studies.

I would like to extend my heartfelt gratitude to my supervisors’ Dr Paradzayi and Mrs Machingauta for their guidance and support during the course of this project. A special thanks goes to my family, friends and classmates for their help and encouragement throughout this project.

Abstract

Solid waste alludes to all materials that are not prime items, for which the individual creating the material has no further use in terms of his or her own motivations for generation and utilization. In developing countries, Zimbabwe included, municipal authorities rely on poor methods and techniques in waste collection administration which are subjective and tend to increase operational costs of solid waste collection activities. Instead of maintaining vibrant information management systems for solid waste collection to efficiently utilise the available resources, much emphasis is directed towards blaming the shortage of financial and human resources as well as the vehicles and equipment for the rapid depletion of waste collection levels. The declination of the solid waste collection results in unlawful open dumping and burning of solid waste which has negative ecological, social and economic effects. The absence of optimized information management systems for solid waste collection by the municipal authorities is causing solid waste collection to be costly and inefficient resulting in the failure to adhere to timeous collection of solid waste. There are likewise no efficient methods of communication between residents and municipal authorities. This study presents an optimised management information system to help in the planning, management and scheduling both human resource and refuse trucks. The system enabled the monitoring of waste collection activities in near real time as well as facilitating for the generation of optimum routes. The optimum routes were generated after considering the road elevation changes, degree of the roughness of the road surface and the traffic congestion associated with a particular road network. This in turn significantly reduces fuel consumptions and time delays in delivering waste collection services to the residents. The system enabled the visualisation of the of the animation of a waste collection vehicle in transit on an optimum route. Furthermore, the system empowered residents to participate in the collection systems through conveying their contributions, suggestions and complaints direct to the administration via the web. However, there is need for the system to be integrated with RFID`s and GSM modems so as to achieve enhanced capabilities that forms the basis of a smart waste collection system.

Contents

Figures

Acronyms

API	Application Programming Interface
DEAT	Department of Environmental Affairs and Tourism
EC	European Commission
GIS	Geographic Information Systems
GPRS	General Packet Radio Services
GPS	Global Positioning System
GSM	Global System for Mobile communication
NPM	NodeJS Package Manager
PHP	Hypertext Pre-processor
RFID	Radio Frequency Identification
VRP	Vehicle Routing Problem

1 Introduction

This chapter gives a review of solid waste management, the frameworks included and the types of waste disposal strategies. It additionally presents the challenges in the collection of waste by local authorities.

1.1 Background

Solid waste generation is a consistently developing problem at global, regional and local levels. Solid wastes are those organic and inorganic waste materials created by different activities of the general public, which have lost their incentive to the primary client. Improper disposal of solid wastes contaminates all the vital components of the living environment. Solid waste is generated regularly due to the rapid increase in production and consumption.

1.2 Solid waste

Solid waste is any material that is disposed of on the basis that it has spared its motivation or is not helpful any more (Makwara and Magudu, 2013). Solid waste is defined from the household's refusal and non-hazardous wastes produced from urban areas where individuals live (Arebey *et al.*, 2009). These urban areas are under the jurisdiction of municipalities who are responsible for the management of solid waste (Manus and Coad, 2010). Solid waste is categorised into municipal, industrial and hazardous, the majority of municipalities in Africa handle solid wastes from households, markets and institutions, street and public open spaces, dead animals, and non-unsafe waste from processing and industries (Achankeng, 2003; Ogwueleka, 2009). Globalization has raised some alarming concerns and one of them is its effect on urbanisation that implied population growth causing the generation of huge volumes of solid waste thereby expanding the difficulties in the administration of municipal solid waste (Manaf *et al*., 2009; Chikobvu and Makarati, 2011).

1.2.1 Solid waste management

Solid waste management alludes to the gathering, transportation, recuperation, and transfer of waste created by human activities, including the supervision of such tasks and after-care of disposal sites (Jerie and Tevera, 2014). The management of solid waste has social, environmental and economic ramifications (TRSC, 2010). It incorporates the entire chain from waste generation, stockpiling, transport, and disposal and is mostly done to lessen their impact on health and the environment (Ngwenya and Jonsson, 2001). However solid waste management is given low priority in most urban areas in Africa (Achankeng, 2003).

1.2.2 Hazards of poor solid waste management

Waste introduces a great threat to the general wellbeing and the environment if it is not stored, collected, and disposed of in the right manner (Ogwueleka, 2009). Inability to practice legitimate and sound solid waste management poses health and environmental hazard especially in high-density suburbs, it prompts the outbreak of diseases such as cholera, typhoid, and dysentery (Huvengwa, 2012). Simelane and Mohee (2012) argue that if the solid waste is not collected it results in the creation of unsanitary conditions and breeding harbours for the disease that lead to epidemic disease outbreaks like cholera and typhoid. A lot of people died in Zimbabwe during the period of 2008-2009 because of cholera resulting from poor solid waste management by local municipalities, characterized by irregular waste collection that prompted random dumping of waste in open spaces (Red Cross, 2010). The aggregation of waste threatens health, damages the environment and is causing rapid deterioration in levels of sanitation and the general quality of urban life (Musingafi *et al.*, 2015). It is essential to effectively and efficiently collect all waste and dispose them to proper disposal facilities.

1.3 The solid waste collection systems

Information assumes a fundamental role in the administration of solid waste (Kokila *et al.*, 2017). However, in developing countries the significance of information and its management has been credited less priority by municipal authorities in charge of solid waste management (Popa *et al.*, 2017). In this regard solid waste management is viewed as an act in which solid waste collection vehicles and equipment are purchased and manpower assembled to collect solid waste from generation points to disposal sites. The absence of resources, as opposed to the utilisation of available resources, is regularly viewed to be responsible for poor and inconsistence solid waste collection by municipal authorities (UNICEF, 1993). The primary practical components of municipal solid waste collection systems are the waste generation, storage, collection, transportation, processing, recycling and disposal in a suitable landfill. (Khan and Samadder, 2014). Just like any other system, solid waste collection systems have inputs, processes and outputs that are facilitated by the five components of a system namely the people, data, processes, software and hardware (Bentley *et al*., 2004)

1.3.1 Stakeholders involved in the solid waste collection

The major stakeholders involved in the management of waste collection are the solid waste producers or residents, health directors/administrators, waste collection supervisors, waste truck drivers, waste collectors and dumpsite managers. Waste producers/residents want better service delivery and accessibility to reports on waste administrations as well as being well informed of the current situation in as much as the waste collection is concerned (Medvedev *et al.,* 2015). Health directors are interested in controlling the process of waste collection, checking the quality of service and monitoring adherence to the waste collection timetables. They are also responsible for the allocation of refuse trucks to various destinations. Waste dump managers are concerned with the adherence of landfills/dumps to stipulated standards and siting new ones. Waste truck drivers are the most influential players as they directly impact the waste collection service together with refuse collectors who manually dispose of refuse from the residents' bins into the refuse truck. Refuse truck drivers are concerned with knowing how to get to the waste generation area and where to dispose of the waste collected once the truck is full (Coffey and Coad, 2010).

1.3.2 Data

Spatial data and non-spatial data are both utilized to enable a sufficient collection of solid waste. This data includes the spatial location and number of houses alongside their associated average number of people per household within a particular administration boundary (UNICEF, 1993). The numerical magnitude number of educational and healthcare institutions, shops, commercial and industrial premises are also used in planning for solid waste collection. Also essential are road qualities, the width of streets, nature of terrain/topography etc. all the above-mentioned information is essential in planning as it enables estimating population growth and quantity of waste that may be generated. Some of the sources of information are existing master plans, maps and/or aerial photographs and or demographic surveys (DEAT, 2001).

1.3.3 Processes

The first process is the generation of solid waste from various human activities that range from production, consumption or recreation through which materials lose value and are discarded (Borough and Hamlets, 2017). After waste is generated it is temporarily stored in plastic bins, community bins and plastic bags as a means of keeping solid waste that awaits collection and final disposal from the local authority. The waste collection encompasses organizing and allocating waste collection fleet so that waste is collected and avoid overspills of bins. It also accommodates the planning of routes, assembling manpower and creation of waste collection schedules (EC, 1994). Efficient collection relies upon the legitimate choice of vehicles; it, therefore, introduces the necessity to assess road conditions, traffic density, availability of spare parts, servicing requirements and haulage distances for the waste collection fleet (Imam *et al.*, 2008).

Waste collection is done in 3 ways namely door to door, community bins and curb side (Coffey and Coad, 2010). The door to door collection entitles the waste collectors to collect waste directly from the waste residents` doorstep. Community bins collection qualifies residents to convey their waste into bins/canisters that are ideally situated within an area (Constantine *et al.*, 2014). Curb side pick-up collection qualifies residents to leave their bins directly outside their homes to enable refuse collectors to exhaust them into their truck (Jerie and Tevera, 2014).

The route optimization for the collection of solid waste is a major component of solid waste management to diminish the costs of operation (Khan and Samadder, 2014). For example, a vector optimization model is formulated where the objectives are to restrain the costs, the amount of waste that is landfilled and the antagonistic ecological effects. Spatial network analyst tools can be utilized to assess fuel consumption along the entire road network, and for optimization of solid waste collection for minimum fuel consumption (Vu *et al.*, 2018). The parameters considered for route optimization are population density, waste generation, and composition, road networks, road length, collection vehicle speed, travel time, traffic direction, vehicle access, characteristics of waste containers and vehicles (Arribas *et al.*, 2010). A noteworthy decrease in the number of collection routes length and time engaged with waste collection, and related operational costs, workforce costs, fuel consumption, and vehicle maintenance, might be accomplished by utilizing spatial technologies (Khan and Samadder, 2014).

1.3.4 Software

The choice of software packages to use is greatly influenced by the financial stability of the municipal. All the software available for usage are divided into FOSS and commercial software. GIS commercial software like Arc GIS, MapInfo, Geomedia and Bentley Map are utilized in the collection of solid waste specifically their Multi-Criteria Decision Analysis (MCDA) and Analytical Hierarchy Process (AHP) tools for selecting optimum sites for landfills and determining convenient areas for placing community bins (Morrissey and Browne, 2004). Furthermore, the network analyst tools can also be used for waste collection fleet routing(Chalkias and Lasaridi, 2009). GovOutlook is a commercial software that conveys dependable communication solutions to track and oversee solid waste collection fleets, enhance customer satisfaction and guarantee driver safety. It has an ESRI GIS-based Automatic Vehicle

Location augmentation that guarantees a productive administration of solid waste collection fleets and adherence to solid waste collection schedules (Supriyadi *et al*., 2000).

FOSS that include Open layers, JavaScript, Geoserver, PostgreSQL/PostGIS and QuantumGIS can be utilized for visualization and monitoring of waste collection fleets and spatially located bins (Singh *et al*., 2016). D-Waste Atlas is an open source mapping library that views the municipal solid waste management data and facilitates for strategic planning (Mavropoulos *et al*., 2012). Web API`s are used for managing waste collection fleets and generating optimum routes for easy traversing amid waste collection (Jansen, 2013). Optimal routing can be achieved using Arc GIS online routing API (Likotiko*et al*., 2017).

1.3.5 Hardware

Waste collection system also involves hardware inform of infrastructure like roads, waste disposal sites, collection vehicles or refuse trucks, plastic bin and refuse plastic bags (Manus and Coad, 2010). Furthermore, computers, plotters, printers and navigation devices also form the basis of the required hardware for waste collection systems. Vehicles used for the waste collection includes compactors trucks, side loaders, rear loaders, mini trucks, tippers and skip trucks (Ogwueleka, 2009).

1.4 Solid waste disposal

The final process of solid waste management is the safe disposal of solid waste at appropriate disposal sites in a manner that does not affect the environment and public health (DEAT, 2001). There are many methods of solid waste disposal but the choice of method is influenced by environmental impacts and costs of operation (Rabl *et al.*, 2008). These methods include landfill, incineration and composting (Herman, 2003).

1.4.1 Landfill

A strategy of disposing of solid waste on land through burial without creating aggravations or hazards to public health or safety. The principles of sanitary landfilling involve the compaction and levelling of waste and lastly covering by the earth (Sharholy *et al.*, 2008). Sanitary landfilling is a satisfactory and prescribed technique for extreme disposal of municipal solid waste. Waste disposal through sanitary landfilling imposes mitigate measures to the contamination of surface and groundwater and environmental hazards (Ogwueleka, 2009). Landfilling is an essential element of municipal solid waste management since other waste disposal options like incineration produce some build-up/residues that must be discarded through landfilling. However, landfilling is regularly thought to be the most worst option because it consumes a considerable measure of land and runs a high risk of spillages that may contaminate air, water, and soil (Leao *et al*., 2001).

1.4.2 Incineration

Incineration is the procedure of control and complete combustion, for burning solid wastes that results in the recuperation of energy and destruction of toxic wastes (Sakai and Hiraoka, 2000). It involves the burning of waste at high temperature in furnaces called incinerators. The left-out ashes and clinkers have to be discarded through landfilling or any other use. The heat produced can be utilized as steam power for running turbines to produce power. It guarantees the complete destruction of pathogenic microscopic organisms and eliminates the odour inconvenience (Sabbas *et al.*, 2003). Less space for waste disposal is required. However, they are expensive to build even compared with present-day landfills with the fitting counteractive action of spilling (Herman, 2003). Furthermore, they cause air contamination and discharge of perilous vapour.

1.4.3 Composting

The bacterial transformation of the organics present in solid waste in the presence of air under hot and damp conditions is called composting, and the final product obtained after a bacterial activity is called compost or humus, which has very high agricultural worth (Sharholy *et al.*, 2008). It is additionally alluded to as a natural strategy for decaying solid waste under a vigorous or anaerobic condition or both creating compost or manure as a final result (Taiwo and Oso, 2004). Compost allows the soil to retain more plant supplements over a longer period. It supplies some portion of the basic components required by the plants and decreases the unfavourable impacts of excessive alkalinity, acidity, or the excessive utilization of synthetic compost (Leao *et al*., 2001).

1.5 Challenges in the solid waste collection by Zimbabwean local authorities

Solid waste generation in developing continues to grow due to economic growth and changing consumption patterns as a result of urbanisation (Makwara and Magudu, 2013). Population increase as a result of urbanisation has expanded the amount of waste produced causing difficulties on waste collection administrations. Solid waste management has risen as one of the significant challenges faced by almost all urban local authorities in Zimbabwe. Rapid population growth currently being experienced, combined with hyperinflation and economic decline, among other factors, put extensive strain on local authority resources, bringing about the inability to give sufficient administration services to residents and areas under their jurisdiction. The deterioration of waste collection levels in recent years has influenced illegal open dumping and burning of solid waste, promoting environmental and health hazards for residents (TRSC, 2010).

Zimbabwe's waste administration has for all intents and purposes fallen, activating confused and widespread waste dumping, putting the well-being of residents at great risk (Makwara and Magudu, 2013). Despite the presence of legal frameworks such as the Environmental Management Act, the Public Health Act, and the Urban Council Act which serve to ensure sustainable waste management, there still remains an issue of adequate solid waste management practices as evidenced by the continuous accumulation of waste on roadsides and open spaces as well as the outbreaks of waste-related diseases such as typhoid, cholera and dysentery (Musingafi *et al.*, 2015). The developing heaps of unlawfully dumped solid waste near houses and open spaces in urban areas of Zimbabwe provide unambiguous proof that local authorities are failing to cope with increasing volumes of solid waste being generated (Masocha, 2004; Chifamba, 2007). There is evidence of inefficient waste collection systems by local municipalities that have prompted unfavourable consequences for the biological system and nature. In May 2005 the government of Zimbabwe conducted a clean-up operation called 'Operation Restore Order' popularly known as 'Operation Murambatsvina' and one of its objectives was to manage the issue of waste in urban areas (Mangizvo, 2007).

Huvengwa (2012) points out that the challenges of waste management in Zimbabwe emanate from the increased volume of waste generated by urban residents, change in the composition of the waste generated and disposal of waste to proper landfills. The implementation of vibrant administration mechanisms for waste management has been weakened by financial, human and material resource constraints being experienced by the councils. There is some inconsistency in following the waste collection cycle which results in waste to go for days or weeks without being collected leading to haphazard dumping of waste at any open space by residents (Jerie and Tevera, 2014). The current waste management systems lack uniformity and coordination. In Gweru, for example, in high-density suburbs of Mkoba, Woodlands, Senga and Nehosho solid waste is burned or dumped in open spaces since it is not collected timeously (Remigios, 2013). Regular waste collection and transportation should be aimed at preventing the accumulation of the waste which would end up creating unsanitary conditions.

Waste collection is a troublesome and costly aspect of solid waste management and the city of Gweru is no exception to natural issues troubling urban solid waste management (Makwara and Magudu, 2013). The greatest challenge confronting the Gweru city council is related to reducing waste collection costs which are influencing inefficiencies in waste collection (Mangizvo, 2007). A proficient routing framework for waste collection should be developed so as to spare time and fuel. However, unsustainable methods of waste collection route determination are being utilized. The determination of routes on which the vehicles move amid waste collection is left to the discretion of the supervisor and the route selection winds up subjective and uneconomical prompting inconsistency in the normal collection cycles (Jerie, 2006). The absence of an optimised waste collection information management system is a noteworthy setback for efficient waste collection by Gweru city council.

1.6 Aim

To develop a web-based waste collection management information system for optimised waste collection in Gwerus. The system will ensure adequate resource utilisation of the scarce resources to improve waste collection and facilitate a communication channel between the residents and the administration.

1.7 Objectives

i). To analyse the existing status of solid waste collection activities.

ii). To gather the information needs for solid waste collection management.

iii). To design a solid waste collection database.

iv). To design an application for optimising solid waste collection management.

v). To develop and test a web-based prototype information system for managing solid waste collection optimally.

1.8 Case study area

Gweru is the capital of the Midlands Province and Zimbabwe's third largest with around 200 000 inhabitants according to the 2015 Demographic Survey. Gweru city council was founded in 1894 by Leander Starr Jameson, it is mandated to perform two main duties within its jurisdiction which are waste disposal and water supply (Dewa et al., 2014). The waste handling in the city of Gweru is overseen by the city council`s Health Department. The Health Director heads the department which is in charge of health care, environmental health, and waste management. It has a cleansing section for the daily work with collection, transport and disposal of waste. The section is headed by a Cleansing Supervisor (Ngwenya and Jonsson, 2001).

Waste is collected daily in the city centre and market areas and at least once a week in the residential areas, industrial areas, hospitals, and schools and colleges. However, there is some inconsistency in following this cycle which results in waste going for days or weeks without being collected. In the high-density suburbs of Mkoba, Woodlands and Nehosho solid waste is dumped in open spaces since it is not collected frequently and timeously (Mangizvo, 2007; Jerie and Tevera, 2014a). The increase of waste dumps in Gweru city is due to non-collection of waste by the city council and requires immediate action to be taken to address it before causing serious health hazards (Mangizvo 2010). He likewise presumed that stakeholders in Gweru city solid waste management needed to play their part in a coordinated way to deal with solid waste management so the city could be a satisfying place with adequate sanitary conditions.

Figure 1 : Waste dumped in the streets of Mkoba (Newsday, 2017)

1.9 Justification

If the system is developed and implemented, efficient waste collection is anticipated through taking advantage of the emerging web technologies. Waste should be collected on a consistent and regular basis to avert the problems of pandemics such as cholera (Mangizvo, 2007). The disposal of waste in undesignated areas harbours disease vectors like rats and flies which have a potential of causing disease outbreaks such as cholera and typhoid hence, refuse collection should be frequent and regular (Jerie and Tevera, 2014). Makwara and Magudu (2013) contend that waste transfer ought to be done in accordance with the best principles of public health, economics, designing preservation, and other appropriate ecological practices.

1.10 Dissertation overview

Chapter 1 gives a review of solid waste management, the framework included and kinds of waste disposal strategies. It additionally presents the challenges in the collection of waste by local authorities. It gives a short outline of the case study area as well as the research procedure. Chapter 2 deals with theoretical background about the solid waste collection in developed countries and in Zimbabwe. It also describes the theoretical background of software development methodologies. Chapter 3 gives a general description of the data acquisition tools and techniques as well as the software development methodology to be utilized. Chapter 4 portrays the results and analysis of the developed software and data collected. Chapter 5 gives the conclusion, describes recommendations to further improve the developed software.

2 Literature review

This chapter deals with the theoretical background of the solid waste collection management. It also describes the theoretical background of software development methodologies and system architectures. Furthermore, it reviews of existing systems developed to optimally manage solid waste collection in other countries. This literature review is both a synopsis and clarification of the entire and current state of knowledge on the solid waste collection systems as found in scholarly books and journal articles.

2.1 Municipal waste

Solid waste is any material that is disposed of on the basis that it has spared its motivation or is not helpful any more (Makwara and Magudu, 2013). It is generated from day to day activities that individuals or groups undertake in the endeavour to satisfy economic, social, political recreational and developmental needs (MLGPC, 2008). As a result of urbanisation, change in lifestyle and eating habits in developing countries, the generation of solid waste and its composition has increased rapidly (Idowu *et al.*, 2012). It is classified into classes namely general waste and hazardous waste.

2.1.1 General solid waste

It is waste which does not pose an immediate threat to individuals or the environment, i.e. household waste, garden waste, dry industrial and commercial waste. (MLGPC, 2008). It can be categorized into residential /household waste, commercial and industrial waste, organic waste, construction and demolition waste. Household waste emanates from food waste, paper, cardboard, plastic, textiles, leather, garden waste, wood, metal, ash, consumer electronics, appliances, batteries, oil, tyres waste and household hazardous waste (TRSC, 2010). It also encompasses organic kitchen wastes, sweepings, rags, paper and cardboard, plastic from food packages, glass, rubber, leather, bones and ashes produced from cooking with firewood. Discarded furniture, used electronic appliances and garden wastes also constitute household waste (MLGPC, 2008). Hazardous household wastes involve residues chemicals such as paints, solvents and detergents, batteries rendered useless both dry cells and lead-acid from vehicles. Fluorescent tubes and discarded electronic equipment (Manus and Coad, 2010). Industrial waste is generated from housekeeping waste, packaging, food waste, construction and fabrication waste, sludge, liquid, ash and scrap material. Construction/demolition waste is generated from wood, steel, concrete, bricks, brush and rocks. The commercial waste comes from paper, cardboard, plastic, wood, food waste, glass and metal. Solid wastes from schools, governmental offices, hospitals, and churches are included in this category. Wastes from hospitals and other healthcare facilities can be differentiated into general and hazardous waste (ADB, 2017).

2.1.2 Hazardous waste

Any waste which may, by the conditions of its utilization or because of its biological, physical or infectious attributes, cause or prompt to cause, harm to the human wellbeing or to the environment. There are distinctive classes of hazardous waste which incorporate substances that are explosive, corrosive, chemically reactive, poisonous, biohazardous (e.g. containing infectious disease organisms), radioactive or cancer-causing. It can be categorized into Explosives, Gases, Flammable liquids, Corrosives, Radioactive substances. Its main sources are from Medical waste and Industrial waste (MLGPC, 2008). However hazardous waste can also be generated at household level though at very low rates. It sources are batteries, fluorescent lights, spent drugs, oils, paints and detergents (DEAT, 2001).

2.1.3 Electrical waste

Electronic is a term used to describe electronic items that have been discarded on the basis that they are no longer working or are old, and have basically reached the peak of their lifespan. Electronic waste, for example, cathode beam tube screens, require exceptional handling as they are hazardous. Basic electronic items commonly disposed of includes PCs, TVs, stereos, copiers and fax machines. Certain parts of some electronic items contain materials that render them dangerous (Balde *et al.*, 2014).

2.2 Solid waste collection management in developed countries

Proper management of solid wastes continues to be a serious problem worldwide and particularly in the developing countries. Growing population, rising standards of living and industrialization are acting hand in hand to generate progressively greater quantities of solid wastes, and thus creating serious problems of their administration and legitimate disposal. However, in developed countries they are utilizing emerging technologies to ensure sustainable solid waste management.

2.2.1 Temporary storage of solid waste at homesteads

Waste is first stored temporarily at the source of the generation which is the residential homesteads in containers provided by the relevant authority responsible for solid waste management (Likotiko *et al*., 2017). Commonly used containers are plastic or galvanized metal bins, and disposable paper or plastic bags. Information and Communication Technologies (ICT`s) have been coordinated with waste management systems in developed countries in an effort to make waste collection efficient (Rada *et al*., 2013). Sensors, barcodes and Radio Frequency Identification (RFID) are integrated with waste collection containers to monitor the level of waste and make a communication to the administration pertaining the level of waste in the bin (Hannan *et al.*, 2015). RFID, Global Positioning System (GPS) and General Packet Radio System (GPRS) with the cameras have been built up for waste collection and monitoring frameworks in the United Kingdom. The framework comprises of two RFIDs, one mounted on a bin and the other on the truck, the GPRS acts as the web server, database server and the control server (Hannan *et al.*, 2011). In Denmark, a waste collection system depends on waste level information from trashcans gathered by ultrasonic ranging module sonar sensors and Arduino Uno microcontrollers (Goenka and Mangrulkar, 2017). The information is sent over the Internet to a server where it stored and processed. The microcontroller is adequate for gathering information from sensors and sending them to the Internet through a system interface. The gathered information is then utilized for checking and advancing the everyday determination of trashcans to be collected (Gutierrez *et al.*, 2015). These technologies empower the administration to be aware of bins that are filled to capacity and needs immediate collection (Medvedev *et al.*, 2015).

2.2.2 Routing and scheduling for solid waste collection

In Denmark, the routing of vehicles amid waste collection is achieved by using a greedy algorithm that builds one route at a time and attempts to reduce the waiting time during waste collection. It does so by avoiding visiting waste generation zone if the trip would incur a waiting time hence it facilitates for visiting the optimum feasible waste generation zone that can be serviced without waiting time. In the event that the vehicle is loaded to capacity, it evaluates the route to the nearest accessible disposal site (Buhrkal *et al*., 2012). Nevertheless, in Italy, they optimise the collection of solid waste by employing constructive algorithms for scheduling vehicles and personnel that are generated from linear programming (Mansini and Grazia, 1998). The optimization determines when waste collection task must be performed, based on its frequency and assign vehicles and personnel to tasks, satisfying constraints related to rest regulations (Ghiani *et al.*, 2013). In India, the daily compactor truck routes are fixed and balanced to provide a fair day's work using several network modules of GIS software to optimize the routes and to find the shortest or minimum impedance path through a network (Ghose *et* al., 2006).

2.2.3 Solid waste collection

Collection of solid waste in India is carried out by using suitable vehicles. The type of vehicle to be used depends on the type of waste collection bin and the width of the road (Ghose *et* al., 2006). The usual vehicle for the residential collection of solid wastes is the manually rear or side-loaded compaction truck operating with a crew of two or three, including the driver. In residential areas, the most common collection methods are curb side, door to door and community. In curb side, the residents carry the single-use plastic bags and containers to the curb or collection point and then return the empty container after pickup (Asase *et al.*, 2009). Refuse collectors walk along the route, following the refuse truck which moves slowly, and manually collect the refuse from containers placed at the collection points by the residents. Compactor trucks with lifts for automatic emptying of waste bins and containers are frequently used for domestic waste collection in Denmark (Poulsen *et al.*, 1995). Community collection is whereby bin are located along streets and at markets places for usage by everyone. These bins when full are emptied into the compactor trucks manually by refuse collectors or automatically using automatic compactor trucks with arm lifts for emptying the bins amid collection by compactor trucks (Nuortio *et al.*, 2006).

2.2.4 Solid waste disposal

There are many waste disposal methods that are practised by developed countries and these range from landfilling, incineration, composting and recycling (Hamer, 2003). In countries like Canada, France, Italy and Netherlands there is an utilisation of all the above-mentioned methods depending on the type of waste being disposed of (Leao *et al*., 2001). However, the most common and cheap method of waste disposal practice is the landfilling (Manaf *et al*., 2009; Narayana, 2009). Waste disposal through sanitary landfilling imposes mitigatory measures to the contamination of both the surface and ground water (Ogwueleka, 2009). Other waste disposal options produce some residues that must be discarded through landfilling (Herman, 2003). In China waste is firstly separated at collection into recyclable and non-recyclable waste and the non-recyclable is incinerated before it is landfilled (Wang and Nie, 2001). Waste collected in the city of London is disposed of by the compactor trucks in the city's landfill (Asase *et al.*, 2009). However, in India, waste is first disposed of at transfer station by the compactor trucks and finally transported to the landfills using one person trailers or large trucks (Ghose *et* al., 2006).

2.2.5 Integration of spatial technologies in the solid waste collection

The variety of Information Communication Technologies (ICT) for Solid Waste Management centred on monitoring, collecting, transporting and disposing of solid waste can be classified into spatial technologies, identification technologies, data acquisition technologies and data communication technologies (Hannan *et al.*, 2015). Spatial technologies are the most broadly utilized ICTs in ecological modelling, as spatial analysis is very important for many environmental studies. These technologies are successful to deal with complex spatial data and to provide platforms for the integration of different models, interfaces and sub-systems as well. Spatial technologies are grouped into two fundamental groups namely GIS and GPS (Milla *et al*., 2005).

GIS is one of the most influential spatial technology. "Geographic information systems are a special class of information systems that keep track not only of events, activities, and things, but also of where these events, activities, and things happen or exist" (Longley *et al.*, 2005, 4). According to Sun *et al* (2001), GIS is a computerized system that facilitates the acquisition, storage, analysis, maintenance and presentation of data about geographic space. The ability of GIS to efficiently store, retrieve, analyse, and display spatial data according to user-defined specifications makes it suitable for waste management (Kallel *et al.*, 2016). GIS can correlate and analyse the spatial relationship between geographical phenomena, enabling an in-depth analysis, and visualisation of trends that can be implemented in strategic planning. It enables analysing data visually which helps in identifying patterns, trends, and relationships so as to simulate various elements of spatial waste management including waste collection (Chalkias and Lasaridi, 2009).

GPS is a satellite-based navigation system that is comprised of satellites, placed into the orbit to record locations from places on the earth (Rada *et a*l., 2013). The satellites intermittently transmit a radio signal of short pulses to GPS receivers to calculate distance and to compute the position of the receiver position (Arebey *et al.*, 2009). The utilization of GPS concurrently with other spatial and communication technologies particularly with GIS helps to track collection vehicles and bins as result enabling observation of their location and collection time (Hannan *et al.*, 2015).

The integration of GIS and GPS with waste collection systems enable new services and modify the existing ones, for instance, static waste collection is modified to waste collection as a service which enables online dynamic scheduling and routing of the waste collection trucks Issues connected to dynamic waste collection providing adequate information with regards to when to collect waste from bins and which optimum routes are available for traversing to collect waste from the generation areas and to dispose of at proper disposal sites (Medvedev *et al.*, 2015).

2.3 Solid waste collection management by Zimbabwean local authorities

Increasing population, rapid urbanization, industrial growth and unsustainable consumption patterns have not spared Zimbabwe but rather have contributed to the growing solid waste problem. Waste management has become one of the topical environmental issues of concern in most of Zimbabwe's urban centres. the majority of the local municipalities responsible for solid waste management are facing challenges that emanate from the economic meltdown and poor administration in executing their mandatory duties.

2.3.1 Legal frameworks for solid waste collection and disposal in Zimbabwe

The responsibility of urban councils in Zimbabwe is to oversee the solid waste management services. The obligation of Zimbabwean urban councils is to clean the streets, ensure waste minimization, waste collection, transportation, disposal, and planning. Urban councils in Zimbabwe may contract individuals to collect waste and perform landfill operations on their behalf (Government of Zimbabwe, 1983). The Ministry of Local Government, Ministry of Environment, Climate and Water, Environmental Management Agency and the Ministry of Health and Child Welfare, is there to administer and regulate urban councils in terms of solid waste management (Muchandiona, 2013). However, this brings a duplication of obligations in policy implementation as government ministries and departments tend to hold diverse legitimate positions but performing similar capacities (Benjamin, 2015).

Section 70 of the Environmental Management Act (2002) states that no individual or group of individuals is allowed to dispose of waste that will contaminate the environment or affect the health of people. Furthermore, section 83 states that illegal dumping of waste in roads, water, streets, land or at any place is not permitted, but to dispose of in assigned places or containers that are accommodated for that purpose. It additionally expresses that any individual who dispose of the waste through unstipulated practices or methods will be guilty of an offence that is punishable through imprisonment or payment of a fine (Government of Zimbabwe, 2002).

Section 83 of the Public Health Act of Zimbabwe (1996) states that states that it is the obligation of each and every local authority to take all legitimate, vital, and reasonably practical measures for maintaining its district, in clean and sanitary condition by preventing the accumulation of waste, which might be harmful or unsafe to the wellbeing. In addition, this law in Section 83 additionally expresses that each and every individual should take fundamental measures to reduce waste through waste minimization, reuse and inactive waste in engineered landfills (Government of Zimbabwe, 1996).

2.3.2 Temporary storage of solid waste in homesteads

In the customary way to deal with solid waste management in Zimbabwe, local authorities or municipal councils are responsible for the collection and disposal of domestic solid waste (Manyanhaire *et al.*, 2009). After waste is generated in the residential areas, it is temporarily stored in plastic or steel bins that are provided by the local authorities after payment of a fixed fee (Tsiko and Togarepi, 2014). In some instances residents tend to temporarily store their waste in plastic bags or sacks as they may find challenges in paying the local authority so as to be issued a proper waste storage container (Nyarai *et al.*, 2016).

2.3.3 Routing and scheduling for solid waste collection

The city council is mandated by its city`s bylaws to draft a waste collection timetable that they should adhere to, in far as waste collection is concerned (Jerie, 2006). The supervisors in the council`s waste collection departments are responsible for defining the shift schedules for both the personnel and the vehicles as well as generating the routes to be used amid waste collection (Oliveira *et al*., 2007). Information about fuel consumption and capacity of the compactor truck, terrain and conditions of roads, spatial location of waste generation areas is used in planning collection routes and assigning compactor trucks to specific locations with regards to their spatial extent and waste generation capacity. The supervisors are responsible for overseeing the administration of waste collection fleet as well as ensuring that they are frequently serviced (Mudzengerere and Chingwenya, 2012).

2.3.4 Solid waste collection

Curbside collection method is mostly employed when collecting waste from residential areas. Solid waste is collected from residential areas by compactor trucks which collect waste from each household once or twice a week. Curbside collection qualifies residents to leave their bins directly outside their homes to enable refuse collectors to exhaust them into their truck (Jerie and Tevera, 2014a). Refuse collectors walk along the route, following the compactor truck which moves slowly, and manually empty refuse containers placed along the road. Initially, the city council notifies the local residents of the time and day on which waste will be collected in their respective locations to avoid inconveniences (DEAT, 2001). On the day of collection, refuse collectors will manually dispose of residential waste. The compactor truck will be following a route either determined by the supervisor or by the driver which will be convenient to him/her (Jerie, 2006).

Community collection methodology is usually employed in the central business district where a lot of people are usually gathered or usually meet from time to time. These places include marketplaces, commuter and bus terminus/rank. It qualifies residents to convey their waste into bins/canisters that are ideally situated within an area (Constantine *et al.*, 2014). Spatial analysis tools are used to determine the convenient location for placing the community bins to ensure adequate access for every resident. Furthermore, the council`s workers who sweep the streets also convey their waste into these community bins and are responsible for ensuring that waste does not spill out (Nyarai *et al.*, 2016). Once the bins are full, they communicate to their supervisors specifying the location and carrying capacity of the bin. The supervisors will then establish the available compactor trucks or tractor and assign either which is available to go and collect the full community bins. In this regards the supervisors will also generate the route to be followed to ensure the smooth flow of getting there. Community bins are collected daily using either compactor trucks or tractors (Mangizvo, 2007).

2.3.5 Solid waste disposal

All the collected waste is disposed of through landfilling. Compactor trucks when full, drive straight to landfills that are usually located on the outskirts of the cities/towns (Mapira, 2011). These landfills are sited using GIS techniques so as to ensure that they do not pose any hazards to the environment and the public health (Jerie and Tevera, 2014). The remaining uncollected waste is either randomly dumped in open spaces or burned (Remigios, 2013). However a very small proportion of residents on the uncollected waste resort to composting (Hobwana and Ngaza, 2018). The landfills are continuously monitored so as to mitigate their potential hazardous implications.

2.3.6 Constraints in the solid waste collection management by Zimbabwean local authorities

The management of solid waste is becoming a major cause of concern in urban areas of many developing countries including Zimbabwe, particularly in large cities as a result of urbanisation

(Chatindo, 2015). Zimbabwean urban areas produce at least 2,5 million tons of household and industrial waste every year (Mapira, 2011). Solid waste management has become a critical problem since the economic meltdown that emanated from the land reform program in Zimbabwe in the year 2000 (Chikobvu and Makarati, 2011). This created a financial breakdown that caused a severe collapse in refuse collection and disposal services. Mapira (2011) maintains the lack of capacity in the administration of solid waste resulting from monetary subjugation and political insecurity in the country set off a deterioration in the quality of waste collection services.

The source of revenue for urban councils to finance their activities are levies paid by ratepayers and grants from the parent ministry. Collection of revenue from ratepayers has been somehow inadequate as residents are also affected by the economic meltdown in the country (Musademba *et al*., 2011)As a result, local authorities have experienced serious shortages of technical and financial resources to meet their waste collection and disposal mandate (Makwara and Magudu, 2013). However, Manyanhaire et al (2009) further argue that the lack of commitment by the local authorities has contributed to the downfall of waste collection and disposal services.

Studies done in Bulawayo demonstrated that there was an intense deficiency of equipment and the city council was struggling to enforce regular waste collection (Mudzengerere and Chingwenya, 2012). Furthermore, solid waste was being collected once every month in the residential areas. In this manner, waste collection was inconsistent and inadequate as waste was being generated daily in large volumes. Chinhoyi urban council likewise was encountering issues in the regular collection of solid waste. The frequency of solid waste collection was once a week with a 0.48 probability of actual manifestation of the collection (Musademba *et al.,* 2011). The genuine shortage of equipment, human and financial resources had been cited as the stumbling block to an efficient solid waste collection system. In this regard, solid waste collection inefficiency by the local authority prompted residents to resort to burning and illegally dumping the uncollected waste which both are un-environmentally friendly practices (Muchandiona, 2013). In Chinhoyi, residents usually utilize unsustainable practices of disposing of waste when the council fails to collect waste, 60% of the residents practised illegal dumping and the remaining 20% resorted to burning (Musademba *et al.*, 2011).

Mapira (2011) uncovered that Chiredza was also facing challenges in effectively collecting and disposing of waste because of poor infrastructure pivoted on the shortage of refuse trucks and proper landfills as well as the shortage of manpower. Manyanhair*e et al* (2009) in their investigation on solid waste administration in Sakubva, Mutare, presumed that there was insufficiency, wastefulness, anomaly, and irregularity in the manner in which solid waste was being handled because of the previously mentioned factors. An examination of the solid waste management in the Avenues, Harare also showed some inconsistency and inefficiency in the waste collection (Tanyanyiwa, 2015). Furthermore, it revealed that Zimbabwe's politically designed financial dejection brought about an extreme fall of solid waste administration in the most urban area bringing about the accumulation of waste in most open spaces. Most municipalities had neglected to give a productive waste collection and disposal system causing residents to aimlessly dump waste in undesignated areas. Jerie and Tevera (2014) in their study on the waste management in Gweru concluded that the absence of an efficient routing system for solid waste collection was the chief architecture in increasing waste collections costs. The vehicle maintenance costs and inadequate fuel consumption was a result of poor route determination that are not using any spatial technologies or mathematical concepts to deduce optimum routes. Mangizvo (2007), further articulated that the absence waste collection monitoring mechanism resulted in variation in waste collection cycles in the same neighbourhood as some households will be skipped leading back to the issue of a poor routing framework that is failing to accommodate all households within the same neighbourhood.

2.4 Types of research

Research is a way of discovering new insights relating to an issue or topic. Kothari (2004) characterized research as the hunt of information through a target and orderly strategy for finding an answer for an issue. there are different types of research that can be carried out in conjunction with various tools and techniques in an endeavour to acquire a solution to a problem.

2.4.1 Quantitative

Quantitative research depends on the estimation of quantity or amount and is relevant to phenomena that can be expressed as quantities (Kothari, 2004). It is essentially focused on measuring things and makes inquiries which help to answer questions like to what extent? or what number of? Quantitative research aims at quantifying data and generalising the results from the sample population. They also quantify the rate of different perspectives and sentiments in a chosen sample (MacDonald and Headlam, 1999). It is the right of choice when generating primary data from a large number of sources and when the research is pivoted on answering questions like, how many people have a certain problem? how many people exhibit a certain attitude?

2.4.2 Qualitative

Qualitative research is essential in discovering fundamental intentions of human conduct. They enable the dissection of different factors which spur individuals to exhibit certain specific behaviours or which make individuals like or dislike specific things (Kothari, 2004). Qualitative research focuses on the quality of information and gaining an understanding of the underlying reasons and inspirations for actions as well as establishing how individuals translate their experiences and the world around them (Carver *et al*., 2004). It is essential when the motivation behind the research is primarily to describe a circumstance, phenomenon, problem or event and if the information is gathered through the use of variables measured on nominal or ordinal scales (Kothari *et al*., 2014). Qualitative research provides an adequate knowledge of understanding the nature of the problem, generating ideas and/or hypotheses (MacDonald and Headlam, 1999). The application of a qualitative research includes a description of an observed situation, the historical specification of events, an account of distinctive opinions individuals has around an issue, and a depiction of the living conditions of a community. Qualitative research gives results that are detailed, offering thoughts and ideas to illuminate the research. It can reveal how individuals feel and what they think (Rahman, 2016). However, it cannot quantify how many of the target population feel or think a certain way.

2.5 Data gathering techniques

Research framework encourages researchers to design a custom research sampling frame. A research is conducted largely for the enhancement of knowledge and hence carefully consideration has to be taken into account when designing a sampling frame from which information is to be obtained from. Macdonald and Headlam (2016) postulate that sample is the section of the wider population that will be engaged in the survey and sampling is the process of identifying who will be selected from that population.

2.5.1 Simple random sampling

A simple random sample is the simplest way of selecting participants of a sample from a population. It, therefore, entails that each individual in the population has the same chance of being selected for the sample (Singh, 2012). Participants are chosen at random without using any formula or principle. It is relevant to use when the population is small, homogeneous and readily available (Umulisa, 2012). It is simple to use and ensures that equal opportunity of being chosen to participate in the sample of the population is guaranteed (Marshall, 1996). It eliminates issues to do with bias. the strategy requires a minimum knowledge of the population to be sampled. However, there are time constraints if the population size is very large. It does not represent proportionate representation (Levy, 2012).

2.5.2 Stratified sampling

Stratified sampling is the process of selecting a sample that permits distinguished subgroups in the defined population to be represented in the same proportion that they exist in the population. Stratified sampling is utilized when individuals in a population can be split into distinct, non-overlapping groups called strata (Teddlie and Yu, 2007). The strata must be non-overlapping and together establish the entire population. In stratified sampling, the number of participants sampled from each stratum is computed proportionally to the total population. Stratified sampling is beneficial when there are huge contrasts between the strata, as it can give a more exact representation of the population (Celano, 2014). Furthermore, it provides greater precision than the simple random sample with regards to the representation of a diversified population. It also guards against an unrepresentative sample and focuses on relative subpopulations but ignores irrelevant ones. However, it is not useful when there are no homogeneous subgroups and makes it difficult to select important stratification variables (Neyman, 1934).

2.5.3 Cluster sampling

Cluster sampling is the procedure of haphazardly choosing intact groups, not individuals, within the defined population having comparative attributes (Umulisa, 2012). Units in the population can regularly be found in certain geographic locations or clusters, for example, primary school children in a certain city or town. A random sample of clusters is taken, then all units within the cluster are analysed (Borkowski, 2005). When a full sampling frame list is not accessible or the target population is too geographically scattered, then cluster sampling will take a sample from only one or a couple of groups and not the whole population. It is a simple and fast method of sampling that doesn't require complete population information (Henderson and Sundaresan, 1982). Cluster sampling is economical and time conscious in its implementation. However, it provides less precision than simple random or stratified sampling (Ahmed, 2009)

2.5.4 Desktop research

Desk research alludes to secondary data or that information which can be gathered without hands-on or fieldwork, it is usually derived from websites, books and e-books, previously published articles, theses, conference papers, contextual investigations, magazines, and different research reports (Prosepk, 2017). Desk research is what expert researchers use to portray the tracking down useful of existing pre-published information. Its motivation is to give as much information on the hands-on plausible conditions, and the likely problems that they will impart to the overall success of the research (Columbia *et al*., 2013). A desk research gives an opportunity to the researcher to outline existing research within the framework of his/her particular study, focus on current trends and assess the gaps in knowledge. Desk study can save time and resources coordinated toward essential information gathering in the field and regularly helps in recognition of important information needs (WFP, 2009). It is critical for identifying information needs, the sources, types and formats of information, how that information is analysed and its associated analytical frameworks and analysis tools. It additionally uncovers the skills, experience, or technical support required in the acquisition and analysis of the information (Sandison, 2003). Furthermore, it is fundamental for keeping away from duplication of past investigations and concentrating the information gathering on issues of concern or areas requiring verification or improvement. It, therefore, answers some assessment questions, other information or give a standard of examination/comparison. In this regard, it provides a baseline for longitudinal comparisons. However, written documents do not necessarily provide exhaustive or correct answers to particular issues, as they may contain blunders, exclusions, or misrepresentations (UNICEF, 2017). They are simply one form of evidence, and ought to be carefully utilized and with different types of data.

2.5.5 Observations

It is normally done over a specific time-frame, months or years. MacDonald and Headlam (1999) contend that the longer the time frame the greater the capacity to get more definite and accurate information about the study. Information is gathered by mere observation of the way things are done, the trends and patterns portrayed in the endeavour to accomplish different activities. This strategy is free of respondents' willingness to co-operate and in that capacity is moderately less demanding of active participation with respect to respondents as happens to be the situation in interview or the questionnaire methods (Kothari, 2004). It is not subjective to bias. However, the information gathered through this technique may be limited and incomplete.

2.5.6 Interviews

An interview is an efficient method for talking and listening in an effort to gather information from individuals through a conversation. According to Kajornboon (2005), interviews can be distinguished as structured, semi-structured and unstructured interview. Structured interviews make use of a set of predetermined questions and are asked in a chronologically ordered manner (Woods, 2011). It is usually utilized when there is a need to gather information using questions with comparable responses. Semi-structured interviews use a framework to address key headlines rather than specific questions. Furthermore, it introduces flexibility that empowers the researcher to develop other relevant headlines and key issues from the responses of the interviewee (Appleton, 2008). Unstructured interviews do not follow any predetermined pattern of questions or themes. Rather, the interviewer will address the issues as they emerge in the interview. It is useful when trying to establish a solid foundation with regards to a research question or problem. MacDonald and Headlam (1999) urge that when conducting an interview, the researcher should be respectful and maintain appropriate boundaries all the times.

2.5.7 Questionnaires

A questionnaire is a document with a rundown of composed questions which will be answered by the respondents Kumar (2011). They are categorised into the structured and unstructured questionnaire. Structured questionnaire entails the delivery of the same question with the same wording to different respondents in the same order. All questions and answers are specified Unstructured questions are those that have a potential of producing unexpected answers as the respondents are not confirmed to any frameworks and are able to answer the questions in a manner they are comfortable with. Kothari (2004) contend that unstructured questions enable the respondent to pass on a sentiment without being influenced by the researcher. A lot of information is collected from a lot of people in a short time frame. However, it is limited to the degree of literacy of the respondent to convey the meaning inherent the questions and provide acceptable answers (SPSS, 2004). Furthermore, it entails respondents to write down their response and handwriting may be illegible at times.

2.5.8 Thematic analysis

It is a process that entails the generation of themes from the raw data, it is usually alluded to as open coding (Hoepfl, 1997). It empowers the researcher to view his/her discoveries with a pre-defined framework, which mirrors the aims, objectives, and interests of the research, therefore ensuring that much focus is pivoted on specific answers and abandon the rest (Pope *et al*., 2000). Thematic analysis is an interpretive process, whereby data is systematically searched to distinguish patterns within the data so as to provide an illuminating description of the phenomenon (Smith and Firth, 2011). The approach involves a systematic process of filtering, outlining and arranging information as indicated by key issues and subjects from the findings of the raw data (Jacelon and O'Dell, 2005). The initial coding framework is created both from an earlier issue and from developing issues utilizing numerical or textual codes to identify the specific pieces of data which compare to various themes. Charts are then created utilizing headings from themes and patterns, affiliations, ideas, and clarifications in the data are searched (Hardy and Bryman, 2009). It provides rich and insightful understandings of complex phenomena moreover it is speculatively versatile, provides a rich translation of the study both inductive and deductive. However, it is subjective and lacks transparency in connection with the development of themes, which can result in difficulties when passing judgment on the certainty of the findings (Stirling, 2001)

2.5.9 Content analysis

Content analysis is a technique for breaking down composed, verbal or visual correspondence messages (Cole, 1988). It arranges verbal or social data for the purpose of classification, synopsis, and tabulation. The content can be dissected on two levels namely descriptive and interpretative (Tilahun, 2012). It strives to attain a dense and broad description of the phenomenon, and the outcome of the analysis is concepts or categories depicting the phenomenon (Elo and Kyngäs, 2008). Content analysis enables the researcher to test hypothetical issues to enhance comprehension of the data. Through content analysis, it is conceivable to distil words into less substance-related categories. Generally, the motivation behind those concepts or categories is to develop a model, conceptual framework and conceptual map or categories. It is content-delicate, adaptability regarding research outline and results in a short-sighted depiction of information (Harwood and Garry, 2003). Furthermore, a large amount of raw data can be transformed into smaller meaningful and manageable information (Woods, 2011)**.**

2.5.10 Narrative analysis

Narrative analysis alludes to a subset of qualitative research designs in which stories are utilized to portray human action (Smith, 2000). It can be viewed as an approach taken on the interview data, that is concerned with understanding how and why individuals talk about their lives as a story or a progression of stories. This unavoidably incorporates issues of personality and the cooperation between the storyteller and the audience (Earthy and Cronin, 2008). The core activity in the narrative analysis is to reformulate stories exhibited by individuals in various settings and in view of their distinctive encounters. Every interview/observation has story angle the researcher has to sort-out and reflect upon them, improve them, and present them in a revised shape to the reader.

2.5.11 Comparative analysis of data analysis techniques

Table 1: Data analysis techniques comparison

	Thematic	**Content**	**Narrative**
Verbal/ visual correspondence	Better	Perfect	Better
Allow new discoveries	Yes	Yes	No
Visualisation of results	Perfect	Better	Better
Pivot focus on specific answers	Yes	No	No
Provision of illuminating description of an issue	Yes	Yes	No

From the comparison table above, the thematic analysis was adopted for this study.

2.6 Database models

A database is an object or mechanism that is used to store and organise related information (Shasha and Bonnet, 2005). Database Management System (DBMS) are software packages/systems that advocate for the creation and maintenance of a database (Greener, 2008). A database model can be loosely used to describe an organized and ordered set of information stored on a computer (Powell, 2006).

2.6.1 Relational database model

Data are presented in tables as a collection of relations with columns depicting attributes and rows portraying entities (Shoko, 2008). Each table has a set of attributes that poses a unique identifier for each entity which is also known as a primary key. The primary key enables the retrieval of just one row from among the others in the table through the manipulation of SQL. Information can be retrieved as one row or all the rows of a table in compliance with a specified SQL condition (Stephens and Plew, 2003). Data in any table can be accessed directly without necessarily accessing all parent objects. This capability enables efficient and time conscience means of retrieving data from the tables and the database at large. There is no need to search the entire hierarchy, from the top to the last entity, so as to find a single entity. Tables in a relational database model can be linked together, regardless of their hierarchical position, therefore, a table can be linked to multiple numbers of parent tables and child tables (Hernandez, 2010). The relational database model is best suited for retrieval of groups of data, but can also be used to access unique data items fairly efficiently. PostgreSQL is an example of an open source relational database management system (Samson *et al.*, 2014).

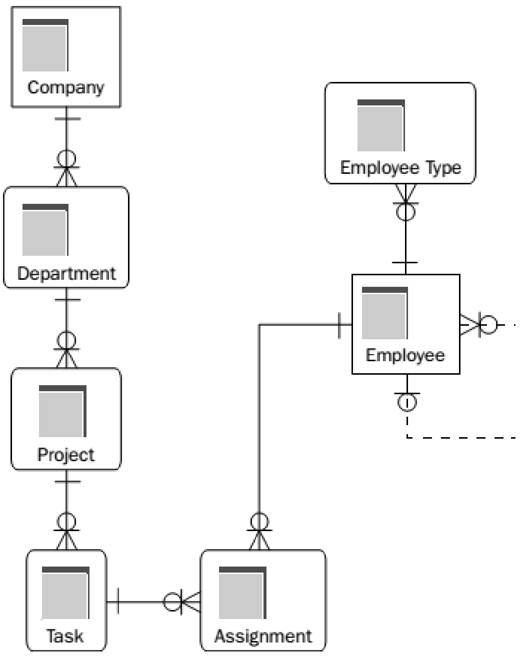


Figure 2: Relational database model (Powell, 2006)

2.6.2 Object-oriented database model

An object-oriented database model provides a three-dimensional structure to data where any item in a database can be retrieved from any point very rapidly. It is designed to blend with object-oriented programming languages such Java and C++ to store data (Shekar and Chawla, 2002). It was designed specifically to address the limitations of the relational database model. The relational database model was limited to handling numbers, dates, and characters data types only and could not store objects like voice, pictures, video, and text documents (Stephens and Plew, 2003). However, an object-oriented database model is not guaranteed to run on many platforms as does the relational database models. Consequently, the object-oriented database model performs poorly when retrieving more than a single item, at which the relational database model is proficient. The object-oriented database model does resolve some of the more obscure complexities of the relational database model, such as the removal of the need for types and many-to-many relationship replacement table (Powell, 2006).

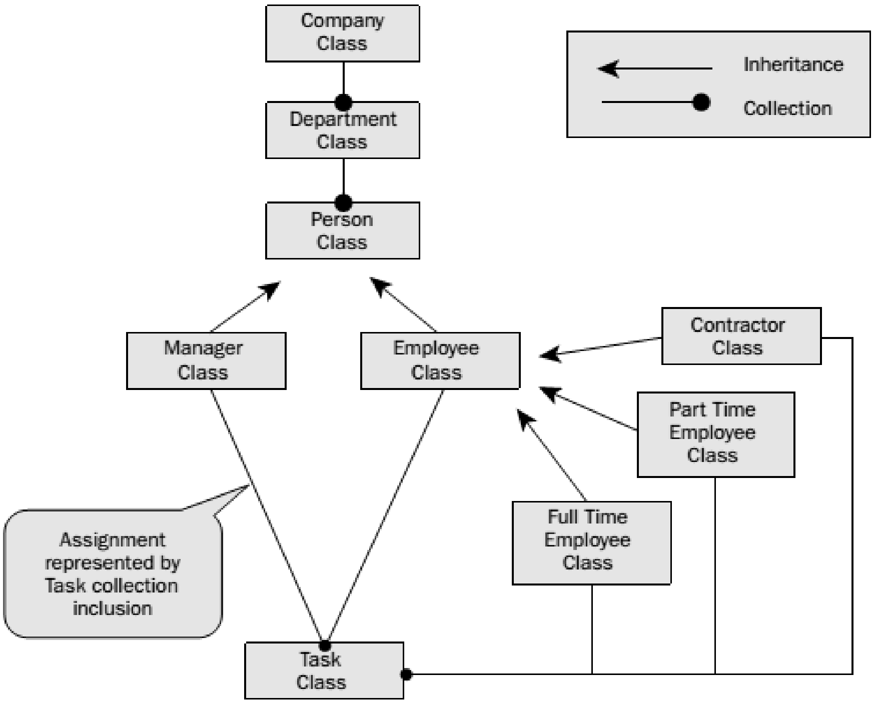


Figure 3: Object database model (Powell, 2006)

2.6.3 Object-relational database model

The object database model allows access to unique elements anywhere within a database structure, with extremely high performance. The object database model performs extremely poorly when retrieving more than a single data item. The relational database model contains records of data in tables across two dimensions. The object-relational database model was created in answer to conflicting capabilities of relational and object database models. Essentially, object database modelling capabilities are included in relational databases, but not the other way around (Güting, 1994). The object database model has a specific niche function at handling high-speed application of small data items within large highly complex data sets. The object-relational model attempts to include the most readily accountable aspects of the object database model into the structure of the relational database model, with degrees of success (Healey, 1991). Object-relational database model combines the attributes of the object-oriented database model with the capabilities of a relational database. It has an extended set of data types beyond the number, dates, and characters to the extent of prompting an individual to create his/her own data types. The objective of an object-relational database model is to provide objective data storage in a relational type of environment. Object-relational database model use a hybrid type of data model that incorporates object support into a relational database model (Stephens and Plew, 2003).

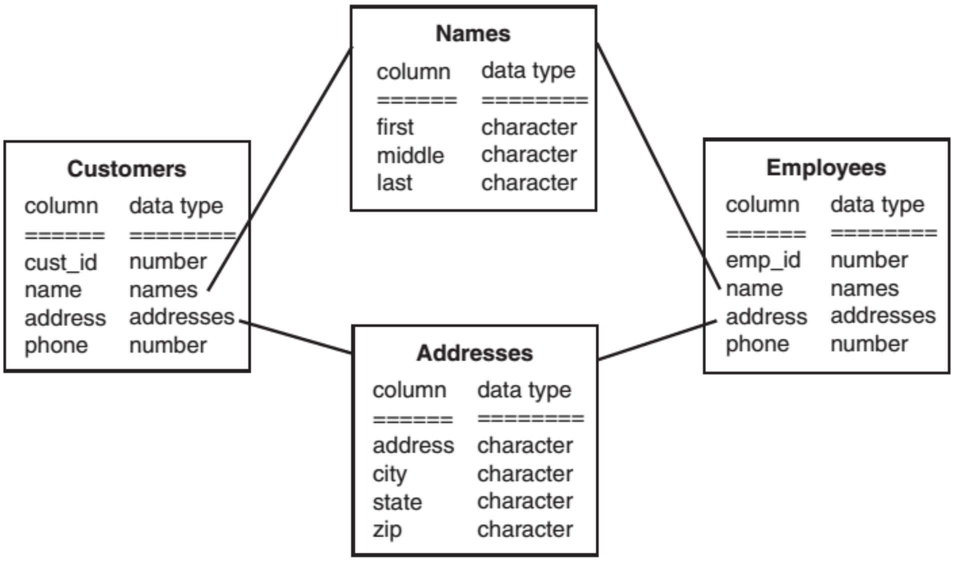


Figure 4: Object-relational database model (Stephens and Plew, 2003)

2.6.4 Spatial databases

A spatial database is a database system that offers the underlying database technology for geographic information systems and other applications. It is a database that stores and query spatial objects that are either points, lines and or polygons existing in space in either 2D or 3D (Shahabi, 1994). It offers spatial data types in its data model and query language. It supports spatial data types in its implementation, providing at least spatial indexing and efficient algorithms for the spatial join. It facilitates Spatial Relationships, Topological relationships, Direction relationships and Metric relationships (Güting, 1994). It enables the querying of spatial selection and spatial indexing as well as supporting spatial join. Some of the spatial databases include Oracle Spatial, SpatialLite, PostgreSQL with its extension PostGIS (Conway, 2012).

2.6.5 Comparative analysis of database models

Table 2: Comparison of database models

	Relational	**Object oriented**	**Object relational**
Data retrieval	Very fast	Medium	Fast
Accessibility of unique data	Perfect	Better	Better
3D structure to data	Poor	Good	Excellent
Integration with other platforms	Perfect	Perfect	Perfect
Performance	High	Medium	High

From the above comparison, the relational database model was adopted for this study.

2.7 Database design

2.7.1 Conceptual design

Conceptual design is the process in which one utilize graphical tools to come up with Entity Relationship Diagrams (ERDs). It additionally involves the creation of tables, fields inside those tables, and the establishment of the relationships between the tables. This progression additionally incorporates normalization (Powell, 2006).

2.7.2 Logical design

Logical design involves the creation of database rules that governs the generation of table. Logical design involves the creation of database rules that governs the generation of table. It defines how a database should be implemented paying little to the DBMS. It establishes a mechanism of rules and data structures governing the database.

2.7.3 Physical design

Physical design implements the enterprise rules to alter the database model for the basic physical characteristics of tables. Physical design visualizes the actual design outline database. It resembles how information ought to be organized and related in an explicit DBMS (Stephens and Plew, 2003).

2.8 Software development methodologies

System development methodology is a framework that is used to structure, plan, and control the process of developing an information system. There are many development methodologies that can be utilized based on the type of information system to be developed, resources available and the availability of time.

2.8.1 System development life cycle

System Development Life Cycle (SDLC) is a more formalized process for taking care of large projects where documentation, preparing, integrity, and security are imperative to the project achievement (Young, 2013). SDLC sticks to critical stages that are fundamental for developers, such as planning, analysis, design, and implementation (Balaji, 2012). SDLC is intended to complete and correct all necessities before the system is designed to ensure that the system will be dismissed by clients or experience substantial rework (Hardgrave *et al.*, 2011). SDLC projects commonly utilize question situated investigation and design. Numerous models will be set up for utilization, relational data, user interface, and a more theoretical conceptual model. It accepts that distinctive administration teams might deal with prerequisites, execution, organization, and monitoring (Balaji, 2012; Young, 2013). The progress of the system development is measurable and there is a strict closedown necessity. It produces many intermediate products that can be inspected to see whether they address the user's needs and conform to standards and guaranteeing that the business gets precisely what it needs (Paul *et al.*, 2017).

In the present technological advancement, there are numerous ways to developing systems, and they all depend on various approaches on the SDLC. These can be categorized as predictive and adaptive approaches (Satzinger and Jackson, 2012). A predictive approach to the SDLC accepts that the advancement of a project can be planned and organized and that the new system can be developed according to the plan (Dennis *et al*., 2012). Predictive SDLCs are useful when developing systems that have clear and unambiguous objectives. An adaptive approach to the SDLC is utilized when the system’s prerequisites and additionally the clients' needs are not clearly defined. In this circumstance, the project cannot be planned completely. Some system prerequisites may need to be resolved after primer development work (Shamieh, 2011). The most used predictive SDLC approach is called a waterfall model. In an adaptive/agile approach, project activities including plans and models are adjusted as the project advances (Lbath and Pinet, 2000). Instead of having the analysis, design, and implementation phases continue successively with some overlap, iterations can be used to create a series of mini-projects that address smaller parts of the application (Deming and Ramamoorthy, 2006). Adaptive/agile methods seek to build up a system incrementally, by building a progression of prototypes and constantly altering them as per client/users` prerequisites. An adaptive approach emphasizes continuous feedback, and each incremental advance is influenced by what was found out in the earlier prototypes. It typically uses a spiral model (Garry and Harry, 2002).

2.8.2 Waterfall Model

The waterfall is the first, conventional and sequential development model software development (Balaji, 2012). It approaches software development through a sequence of stages in which the output of each stage becomes the input for the next (CMMS, 2008). It, therefore, entails that each phase of development proceeds in order without any overlapping. This is a direct technique in which there is a major emphasis on gathering prerequisites and designing the software architecture before doing development and testing. The advantage of this is the project is well arranged, limiting mid-project costs for changing necessities and that these projects tend to be very much archived. It is perfect for supporting less experienced project teams and project supervisors, or a project team whose creation varies. Emphasis is on planning, time schedules, deadlines, budgets and implementation of an entire system at one time (Bassil, 2012). The burden is that it is difficult to modify the list of capabilities amidst advancement, which frequently occurs as issues are revealed during development or changing business situations (Mascolo, 2009). This is such an issue, to the point that numerous organizations put in place a feature freeze in which they decline to change the features to be incorporated into a given system once programming starts and, in this way, required features get pushed to later software versions driving the users of the software to sit tight and wait some years for those features (Young, 2013). It relies on early recognisable proof and detail of prerequisites, yet clients may not be able to unmistakably characterize what they require early in the project.

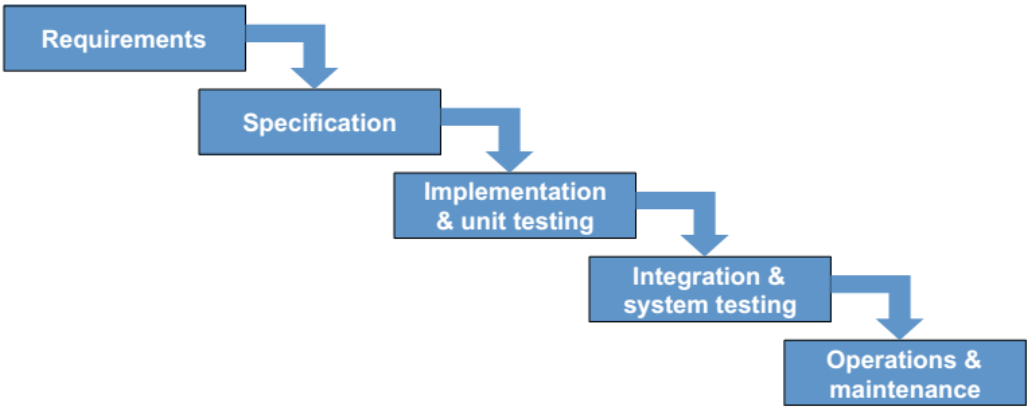


Figure 5: Waterfall model (Deming and Ramamoorthy, 2006)

2.8.3 Spiral model

The spiral model is an improvement of a waterfall model combined with an iterative model (Boehm *et al.*, 1987). Each phase in the spiral model begins with a design goal and ends with the client reviewing the progress. The Spiral approach "peels the onion", advancing through the layers of the improvement process. A prototype gives clients a chance to decide whether the project is on track, ought to be sent back to earlier stages of development, or ought to be ended (Sparrow, 2012). Each iteration comprises the majority of the standard Waterfall stages, but each iteration only addresses one set of parsed functionalities (Benington and Royce, 1983). The overall project deliverable has been divided into organized subsystems, each with clean interfaces. Utilizing this methodology, one can test the achievability of a subsystem and innovation in the initial iterations. This approach improves cost control and ensures the delivery of a largely client-accepted system furthermore it improves the overall flexibility. Project estimates in terms of schedule and cost turn out to be increasingly reasonable as the project advances. However, further iterations result in the usage of more resources and increases significantly the time frame for the system delivery (Schwaber, 1997).

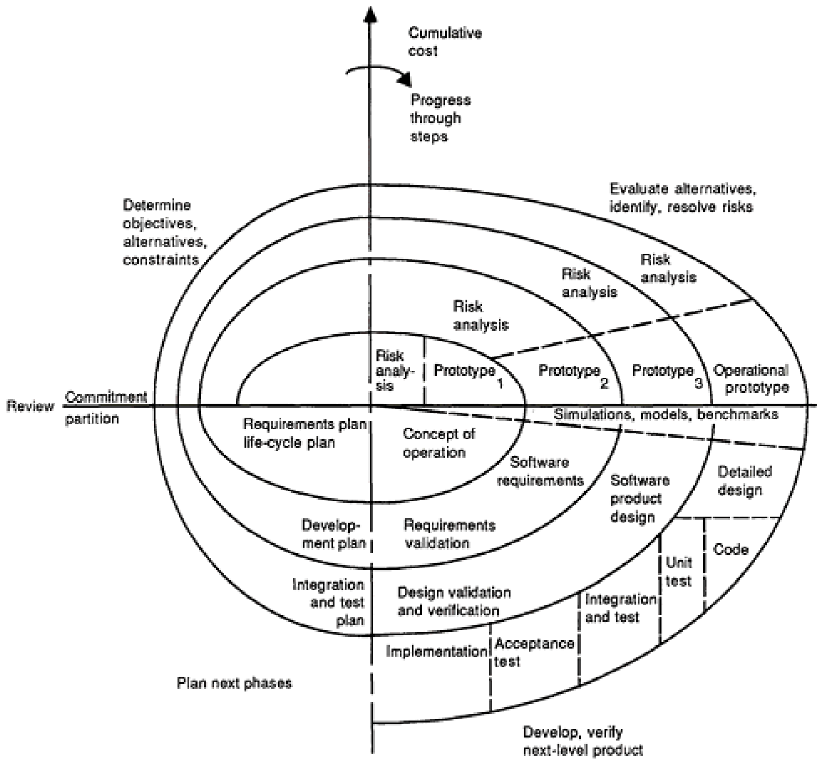


Figure 6: Spiral model (Feitelson and Boehm, 2009)

2.8.4 Prototype approach

A prototype is an early working version of a system that exhibits all the essential features and is used as a benchmark to evaluate the finished system (Bally *et al*., 1977). Prototyping tests system concepts and provides an opportunity to inspect the input, output, and user interfaces before official conclusions are made. Prototyping speeds up the development process significantly and encourages correspondence among clients and developers amid the design procedure (Neumann, 2004). It gives the client substantial methods for comprehending and assessing the proposed system and evokes significant criticism from clients as far as their needs and prerequisites. Prototyping outlines a reference point for both users and developers by which to recognize potential issues and opportunities early in the development process. A possible disadvantage of prototyping is that imperative choices may be made too soon before business or IT issues are understood thoroughly and it generally has slower processing speeds (Garry and Harry, 2002).

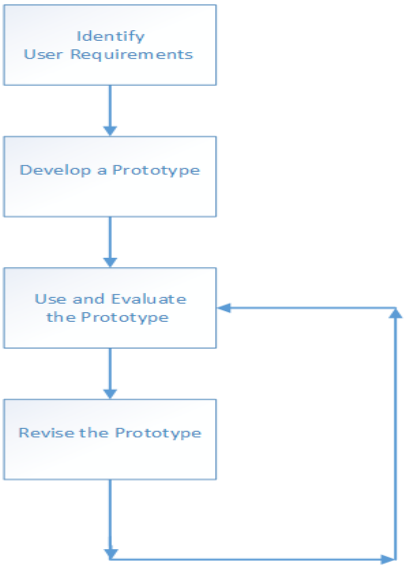


Figure 7: Prototyping approach adopted from (Alavi, 1984).

2.8.5 Comparative analysis of software development models

Table 3: Comparison of software development models

	Waterfall	**Spiral**	**Prototype**
Specification of all the requirements in the beginning	Yes	No	No
Cost	Not costly	Costly	Costly
Cost estimation	Easy to estimate	Difficult	Difficult
Flexibility	Not	Less flexible	Flexible
Simplicity	Simple	Intermediate	Intermediate
Guarantee of success	Medium	Low after each iteration	Higher after each iteration
User involvement	Low	Low	High
Ease of implementation	Easy	Complex	Easy

From the comparison table above, the waterfall model was selected and utilized for the development of the solid waste collection management information system.

2.9 System architectures

There are essentially two common types of system architectures namely the two-tier and three-tier. Two-tier architecture has two components namely the client PC and a database server. It has a simple structure easy to set up and maintain (Kambalyal, 2010). However, the commonly used is the 3-tier architecture in the majority of web application development. A typical web application has three essential tiers namely a presentation tier, application logic tier and the data tier (Karnatak, 2016). A three-tier architecture is deployed to achieve the system robustness and flexibility. It aims to illuminate various repeating design and advancement issues, consequently to make the application development work more effectively and proficiently (Bretl *et al.*, 1998).

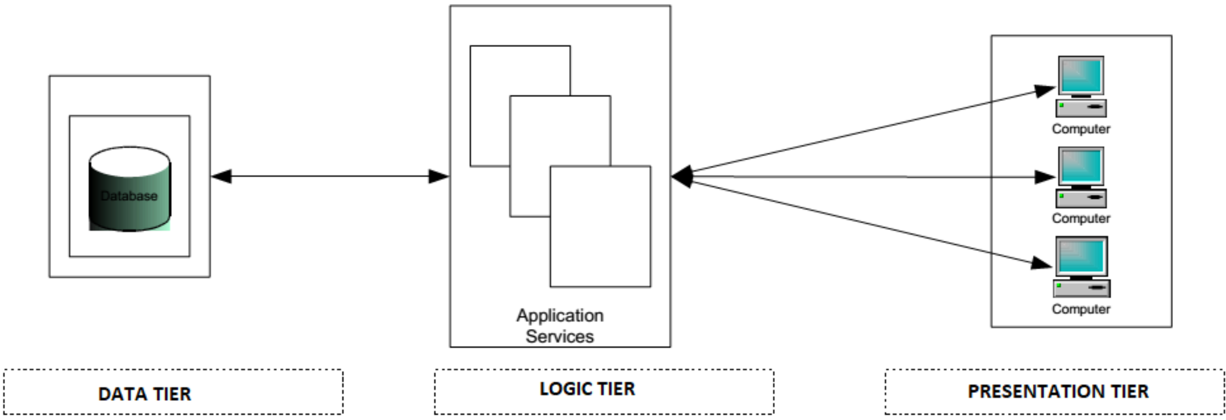


Figure 8: 3tier architecture adopted from (Kambalyal, 2010)

2.9.1 Data Tier

The data tier comprises of a database where all the information is stored and retrieved as per user`s requests (Jethva, 2016). The database is made up of data sets and the database management system that manages and provides access to and models data needed by the application/system (Lee and Wu, 2014). The data tier is responsible for modelling and storing information needed for the system and for optimizing the data access. Data needed by the application logic layer are retrieved from the database, then the computation results produced by the application logic layer are stored back in the database (Huang *et al.*, 2003). These days, there are a lot of alternatives to developing a database, like MySQL, MongoDB, PostgreSQL or Oracle DB (Chilela, 2016).

2.9.2 Logic Tier

The logic tier essentially controls application functionality and performs detailed processing of the user request and pass it to the data tier (Papagelis, 2013). It additionally gets the results of the user`s requests from the data tier and sends them to the presentation layer (Adnan *et* al., 2010). The application logic layer bridges the gap between the user interface and the underlying database, Programming languages like PHP, Ruby, Python and JavaScript are utilized in its development (Mulloy and Swiber, 2017). Elements in this layer receive requests from the presentation layer and interpret the requests into their respective computer-readable language in accordance to pre-defined rules and execute the necessary communication for getting/pushing information from the database (Karnatak, 2016).

2.9.3 Presentation Tier

The presentation tier comprises a user interface responsible for presenting information to external entities like users or other systems and allows the external entities to interact with the system (Cunningham, 1989). The presentation tier empowers the user to send a particular request and view their outcomes. This layer manages the input/output data and their display. It offers greater convenience to the user since it allows them to access the system through existing web browser software (Huang *et al.*, 2003). The presentation tier is usually developed using Hypertext Mark-up Language (HTML) additionally alongside CSS as the styled language (Mendel, 2004). JavaScript is also utilised to make the presentation tier dynamic (Aquino and Gandee, 2016). HTML elements are essential for collecting incoming information and to display the information received from the application logic layer. The protocols like HTTP and SSL are utilized in sending requests and receiving results (Kambalyal, 2010).

2.10 Application design

2.10.1 Backend

Back-end development alludes to the serve- side development. It is basically centred around how the application under development functions.

Node.js

Node.js is actually not a framework, but a runtime environment that allows to the execution of JavaScript on the server side. It is a full-stack JavaScript for serving both the client and the server-side applications. The open-source runtime environment of the Node.js also provides the facility of caching single modules (Cantelon et al., 2017). Whenever there is any request for the first module, it gets cached in the application memory. The system can handle the concurrent request handling efficiently better than others including Ruby or Python. The incoming requests get lined up and are executed quickly and systematically (Bell, 2016). However, Node.js lacks consistency. Its API changes frequently, and the changes are often backwards-incompatible. The fact that Node.js is unopinionated can also be seen as a drawback framework like PHP provides you with a lot of directions from a fresh install and guidelines into the way of doing things, but with Node.js you basically need to write everything from scratch which results in a decrease in productivity, slowing down the progress. Node.js doesn't support multi-threaded programming, it is able to serve more complicated applications but it's not suitable for performing long-running calculations (Braul et al., 2011). Heavy computations block the incoming requests, which can lead to a decrease in performance. Even though the core Node.js is stable, many packages in the NPM registry are not properly documented. The Application Programming Interface (API) keeps on changing at frequent intervals and does not remain stable.

PHP

PHP is an established server-side scripting language for creating dynamic Web pages. Unlike JavaScript, PHP is server-aligned and known to be easier to rebuild and customize. It can integrate with Java, which means that it can be used as the scripting language for activating Java logic (Eukhost, 2007). PHP scripts can be embedded straight into the core of the HTML code and are compatible with various web servers like Apache and the Microsoft's IIS. Unlike ASP / ASP.Net and JAVA, PHP doesn't need any specified framework to build a website application (Bharamagoudar et al., 2013). PHP based web applications can be developed with an Integrated Development Environment (IDE) on any platform with any local host installed. This means that PHP doesn't oblige to any strict or specified framework or the environment. However, PHP has a poor quality of handling errors and lacks debugging tools, which are needed to search for errors and warnings (Php freaks, 2011). It has a smaller number of debugging tools when compared to other programming languages.

2.10.2 Frontend

Front-end development is for the most part centred on the user side of an application. Front-end development languages include Bootstrap HTML, CSS, and JavaScript.

Bootstrap

Bootstrap is a front-end framework that is developed to support creating dynamic websites and web applications. It is one of the most preferred front-end frameworks as it aids an easy and fast processing to develop a website. It supports all major browsers and fast loading responsive web pages. It contains pre-built components and design elements to style HTML content. Bootstrap is an extremely famous HTML, CSS, and JavaScript framework for developing dynamic websites (Devsaran, 2015). Modern browsers such as Chrome, Firefox, Opera, Safari, and Internet Explorer support Bootstrap. It includes a responsive grid system for varying layouts. It is a great starting point for building a mobile-friendly website. It also includes optional JavaScript functionality like collapsible content, carousels, and modals. Bootstrap can be customized as per the designs of the project and can be simply integrated along with distinct other platforms and frameworks (Chouhan, 2017).

JavaScript

JavaScript is viewed as a front-end programming language. It interpreted as a programming language with object-oriented capabilities (Chilela, 2016). It has scripts that interact with users, controls the web browser, and modify the archive content that appears within the web browser window. JavaScript plays nicely with other languages and can be used in a huge variety of applications. Unlike PHP scripts, JavaScript can be inserted into any web page regardless of the file extension. JavaScript can also be used inside scripts written in other languages such as Perl and PHP (Sang, 2016). It is possible to develop an entire JavaScript app from front to back using only JavaScript only. Client-side JavaScript is very fast because it can be run immediately within the client-side browser. The JavaScript code is executed on the user's processor instead of the web server thus it saves bandwidth (Lindley, 2013). There is less server interaction which saves server traffic, which means less load on your server. However, JavaScript is sometimes interpreted differently by different browsers. Whereas server-side scripts will always produce the same output, client-side scripts can be a little unpredictable.

AngularJS

AngularJS is an open-source front-end JavaScript framework. AngularJS extends HTML to develop rich and powerful front-ends (Maulik, 2018). It reduces the repetitive use of HTML code. This repetition can be avoided by using the directives provided by AngularJS which saves much time and effort (Aquino and Gandee, 2016). AngularJS is more intuitive as it makes use of HTML as a declarative language. AngularJS is a comprehensive solution for rapid front-end development. It does not need any other plugins or frameworks. AngularJS is unit testing ready. AngularJS facilitates faster and easier data binding. Angular reduce the burden from server CPUs. It means that the server performs extremely well thanks to reduced traffic and because it only serves static files and responds to the API calls. However, the user interfaces severely lag when the numerical magnitude of users is large users (Mehul, 2016). Many AngularJS features like dependency injections and factories can be problematic and the browser may take time to render pages of websites and applications designed using the framework. It may happen because the browsers would be overloaded to perform additional tasks like DOM manipulation.

Table 4: Comparison of development frameworks

	PHP	JavaScript	NodeJS	AngularJS
Simplicity	Yes	Yes	No	No
Flexibility	Yes	Yes	Yes	Yes
Integration with other frameworks	Perfect	Good	Good	Poor
Processing speed	High	Medium	Medium	Slow
Handling CPU intensive applications	Good	Better	Better	Poor
Full stake applications	Yes	Yes	Yes	No
Back end	Yes	Yes	Yes	No
Font end	No	Yes	Yes	Yes

From the comparison table above, PHP programming language was selected for the development of the backend and JavaScript was selected for the development of the frontend conjunction with Bootstrap.

2.10.3 Mapping libraries

Leaflet is an open source JavaScript library utilized for the advancement of interactive web maps. It's a lightweight, straightforward, and adaptable framework for visualizing and interacting with any mapping (Leaflet, 2017). It was developed with simplicity, superior performance and easy as top priorities. It works efficiently with most desktop and mobile platforms. It can be integrated with multiple plugins to enhance other functionalities like vehicle routing and animating vehicle on transit on a particular route.

OpenLayers is a free, high-performance Open Source JavaScript mapping library that makes it simple to publish dynamic maps on any web page. It can display map tiles, vector data and markers loaded from any source. OpenLayers has been produced to facilitate the utilization of geographic data of numerous kinds (Dhakal, 2010).

Mapbox is a commercial JavaScript mapping library that renders interactive maps services(Mapbox, 2018). It was developed with simplicity, superior performance and easy as top priorities. It works efficiently with most desktop and mobile platforms. It can be integrated with multiple plugins to enhance other functionalities like vehicle routing and animating vehicle on transit on a particular route.

OpenStreetMap is an open source framework to create, convey and disseminate free geographic information, for example, road maps, maps of areas of interest, and maps with geospatial examinations (Chilela, 2016).

2.11 Scheduling and routing algorithms

Solid waste collection and hauling represent most of the aggregate expense in present-day solid waste management systems (Johansson, 2006). Adequate scheduling and routing can essentially lessen these expenses. The scheduling and routing can be done in two ways namely static and dynamic. Static scheduling and routing impersonate the genuine tasks of the waste collection system honed today with fixed collection days and routes. It insinuates that decisions not based on traffic and topology rapid changes but instead the schedules and routes are computed in advance. The procedure for solving the static scheduling and routing problem depends on the heuristic algorithms (Fisher, 2018). This strategy depends on an initial computation of an optimal collection frequency for each container and grouping of collection days and containers aiming at are completely occasioned the total collection cost (Bodin *et al.*, 1983). Dynamic scheduling and routing are completely occasioned driven and decisions to schedules and routes are as often as possible changed in order to reflect changes in the topology and activity. It initiates collection of containers/goods within 24hours from the receipt of a notification. A notification that is received while a vehicle is already collecting waste will not re-route that vehicle, but will instead initialise another schedule and route to be executed inside the 24hours of the reception of a notice. Dynamic scheduling and routing assume that the system has adequate vehicles and labour to deal with the collection requests (Larsen *et al*., 2002).

The advances in communication and information innovations enable information to be received and processed in real time (Hannan *et al.*, 2011). In this case, some of the schedules are known in advance before the beginning of the working day, however, as the day advances, new schedules emerge and the waste collection system has to fuse them into an evolving schedule in progress. The presence of a communication system between the depot where the routes are computed i.e. the headquarter of the company and the drivers have been made conceivable by the emerging communication technologies (Lee and Wu, 2014). The depot can occasionally impart to the drivers the new undertakings allocated to them. In this way, during the day, each driver always has a knowledge about the next customers assigned to her/him. In this regards, vehicles do not have to go back to the depot with the end goal of being informed of the new tasks assigned to them when they had already left the depot (Montemanni *et al.*, 2005).

2.12 Factors considered in route generation

2.12.1 Road elevation

Elevations or gradients play a pivotal role in fuel consumption especially of heavy-duty vehicles that transport different types of goods (Bishop *et al.*, 2001). When these types of vehicles are loaded, they tend to use a lot of fuel when going uphill. A lot of energy in form of fuel is consumed in overcoming frictional forces and gravitational forces. Since work is being done against gravity, a lot of greenhouse gases are emitted into the atmosphere (Zervas, 2011). In addition, this scenario results in compromising the time window periods. As a result, making it difficult to adhere to timeously deliver goods or services. It is of paramount importance to design routes that have lowered elevations for these heavy trucks to use when they are loaded so as to save fuel and avoid constraining the engines capacities and capabilities.

2.12.2 Road roughness

Roughness has the greatest effect on fuel consumption. Roughness entails the degree to which a road surface is bumpy or smooth (Gregory, 2018). The bumps are greatly experienced when a vehicle hits road cracks or potholes. The smoother the road, the less fuel the vehicle consumes. As the vehicle traverses on a bumpy road network, a lot of energy is dissipated through the shock absorbers, suspension, and tires in an effort to compensate the roughness of the road network and make the vehicle stable (Soliman, 2006). On smooth road surfaces, fewer vehicle oscillations are experienced therefore the energy lost through these oscillations is minimum (Pouget *et al.*, 2012).

2.12.3 Traffic congestion

When there is traffic congestion, the combustion engines of vehicles are continuously braking and accelerating as a consequence of inefficient planned traffic flows thereby increasing the fuel consumption and greenhouse gases emissions (Jereb *et al*., 2018). In addition, it also increases the time delay with which goods or service is delivered. An adequate and efficient route should try to eliminate road networks with a lot of congestion so as to ensure that there is a timeous delivery of goods or a service as well as an optimum usage of fuel (Castro and Monzon, 2017).

2.12.4 Shortest route

The shortest route is given by the shortest distance between the start point and the destination point (Levin *et al*., 2010). This shortest distance may not present the most optimum route as it is greatly affected by the road quality and traffic congestion. Furthermore, it might be the shortest route but a very costly route in terms of fuel consumption and time inefficiencies. In crafting optimum routes, there is a need to take into account the traffic flows and roughness of the road network apart from its nature of being the shortest route (El-Sherbeny, 2010).

2.12.5 Fastest route

The fastest or quickest route is the path along a road network that is associated with the minimum time of travel (Gilman *et al.*, 2011). It allows high speeds to be exercised within a road network so that the time of travel is greatly reduced from the initial expected time of travel (Qian and Eglese, 2016). Additionally, the fastest routes are influenced by the road width and quality, allowable speed limits and the traffic flows within the road network.

2.13 Routing algorithms

The Vehicle Routing Problem (VRP) can be portrayed as the issue of planning optimal conveyance or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints (Laporte, 1992). Constraints which incorporates the types, numerical magnitude and capacities of vehicles, maximum route time or route distance, link capacities, routes with customers closer together, operator scheduling and vehicle assignments are considered in generating optimum routes. The issue is to acquire a set of optimum routes from a central depot to the various customers, each of which has known prerequisites, to minimize the total distance covered by the entire vehicles (Tobergte *et al*., 1976). Vehicles start and finish at the central depot and have capacities and maximum route time constraints associated with them.

Routing algorithms help in finding the best shortest (optimum) path with the least energy consumption in the network (Tilli *et al*., 2013). Issues to do with fuel consumption with regards to elevations and nature and types of road networks are taken into account in generating the optimum routes. When the elevation of the shortest path increases, it remains the shortest path but energy consumption will be maximized as a result the algorithm will generate a route that endeavours to balance off elevations and distances in a more sustainable way (Solanky *et al.*, 2016). Heuristic algorithms using linear programming ideas and aggregation of nodes have been developed to take care of the vehicle routing problems (Araque *et al.*, 1994).

2.13.1 Savings heuristic algorithm

The savings heuristic begins with n particular routes in which every client is served by a devoted vehicle (Golden *et al*., 1977). This visit-generating heuristic is characterized by the addition of a customer at every iteration of a link of distinct and partially formed routes between two end customers (Tobergte *et al*., 1976). It reduces the travelling distance through servicing two or more customers on one route as opposed to servicing them individually, directly from the depot (Solomon, 1987). As a result, a great deal of time and fuel are saved. Due to the existence of time windows, route orientation is accounted for by two partial routes. The two partial routes have two end customers that have compatible orientations if the admissible links are from the last customer on one route to the first customer on another. In addition to taking into account vehicle capacity constraints, it checks time window constraints for violation at every step in the heuristic process (Bernstein and Federgruen, 2014). The savings heuristic finds it profitable to join two customers very close in distance but far apart in time. Such links introduce extended periods of waiting time, which can have a high opportunity cost since the vehicle could be servicing other customers instead of, for example, waiting for a customer to be ready for service (Fischer and Jaikumar, 1974).

2.13.2 Nearest neighbour heuristic algorithm

The nearest-neighbour heuristic starts every route by finding the un-routed customer closest to the depot (Desrosiers, 2016). At every subsequent iteration, the heuristic searches for the customer closest to the last customer added to the route. This method which groups customers into routes based on the nearest neighbour concept (Faulin *et al.*, 2011). That is, customers are added to a route sequentially, each new addition being the closest point to the last customer added to the route (Golden *et al*., 1977). This search for the closest customer is performed among all the customers who can feasibly (with respect to time windows, vehicle arrival time at the depot, and capacity constraints) be added to the end of the emerging route. A new route is started any time the search fails unless there are no more customers to schedule. The metric used in this approach tries to account for both geographical and temporal closeness of customers (Malandraki, 2017). Then the metric used, measures the direct distance between the two customers, the time difference between the completion of service at the end and the beginning of service, and the urgency of delivery to a customer as expressed by the time remaining until the vehicle's last possible service start (Solomon, 1987).

2.13.3 Sweep heuristic algorithm

This heuristic can be viewed as a member of a broad class of approximation methods that decompose the VRP into a clustering stage and a scheduling stage (Desrosiers, 2016). In the first phase, there is the assignment of customers to vehicles. In the second phase, there is the creation of a single vehicle schedule for the customers in the cluster of interest, using a tour-building heuristic (Solomon, 1987). Due to the time window constraints, some customers in the cluster of interest could remain unscheduled. After eliminating scheduled customers from further consideration, there is the repeat of the clustering-scheduling process. To preserve geographical cohesiveness, one might consider different seed selection criteria for the next cluster (Desrosiers, 2018).

2.13.4 Comparative analysis of routing algorithm.

Table 5: Comparison of routing algorithms

	Savings	**Nearest neighbour**	**Sweep**
Shortest route	Yes	No	Yes
Fuel efficient	Yes	Yes	Yes
Time conscience	Yes	Yes	No
Traffic congestion	Not accounted for	Accounted for	Not accounted for
Road elevation	Accounted for	Accounted for	Accounted for

From the comparison above, the saving heuristic algorithm has been selected for this research.

2.14 Network topology and analysis

Topology analysis is helpful in distinguishing critical and vulnerable elements of a road network. The analysis demonstrates how well a road network joins locations between which individuals want to travel (Vasvari, 2015). A network in this context is characterized as a structure composed of elements or points, frequently alluded to as nodes (or vertices), connected by links (or lines, arcs or edges) that guarantees their interconnection or interaction. The road network represented as a set of links and a set of nodes (Huseyin, 2010). A link associates/connects two nodes and a node interfaces at least two links. A movement in a road network corresponds to a flow with a distinct origin and destination. Origins and destinations are represented by node, referred to as a centroid. Each centroid is associated with at least one node by a link. Links are portrayed by their length, travel time and maximum flow (Milchtaich, 2005). The topology of GIS is expressed by a set of rules managing relations between spatial entities. It is with respect to these rules that the topological coherence of a network is resolved. This is essential for any type of spatial analysis. Network consistency comprises of checking for intersection, overly and dangles (Polyzos, 2017). Lines can intersect or cut each other, but they cannot have segments in common. In the case of common segments, the network consistency procedure removes one of the segments by splitting this segment into two distinct segments. Intersection must occur only at the ends, i.e. at the nodes. When two lines are intersecting, the procedure divides the two lines into two distinct segments. A dangle is an endpoint of a line that is not connected to another line dangle. The network consistency procedure places the dangles exactly at the location of the reference geometry (Baghdadi *et al*., 2018).

2.15 Vehicle tracking technologies

2.15.1 Satellite based tracking

GPS technology is utilized in tracking and monitoring vehicles. The GPS tracking framework provides some insights into the whereabouts and course taken by the vehicle (Verma and Bhatia, 2013). This information can be observed from any remote area providing the exact location of a target vehicle. A lot of bad incidences occurs daily on the road; therefore, GPS provides security and monitoring in real time of the vehicles in transit. GPS is integrated with other emerging technologies to effective vehicle tracking.

2.15.2 GPRS based tracking

GPS tracking devices integrated with GPRS are mounted onto the vehicles. The GPS tracking device communicates with the satellite to get the location data and then this data is sent to the server using GPRS modules (Aydin *et al*., 2015). Socket programming protocol is used for providing the communication between vehicle tracking device and server. Once the information reaches the server, it can be retrieved from any remote location via the web (Fernandes, 2015). Different mapping libraries can be employed for enhanced and adequate visualisation.

2.15.3 GSM based tracking

GPS and GSM technologies are integrated into a vehicle tracking system that uses a mobile phone platform. GSM modem is utilized for transmitting and receiving data about the location of a vehicle of interest, between a remote server and the vehicle in transit (Verma and Bhatia, 2013). In order to get the position of the vehicle of interest, a request has to be sent to the mobile number of the GSM modem on board the vehicle, from a mobile. The GPS device onboard the vehicle will communicate with the satellite in space so as to triangulate the location of the GSM modem also on board. Eventually, the tracking system will then send a reply to the mobile that had previously sent a request. This reply is information of coordinates that indicate the position of the vehicle (Kamble, 2012).

2.16 Previously developed information systems to optimise waste collection

Idowu *et al.*, (2012) developed a web base GIS waste disposal management system for Nigeria. The system was developed to publish the spatial distribution of waste collection zones and allowed the public to view the time and day in which refuse will be collected in any location. The system enabled health workers update details of the work carried out in the field through a standard web browser and instantly uploaded the information into the management system. It displayed the schedule of staff, supervisors and the sites they are responsible to service. In its design, the system followed a 3tier architecture that comprised of a database, business logic, and a user interface. Smart phones tablets or laptops were used to access the pages and forms of the web application through a web browser. The development of this system was based upon the open source tools and techniques. PHP scripts controlled the movement of data between the user front-end and the application back-end. The system was developed using Dreamweaver, object-oriented PHP, JavaScript, XML, MySQL and Apache.

Mangukiya and Amit (2016) developed an online e-waste collection system aimed at collecting electronic waste material from residents via a web platform. The system provided residents with the power to dispose of their e-waste through making necessary communications via the web. The notion behind the development of this system was to make use of environmentally sound technologies to decrease electronic waste in households. In its design they employed the Spiral System development methodology that consolidated both prototyping and configuration in stages. Additionally, it followed a 3tier architecture that comprised of a database, business logic, and user interface. The coding of the system was done using HTML5, CSS, JavaScript and PHP for both the front-end and back-end.

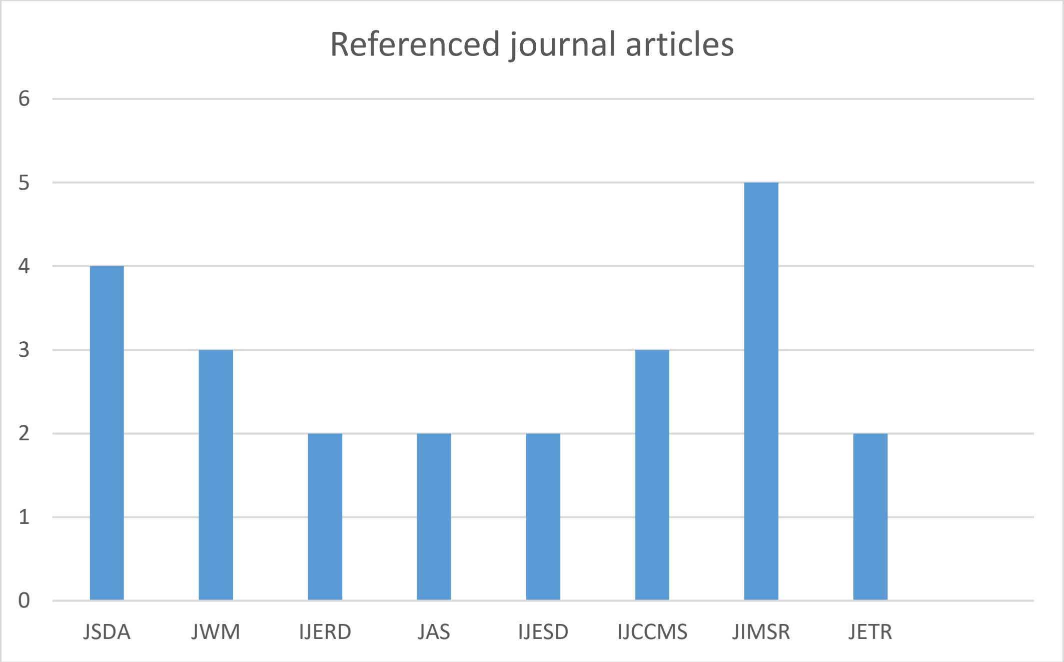


Figure 9: Referenced journal

key

JSDA-Journal of Sustainable Development in Africa

JWM-Journal of waste management

IJERD-International Journal of Engineering Research and Development

EJSS-European Journal of Social Sciences

JAS-Journal of American Sciences

IJESD-International Journal of Environmental Sciences and Development

IJCCMS-International Journal of Chaos Control Modelling and Simulation

JISR-Journal of Information Management Systems Research

JETR-Journal of Engineering and Technology Research

3 Methodology

This chapter elaborates the methods for carrying out the research and data acquisition techniques.

3.1 Software development framework

The Software Development Life Cycle selected is the Waterfall model as per the advantages portrayed in chapter 2. The stages involved includes the following:

3.2 Sampling frame

The study population comprises of all the worker of the city council in the Health Department. Probability sampling technique namely stratified sampling will be employed in constructing the sampling frame for the council workers in the Health Department.

3.3 Stratified sampling

A sample size of 10 council's employees in the Health Department will be used for the stratified sampling methodology. The Health Department is subdivided into two strata namely the administration stratum and the technical services stratum, therefore stratified sampling will ensure that these two distinctions are represented in the same proportion that they exist within the department. Sampling unit that constitute each stratum are then selected at random. The sample unit from each stratum are calculated using the proportional allocation approach.

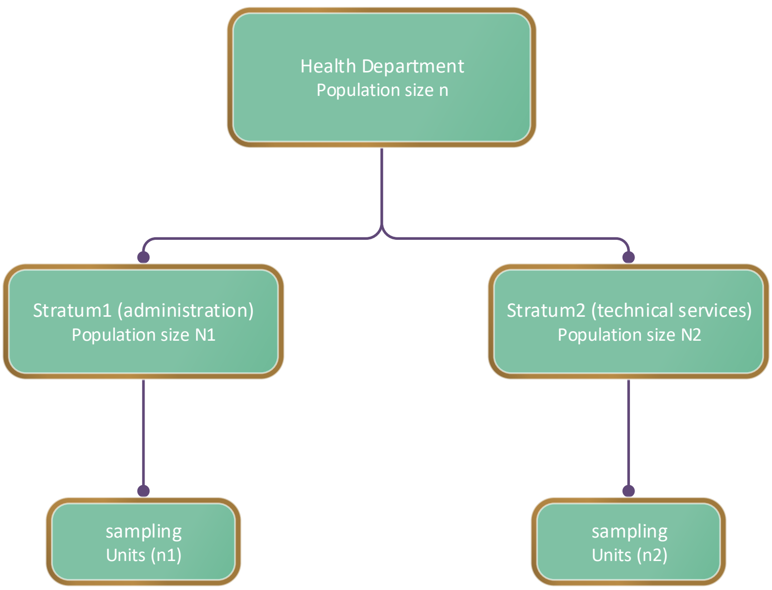


Figure 10: Sample unit allocation

3.4 Requirement gathering and analysis

It is a comprehensive description of the conduct of the software to be developed. It empowers system and business analysts to define both functional and non-functional requirements. Usually, functional requirements are defined by means of use cases which describe the users' interactions with the software (Bassil, 2012). These requirements include software properties, user characteristics, system capabilities, user interface prerequisites and database requirements. In this phase, all possible requirements of the system to be developed are established and documented. Both quantitative and qualitative data will be gathered since their combination improves the evaluation process by ensuring that the limitations of one type of data set are complemented by the strengths of another. In order to gather the system requirements, consultation with directors and stakeholders in the Department of Health at Gweru city council is to be done in order to identify the setbacks in the current system in use for solid waste collection. Desktop surveys, questionnaires, interviews, entity relationship and use case diagrams will be utilized to define both the functional and non-functional requirements of the solid waste collection information management system of Gweru city council.

Thematic analysis technique will be employed for analysing, interpreting and presentation of all the findings emerging from interviews and questionnaires. Thematic analysis provides rich and insightful understandings of complex phenomena and additionally provides a rich translation of the study. Content analysis enables a dense and broad description of the phenomenon and yields concepts or categories that explicitly depict the phenomenon. Microsoft excel spread sheets will be used in the analysis, interpretation and depiction of quantitative findings from the raw data. Data obtained from questionnaires and interviews will be encoded and all the relevant emerging themes extracted for further analysis before being presented using platforms that includes tables, bar graphs and pie charts.

3.5 System design

The study will utilize workflow diagrams, use case diagrams, dataflow diagrams and class diagrams to define the procedures for data entry, algorithm design, software architecture design, database conceptual schema and logical design, graphical user interface design, and data structure definition. The consequences of the system prerequisites and the user need assessment are utilized to design all the essential components of the three-tier architecture. The system will be developed in multiple small units called sub-systems, that will be integrated after being tested. These subsystems are the backend and front-end components of the system architecture. Each unit will be developed and tested to evaluate if it is working correctly. The system will be programmed using JavaScript, PHP and HTML programming languages additionally with CSS, Bootstrap and Leaflet mapping library. The system will be developed on a windows operating system environment manipulating JavaScript, PHP, HTML and CSS programming languages. Sublime text editor, PostgreSQL + PostGIS will be utilized together with QuantumGIS and Leaflet mapping library.

3.6 System prototyping

Prototyping involves structuring a framework dependent on user requirements, and testing the feasibility of the system. All the units developed will be integrated into a functional system. After the integration, the whole system will be tested for any faults and failures, and corrections made accordingly so that all the initial system objectives are met. All the functionality of pages, forms or other scripts is tested. The testing will be done through manipulating various datasets in the system and executing all functionalities of the system with regards to the system`s objectives and user needs functionalities. Compatibility with various web browsers will be tested so as to ensure the system is optimized to run efficiently in multiple browsers.

4 Results and analysis

This chapter depict the results and analysis derived from the findings of the research in relation to the specific objectives.

4.1 Findings

The following information was obtained from the different types of surveys employed. Each type of survey had its own results which all were in line with the objectives of this research.

4.2 Desktop survey

Desktop survey executed reviewed that the municipalities are made up of various departments that includes finance, survey, GIS, waste management, town planning and IT. All these departments have their specific function that when combined they fulfil the mandate of the municipalities. Municipalities are responsible for the collection and disposal of solid waste from the generation zones to adequate disposal facilities. Of interest is the waste management department that is responsible for the activities of planning, collection and disposal of solid waste. It is made up of the waste collection managers/directors, refuse supervisors, drivers and refuse collectors who are housed at a central depot. In addition, this depot also houses waste collection vehicles, and equipment (Pires *et al*., 2011). Vehicles and human resources are dispatched from this depot to scheduled zones for waste collesction and return to the same deport at the end of every shift. Solid waste collected is disposed of at disposal facilities before returning to the deport. Therefore, waste collection vehicles leave and return the deport empty. Planning for the waste collection and disposal activities entails the acquisition, manipulation, dissemination and visualisation of all the relevant information about waste generation locations, rates and network topologies (Arribas *et al.*, 2010).

Waste management officers/Directors

Waste management officers are responsible for organising and managing waste collection, disposal and recycling facilities. They oversee waste management schemes, assist with the development, promotion and implementation of new waste disposal schemes. Furthermore, they formulate and control budgets for waste collection and disposal. They are also responsible for monitoring the quality and performance of waste collection services. They implement and monitor company procedures for the collection, transport and disposal of waste, in compliance with all regulations and legal requirements. Liaise with managers of other departments ensuring effective service and communication, i.e. sales, planning, purchasing, trading, distribution and technical.

Refuse Supervisor

Refuse supervisors are responsible for the technical and administrative work in planning, organizing and directing the operations solid waste collection and disposal. They supervise daily activities for the collection of solid waste, plans, prioritizes, schedules and reviews ongoing work. They establish and outline the routes to be followed amid solid waste collection so as to ensure efficient and fast solid waste collection in the designated area. In addition, they coordinate the use of available equipment, material and manpower to obtain maximum effectiveness and efficiency. They also inspect equipment for proper working condition, coordinates equipment maintenance and repairs. Receives, investigates and responds to internal and external concerns, requests and inquiries. In this regard, they deal with enquiries and complaints from members of the public both in person and by phone or email and consult with residents, community groups and councillors about waste management issues, identify their requirements and deducing appropriate solutions(Vu *et al.*, 2018).

Drivers

The drivers are responsible for traversing with waste collection trucks following predetermined routes so as to collect solid waste from the specific areas. They are also responsible for disposing of waste at designated waste disposal facilities. The drivers are responsible for checking the operating and safety conditions of vehicles, performing minor servicing, and reporting needed repairs or servicing. In addition, they are responsible for performing pre-trip/ post-trip vehicle inspections and complete daily work sheet for equipment operated.

Refuse collectors

Refuse collectors manually picks up trash along designated routes and deposit it into waste collection trucks. They ride on the back of waste collection trucks and should be in good physical condition with the ability to work in various changing weather conditions. Refuse collectors help in directing the driver when dumping solid waste at disposal facilities. Furthermore, they work hand in hand with the drivers to check the operating and safety conditions of vehicles, perform minor servicing, and report needed repairs or servicing.

Planning (scheduling and routing)

Information about the population density and spatial extent of zones, location with street-level details of households and the average amount of waste generated per zone is used in generating schedule and assignment of human resources as well as the waste collection vehicles. In addition, the number and type of collection vehicles, the personnel available, size and capacity of collection vehicles is also essential in the generation of shifts and schedules. The selection of optimal routes that results in the most efficient use of labour and equipment, is done utilizing computer application analysis that account for all the many design variables that include frequency of collection, haulage distance, rate of waste generation, location of households and solid waste disposal facilities. Route optimization balances travel path times, service and maximizes productivity of vehicles. Optimized routes reduce the possibility of the collection vehicle to travel some time without pickup. Above all they decrease fuel consumption, mileage driven and possible maintenance costs (Anagnostopoulos *et al.*, 2015).

Collection

Solid waste collection usually occurs at least once per week and homesteads are divided into zones for waste collection. A driver and two or more refuse collectors are assigned a single collection vehicle and dispatched to a particular zone to collect solid waste. Some of these vehicles have a compaction mechanism that reduces the volume of solid waste in the truck to less than half of its loose volume. They are also equipped with appropriate compartments to facilitate efficient storing of sorted wastes while in transit. Vehicles used in the transportation of solid waste include compactor trucks, skip lifter trucks, dumper trucks, JCB front end loaders, tractors etc. (Manus and Coad, 2010)

Disposal

Land disposal is the most common and cheapest disposal strategy for municipal solid waste. Solid waste can be safely deposited in a sanitary landfill. These are disposal sites that are carefully sited, designed, constructed, and operated to protect the environment and public health. One of the most important factors relating to landfilling is that the buried waste never comes in contact with surface water or groundwater. Engineering design requirements include a minimum distance between the bottom of the landfill and the seasonally high groundwater table.

4.3 Interviews

Interviews were conducted with the Gweru city council Health Department employees. The researcher managed to interview only 30 employees namely the Cleansing Superintendent and 2 compactor truck drivers. The Department of Health provide and deliver health services to the city of Gweru through disease prevention and implementing curative measures. They provide effective public health systems and create conducive environments for the city through the removal and proper disposal of refuse/waste. The health department has 400 employees who take part in the waste management and pest control.

Cleansing Superintendent

The Cleansing Superintendent is responsible for the management of solid waste. He/she is responsible for overseeing the removal and collection, transportation and disposal of solid waste as well as street cleaning, public toilet cleaning and litter control. The Cleansing Superintendent receives complaints from the residents and assigns his subordinates to resolve them after which, the subordinates give feedback within 24hrs of the progress made on resolving issues in question. At the end of the month, the Cleansing Superintendent generates peer review report that is submitted to the Cleansing Officer. These reports show the service level benchmark, portraying how many properties have been serviced and the cumulative volumes of waste collected. Furthermore, they contain information about all the reported issues by residents, the number of resolved issues and challenges that caused some of the issues not to be resolved in there are any.

Waste collection fleet

According to the Cleansing Superintendent, the department should have 7 compactor trucks to efficiently cater for the collection of solid waste within their jurisdiction. However, at the time of this research, the department had only 2 compactor trucks, 1 skip truck and 1 tractor to service the whole of Gweru. The Cleansing Superintendent additionally create schedules and shifts for both the human resource and the equipment. Assignment of compactor trucks to specific locations for waste collection activities is done taking into account their carrying capacity and fuel consumption. The compactor trucks had a capacity of 10-15 cubic meters with a compaction ratio of 4:1 meaning to say 4 collected bins are compressed to a volume of a single bin. Furthermore, the number of households, nature of roads and the general nature of terrain influences the compactor truck to be dispatched to that area.

Routing

Maps inform of hard copies obtained from the GIS department are used to navigate so as to collect solid waste from residential areas. The Cleansing Superintendent with the help of the GIS personnel creates routes to be followed using ArcGIS software. Routes are created using a rooftop principle in which they identify all rooftops in a residential and they initialize collection to start at the last roof to be collected for that daily schedule. The first roof within the daily schedule is the one that is closest to the road with which the compactor truck used to traverse from the depot and the last roof is the furthest from that same road. The routes are generated systematically from the furthest roof up to the closest roof. This is done to minimize the distance travelled with a great quantity of load so as to reduce fuel consumptions. After the routes are generated, the Cleansing Superintendent takes the driver on a tour showing him/her the routes to use as per the rooftop map produced.

Driver

The driver is first shown all the routes to be followed after which he/she has to rely on his/her own memory to traverse those routes on the next schedule. The driver is assigned a team of 4 assistants who will manually empty residents` bins into the compactor truck. After the end of the day, the driver has to submit a report to the Cleansing Superintendent, reporting on the progress made and challenges encountered during the day. While in transit doing the waste collection, the driver has to take note of new developments such as recently completed houses so as to add them on the existing route for waste collection. In the report submitted to the Cleansing Superintendent, the driver has to include the volume of waste collected in a particular ward and the mileage covered during the day.

4.4 Questionnaires

Questionnaires were distributed to residents in the suburbs of Senga and Nehosho. The researcher distributed 25 questionnaires and only 20 responses were received from the residents which constituted eighty five percent of the sample population. The residents maintained that the city council provides them with bins that are either plastic of galvanised steel upon the payment of a fixed fee. All the residents concurred that the city council does not communicate as to why they did not collect waste. Furthermore, their responses revealed that there was some inconsistency in the solid waste collection cycles in the Senga and Nehosho suburbs. In some parts of Senga solid waste was being collected once a week whilst in some other parts it was being collected once a month and in other parts it was not being collected at all. Additionally, they also expressed the need for communication as at times they may be having sustainable solutions with regards to waste collection which they can contribute to improve collection.

The question as to how often solid waste was collected produced varying responses which was an explicitly revealed some inconsistency in the solid waste collection cycles as shown in the diagram below.

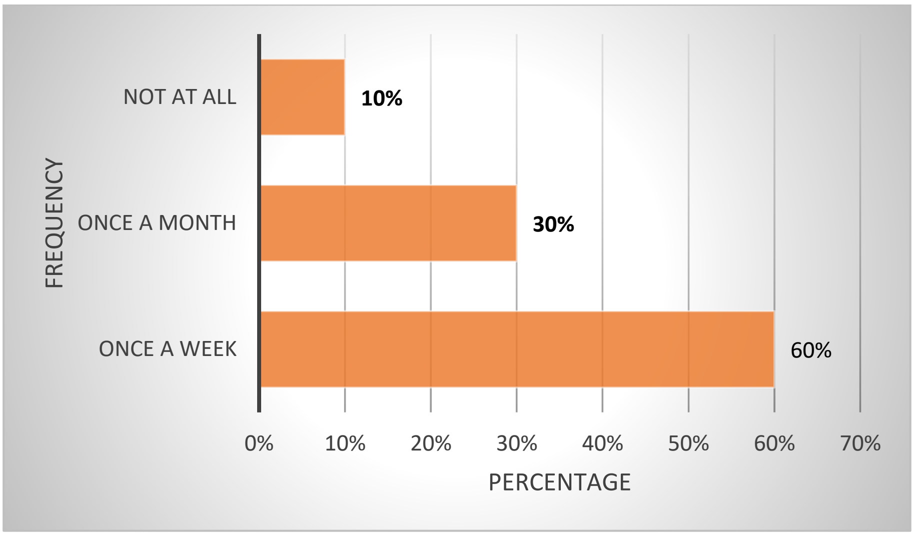


Figure 11: Frequency of solid waste collection

The council provided bins for the tempoary storage pf waste at homesteads upon the payment of a fixed fee. How ever some residents used plastic bins, some used galvanized steel bins and some resorted to other methods like composting.

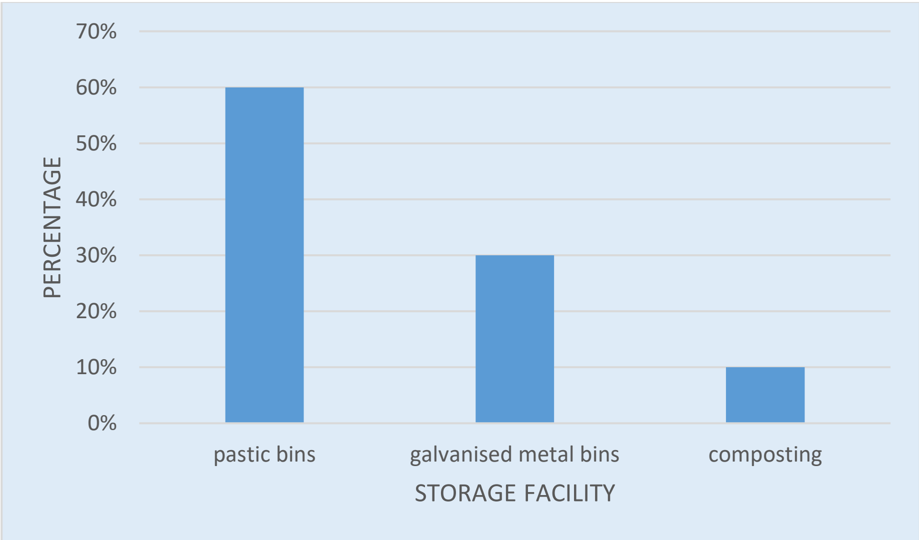


Figure 12: Ways of waste storage at the source of production

In the event that waste was not collected on time, the residents employed different techniques of handling their waste as shown in the diagram below.

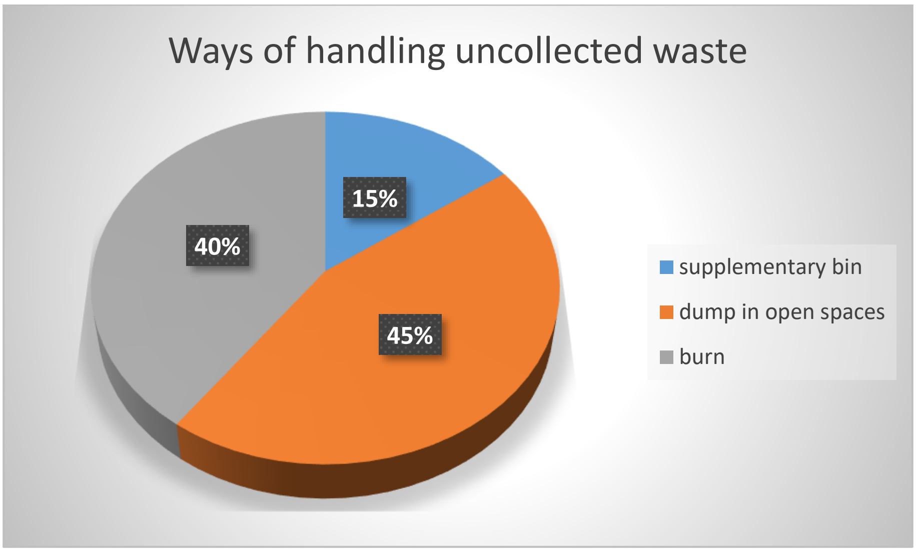


Figure 13: Alternative ways of disposing solid waste if it is not collected on time

In an effort to convey queries with regards to the uncollected waste, the residents employed the techniques shown in the diagram below.

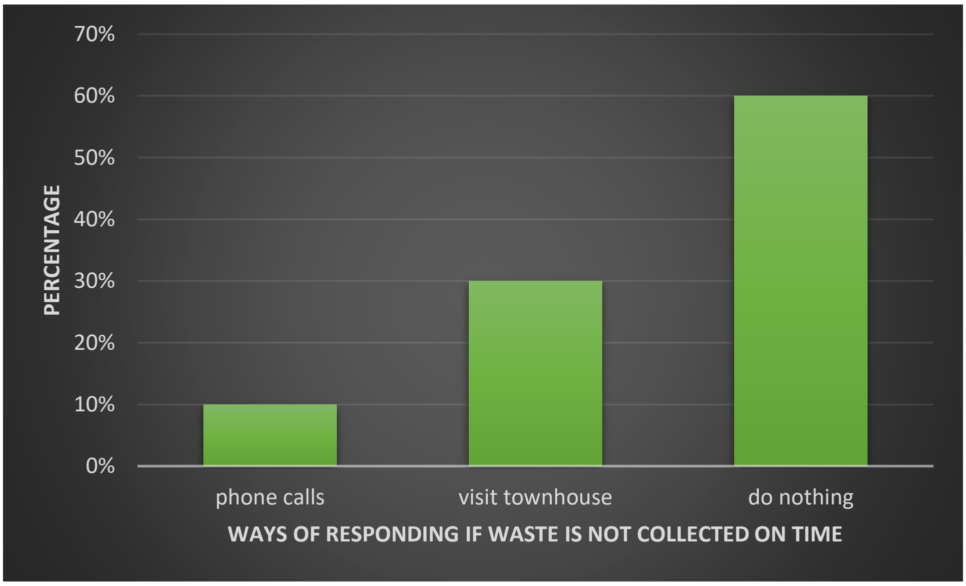


Figure 14: Ways of conveying queries if solid waste is not collected on time

All the residents concurred that the city council does not communicate as to why they did not collect waste on time but however, they revealed that they would like to be notified of such issues through various mediums shown below

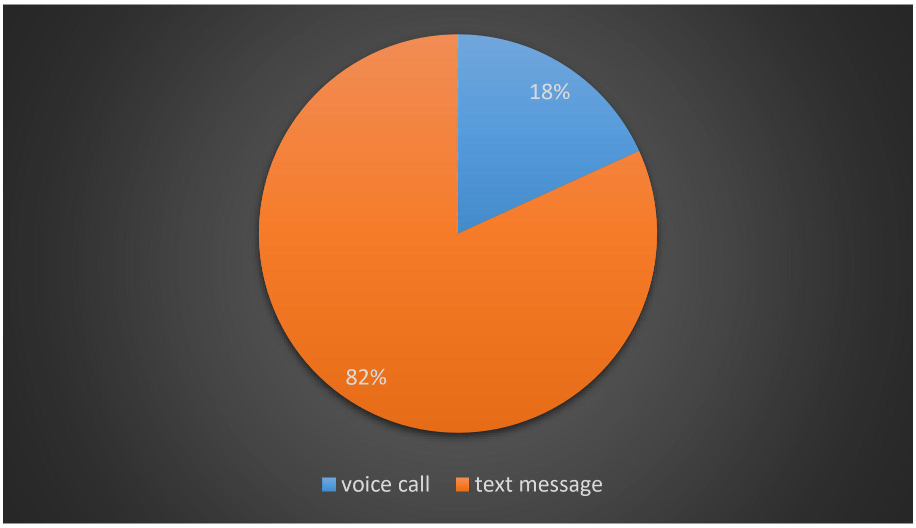


Figure 15: Mediums for receiving notifications about waste collections cycle changes

The majority of the residents concurred that they would love to conveys their queries to the city council through various platforms shown below.

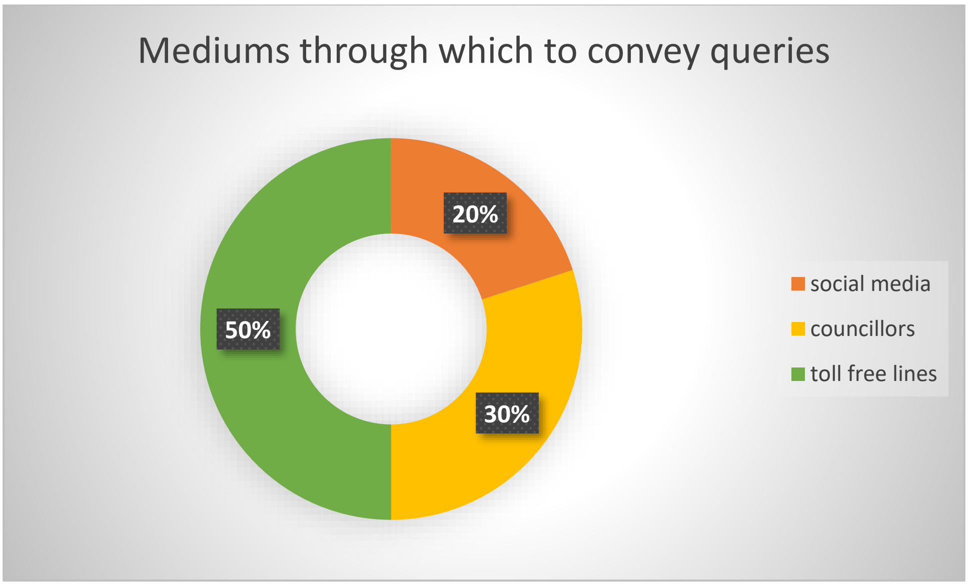


Figure 16: Mediums through which to convey queries

4.5 System requirements

From the user requirements carried out in this study, the researcher was able to identify the gaps and user needs that formed the basis for the identified users and system requirements.

4.5.1 Verbal description

The proposed solid waste collection information management system should allow the administration to generate shifts and schedules for both the personnel and the collection vehicles for efficient waste collection. Furthermore, the system will enable the generation of optimum routes for both waste collection and disposal from waste generation zones/wards to waste disposal facilities respectively. In addition, the system will also allow the monitoring of solid waste collection activities in near real time through a dashboard showing the current location of a collection vehicle amid waste collection. The dashboard will be showing locations as received from a GPS device mounted on the collection vehicle. The system also addresses issues to do with communication between the residents and the solid waste collection administration. The systems aim at improving the communication between the residents and the administration in such a way that promotes resident`s participation in waste collection systems. It, therefore, entails that the system will allow residents to convey their queries, grievances and feedback directly to the administration responsible for solid waste collection. Likewise, the administration will be empowered with the liberty of conveying public notices in as far as the collection and disposal of solid waste is concerned. Waste collection timetables and sudden changes to normal solid waste collection cycles can be uploaded and viewed from the website without the necessity to incur travelling costs in an effort to get that information. Finally, the system will allow the generation of reports based on the volumes of waste collected per ward. This, as a matter of fact, will enable further analysis based on location which plays a pivotal role in assigning human resources and dispatching solid waste collection vehicles to specific wards taking into account their spatial extent of and their waste generation capabilities derived from the previously collected solid waste volumes.

4.5.2 Functional requirements

A functional requirement is an element of a system and its segments. An element is portrayed as a set of inputs, processes and outputs of the system. Functional requirement basically determines things the system ought to do so as to solve the research problem. The functional requirements of the solid waste collection information management system entail that it should generate shifts and schedules for both the personnel and the vehicles. It should enable a continuous monitoring of the progress of solid waste collection activities as well as to generate optimum routes to be used for collection and disposal of solid waste. Furthermore, the system should be able to generate reports and facilitate a communication platform between the administration and the residents. The administration should be able to convey refuse collection timetables and other relevant notices to the residents as well as getting hold of the resident`s feedback.

4.5.3 Non-functional requirements

Non-functional requirements basically determine how the system should behave. They are the characteristics of the system that the organisation is extraordinarily worried about. These characteristics impact their level of satisfaction with the system and include the following:

Performance

This has to do with how the system handles processes under execution and considers processing speeds. Hardware and software prerequisites greatly influence the performance of the system and accordingly programming languages, system architectures and mapping libraries were chosen in such a way that does not yield constraint to the available hardware and software so as to minimize the possibility of the system to perform poorly.

Security

It guarantees that the confidentiality, integrity and availability of information are not disregarded. Security involves issues to do with ensuring that data is not lost even when the system malfunctions or is bugged, all the data has to be recovered efficiently. It therefore ensures that only the authenticated users have access to view, edit, download and delete both reports and data within the system. All users were entitled to different rights that authenticated them to have access or restrictions to some information within the system with regards to their positions and responsibilities in the department.

User support

Providing a section that enables users to learn how to use the system. It will show the users the directory of specific tools within the system. This section should also give the users notifications of current events of processes being executed within the system, their progress and a notification upon completion.

4.6 Database design

4.6.1 Conceptual model

It is a descriptive model of a system based on qualitative assumptions about its elements, their interrelationships, and system boundaries. It is a way of representing a particular concept or set of concepts, that enhances the understanding or simulation of the subject of that model. Conceptual models show the relationships between the system users and the flow of data or processes. The users of the system are the supervisor, the director, the driver and the residents and the information flows are shown below:

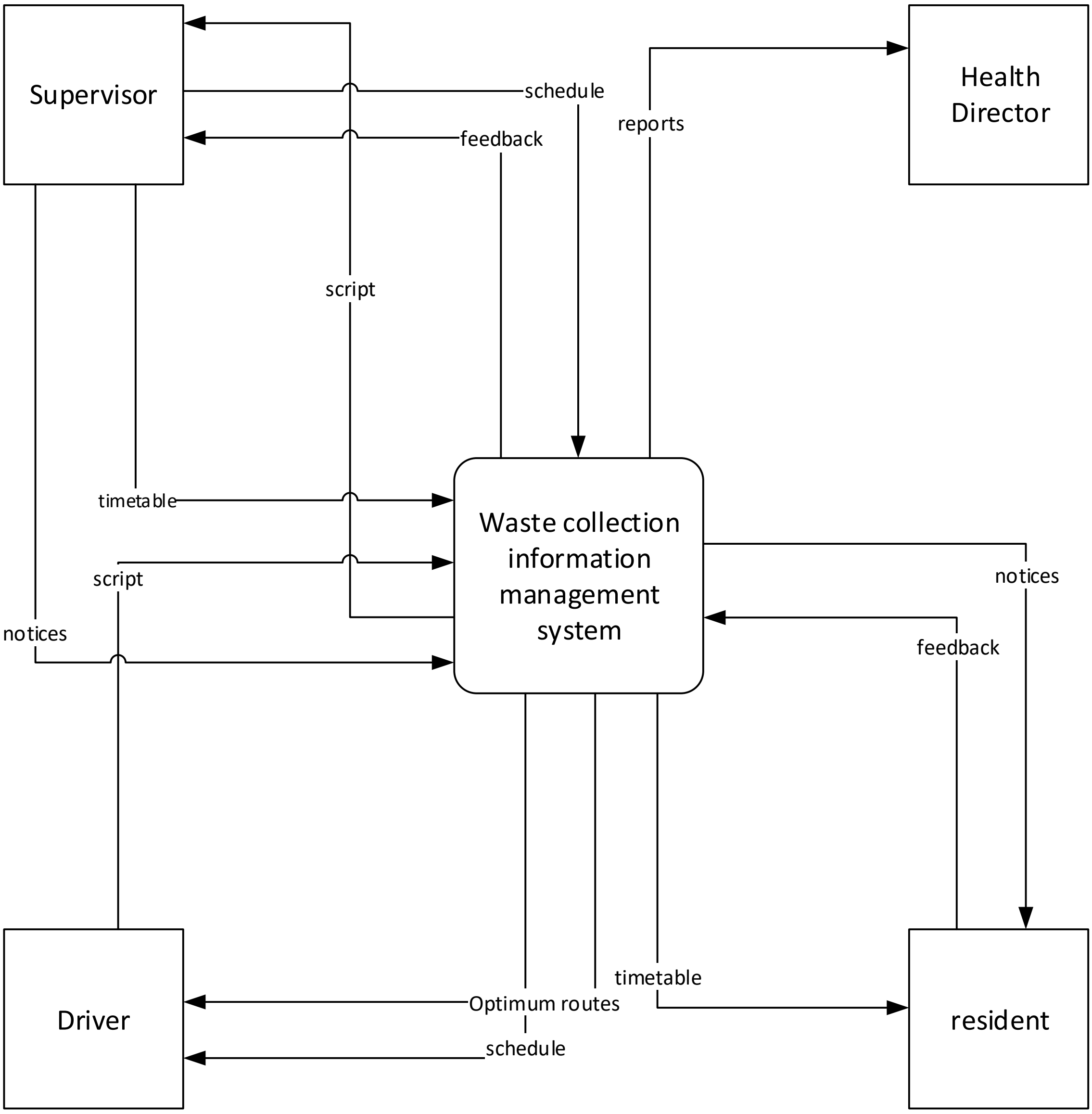


Figure 17: Conceptual dataflow model

4.6.2 Logical model

A logical data model demonstrates the data in as much detail as possible, without respect to how they will be physically executed in the database. Features of a logical data model include all entities and relationships among them. All attributes for each entity are specified. The primary keys and foreign keys for each entity are specified identifying the relationship between them.

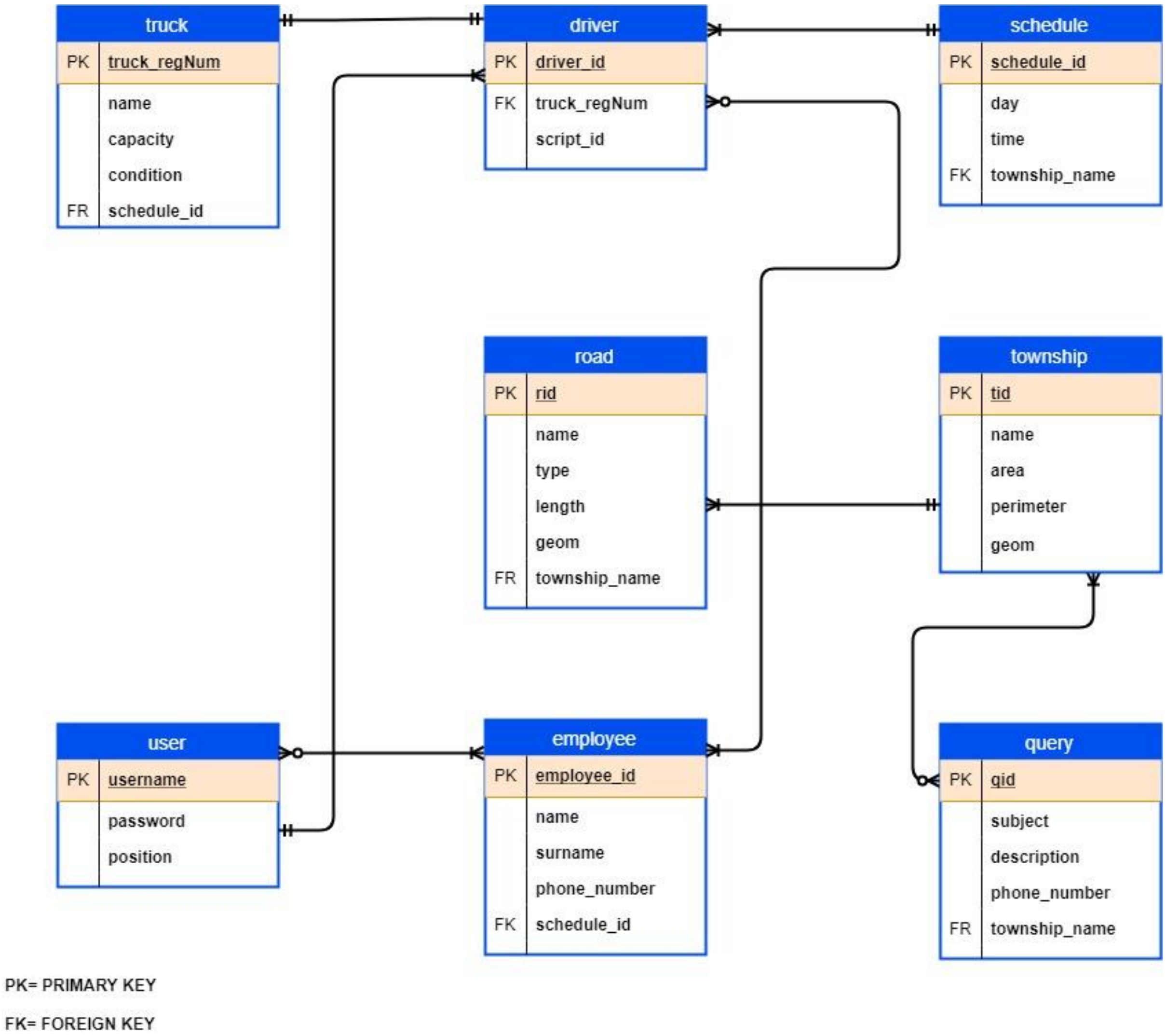


Figure 18: ER diagram

4.6.3 Database tables

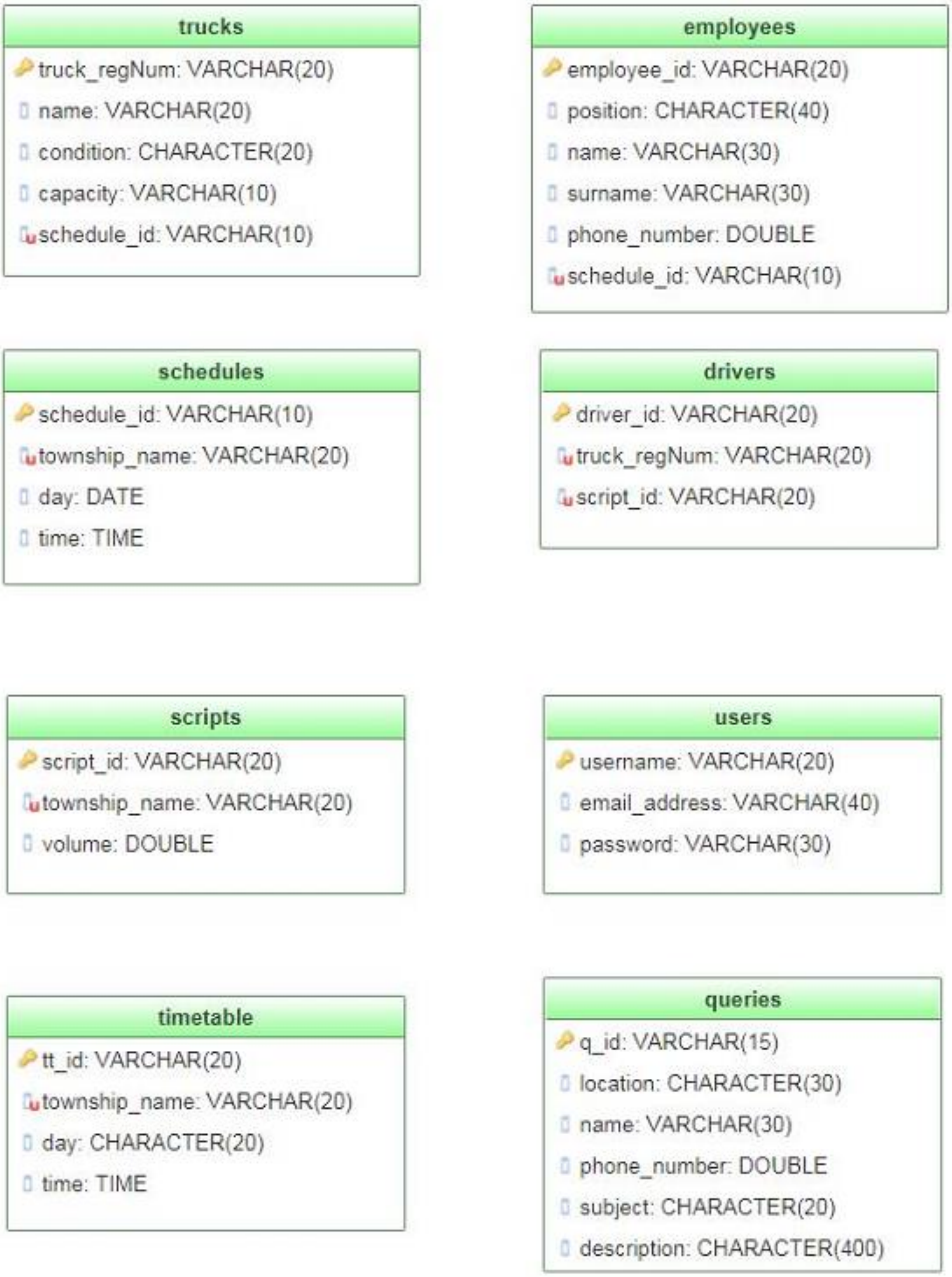


Figure 19: Skeleton tables

4.7 System configuration

The system architecture is presented in three main tiers namely the data tier, logic tier and the presentation tier. The data tier hosts a database where all the system data is stored and retrieved upon a directive by the users. The logic tier provides a platform for that enables the users in the presentation tier to access data that is located in the data tier. the presentation tier presents the data to the users for visualisation. It also facilitates data entry into the system as well as enabling the users to interact with data. The system architecture of the system is portrayed by the figure below:

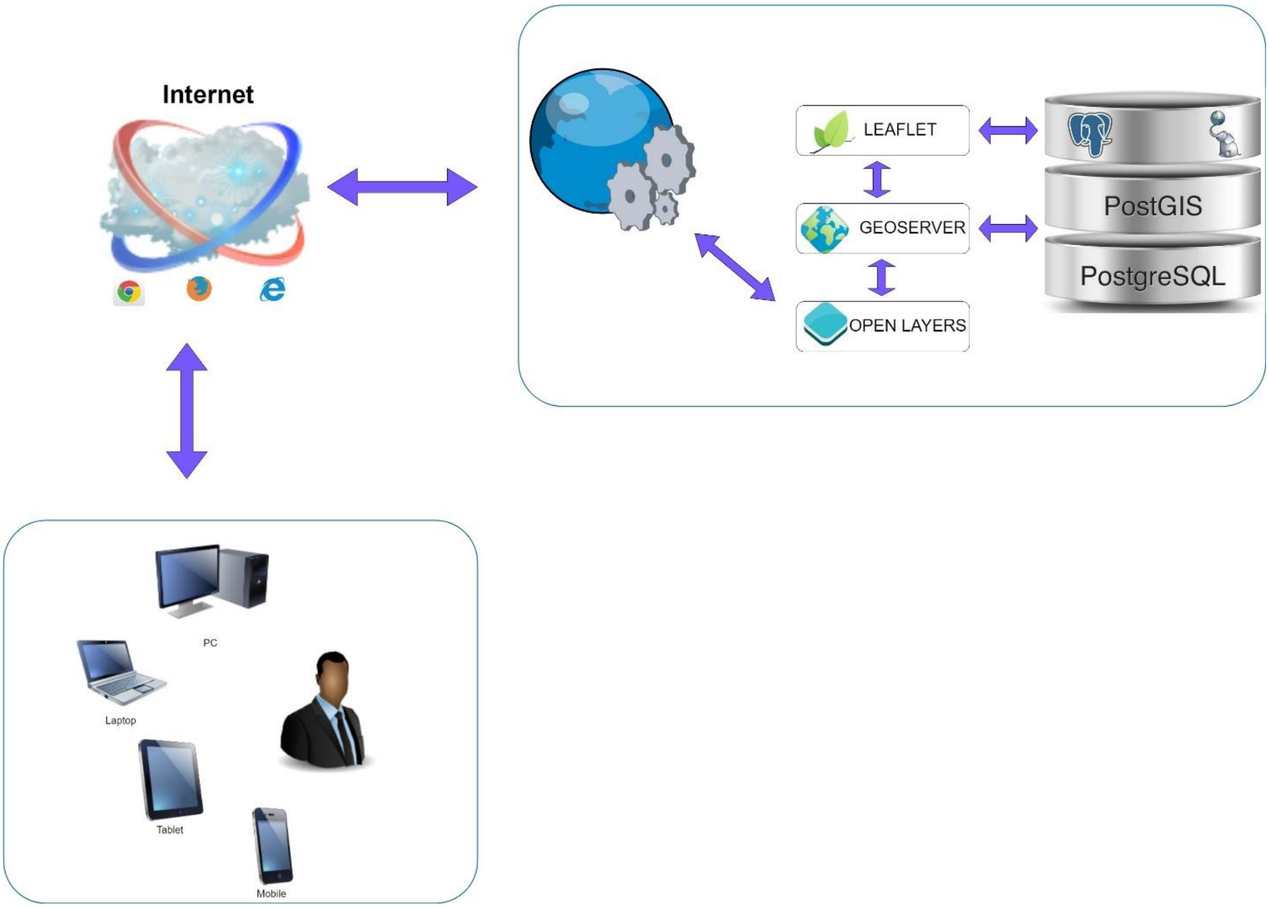


Figure 20: System architecture

4.8 Application prototype

The notice page is the first page seen after accessing the system. From this page residents can view the waste collection time timetable as well as other notices posted by the waste collection administration from time to time.

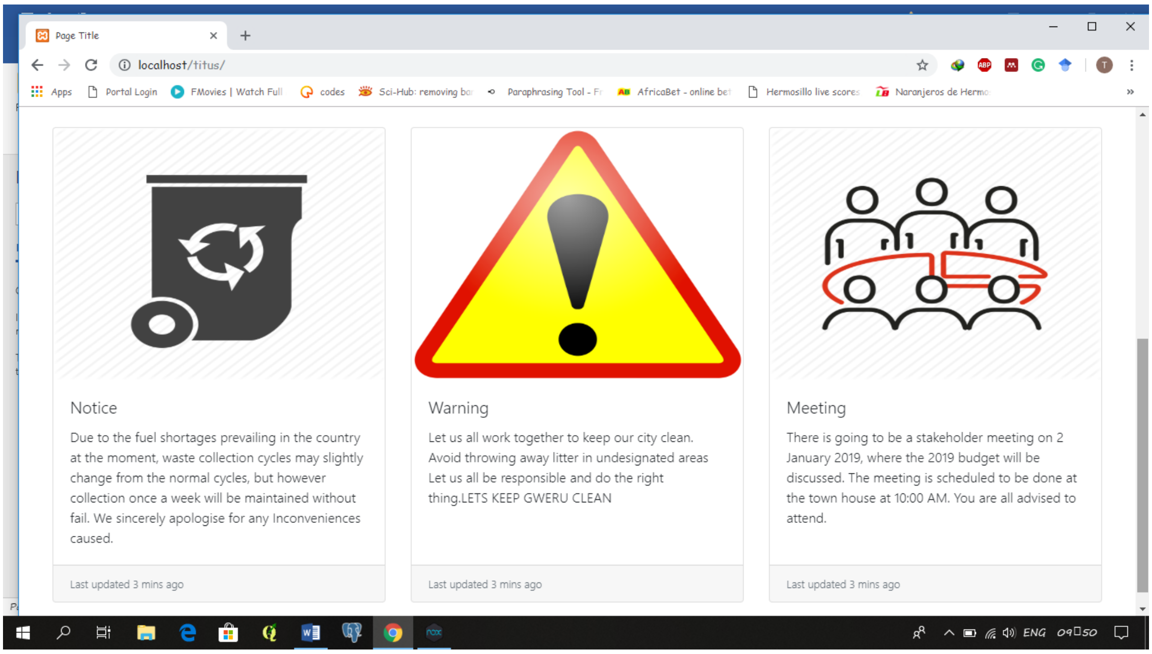


Figure 21: Residents` notice page

From the notice page the residents can view the waste collection timetable.

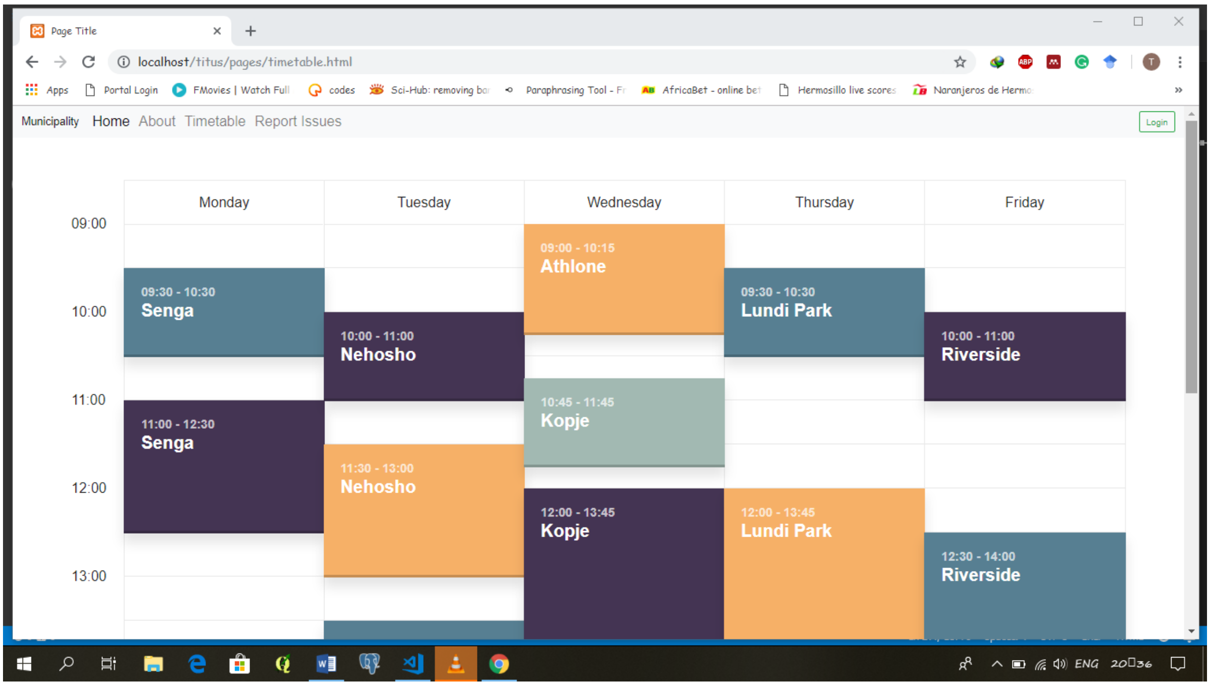


Figure 22: Solid waste collection timetable

The residents can report their issues to the solid waste collection supervisor through the form shown below:

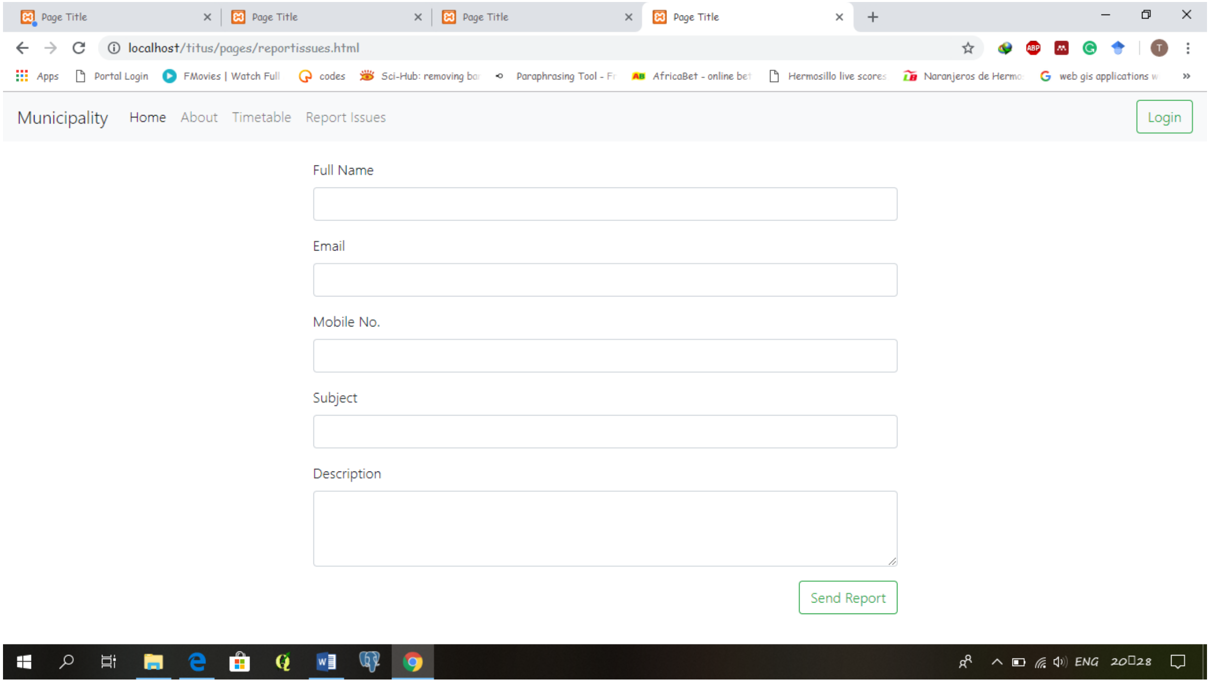


Figure 23: Residents` Issues form

In order gain access to other administration functionalities of the system, users are required to login using their username and password provided to them by the administrator.

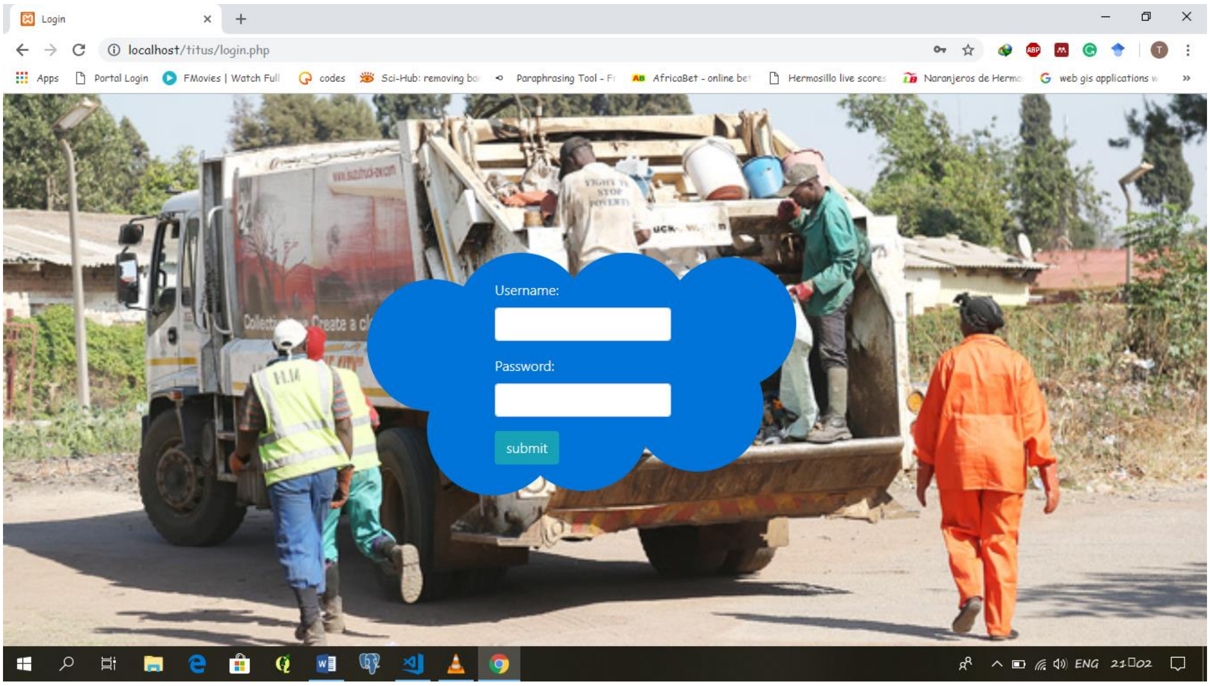


Figure 24: Login form

The supervisor can create a new schedule and assign a truck to a driver as well as the location from which solid waste is to be collected.

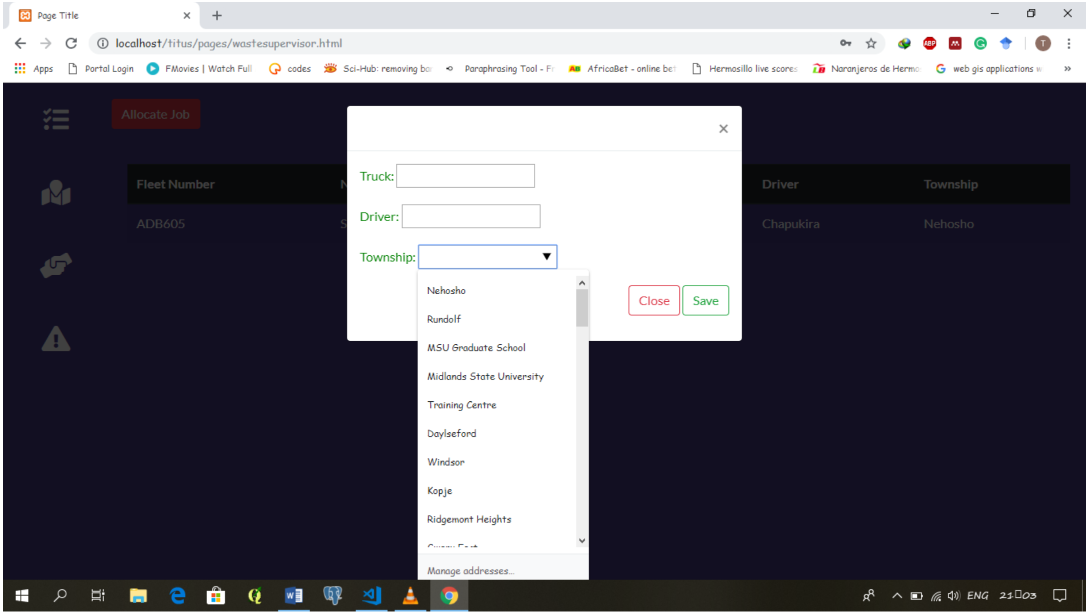


Figure 25: Creating a new schedule

Once a schedule has been created and assigned to a driver, the system automatically generates an optimum route and give an estimate time of travel based on the current traffic flows within the road network.

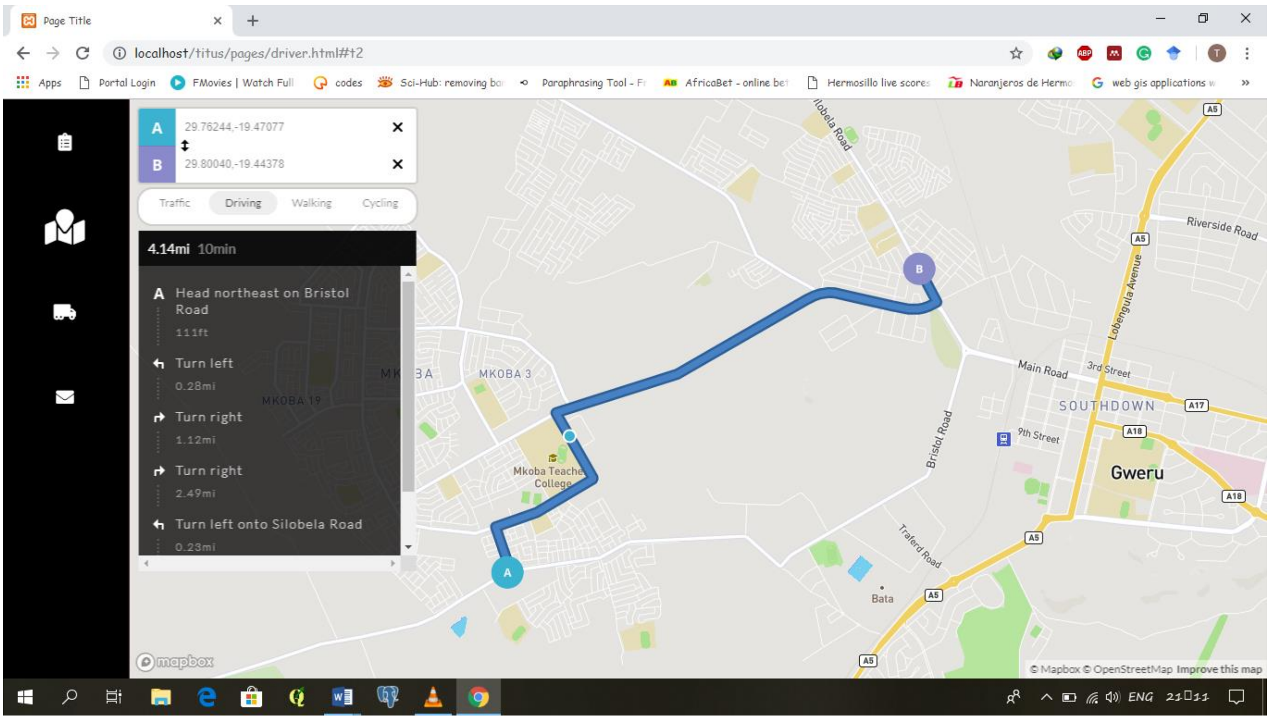


Figure 26: Waste collection route

Once collection of waste is completed in a particular area, the driver confirms the completion through a collection script form that is created automatically by the system when a schedule has been created.

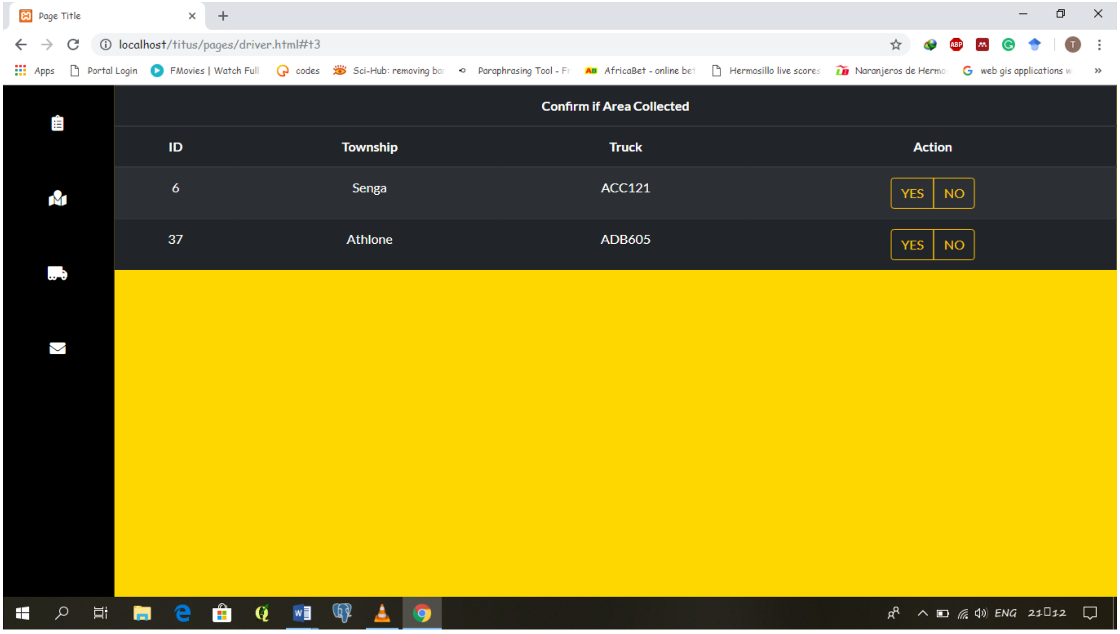


Figure 27: Waste collection Script

The supervisor can also monitor and view the current location of the waste collection fleet in transit, in near real time using the system dashboard shown. The dashboard will be reading the last location of the refuse truck when the driver completed a collection script. When filling the script, the driver logins and the location from which the login is made is recorded by the system and the truck is displayed on the dashboard map as shown

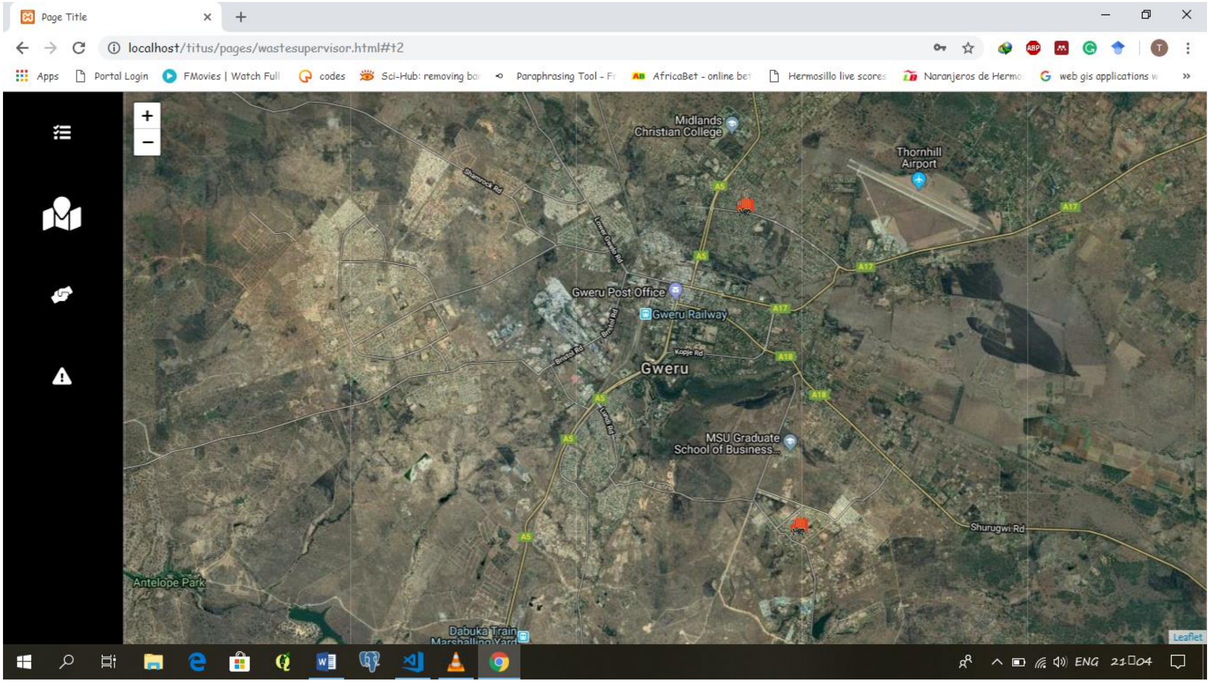


Figure 28: Progress monitoring dashboard

The system can perform quires to show the volume of waste collected, fuel consumptions of the trucks as well as solved and unsolved reported issues by the residents.

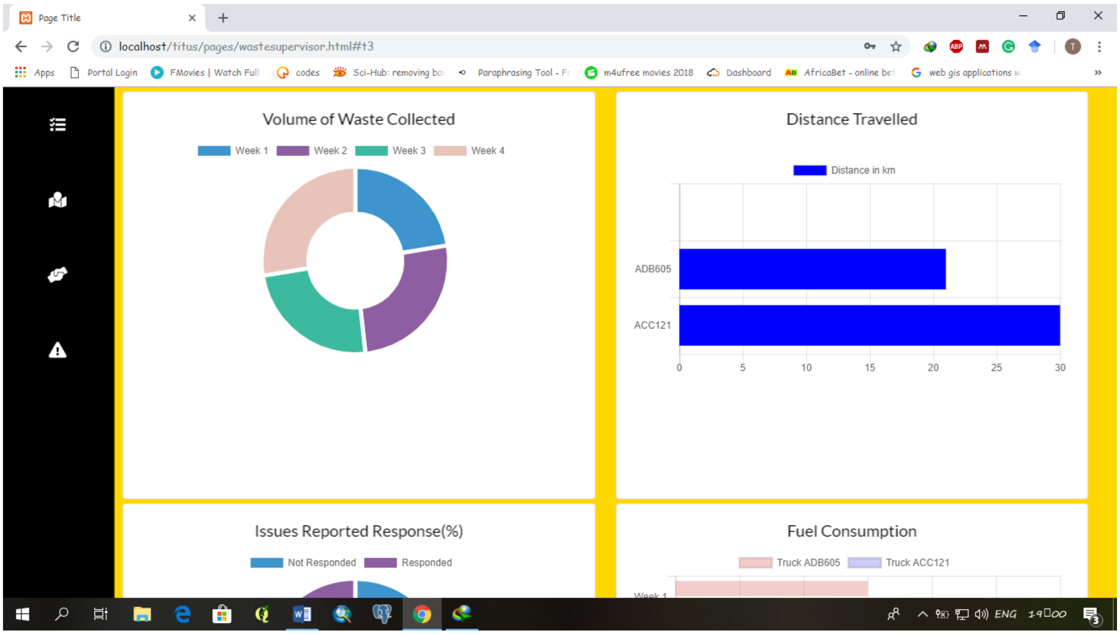


Figure 29: Generated queries

5 Conclusion and recommendations

This chapter gives the conclusions and recommendations with the regards to the developed solid waste collection information management system.

5.1 Conclusions

Objective 1: To analyse the existing status of solid waste collection activities

The researcher managed to gather sufficient information pertaining to waste collection activities. This information revealed the essential elements of a waste collection system that are influential in the successful execution of such activities. This information was obtained through observations, desktop surveys and interviews with the Gweru city council`s Health Department administration. However, the researcher encountered challenges with regard to interviewing the majority of the council`s employees in the Health Department as they were committed to other tasks that could not be paused at the expense of this research. By the time of this research, the city of Gweru particularly in Mkoba there was an outbreak of typhoid and the Health Department was trying to contain the situation though driving away all the vendors from the streets. As such the supervisors were not accessible at all which prompted, them to be interviewed via the telephone during the night as per their suggestion.

Objective 2: To gather the information needs for solid waste collection management.

Information needs for solid waste collection management were gathered though desktop surveys and interviews. The results of the desktop survey played a vital role in the drafting of an adequate interview guide. These results provided some great insights into the general management of the solid waste collection. However, the desktop survey was rich in content that was not locally or globally oriented i.e. information particularly of Zimbabwe or surrounding neighbouring countries like Zambia, Mozambique Malawi etc. some of the information obtained from the desktop survey was incomplete and some did not entirely apply to countries with crippling economies like Zimbabwe`s.

Objective 3: To design a solid waste collection database.

The database was designed using draw.io an online open source drawing tool and implemented using PostgreSQL and its extension PostGIS. Internet connection challenges were faced during the design since the only open source tools were found online, whenever there was poor internet connection such tools were not accessible thereby dragging the design process behind.

Objective 4: To design an application for optimizing solid waste collection management.

The optimization application was designed using FOSS frameworks Leaflet being one of them. The Leaflet mapping library has a restriction of data volume it renders hence the need to use more commercial mapping libraries to overcome such a challenge. There is no specific numerical magnitude of the limit of data volume rendered by leaflet, however, performance, processing speed and internet connection speed and the capacity of the server to handle incoming request will be greatly affected when more data layers are rendered or when just one data layer is rendered but with a lot of points and polygons.

Objective 5: To develop and test a web-based prototype information system for managing solid waste collection optimally.

The system was developed using the waterfall instead of the spiral model which was the best model to use because of its ability to continuously develop prototypes till the users are satisfied. The spiral model was, however, side-lined because it involved incurring a lot of expenses through the development of multiple iterative prototypes as well as being time-consuming. As a result, an alternative was chosen which was the waterfall model. Furthermore, the system development utilized JavaScript programming language on the front end and it is associated with JavaScript mapping libraries that have dependencies that are referenced from the internet. If ever there was a poor internet connection some of these libraries' functionalities were limited. As a result, poor internet connections slowed down the overall progress of the system prototyping particularly the testing phrase.

5.2 Recommendations

The system should be integrated with a GSM module that will facilitate the tracking of the waste collection vehicle in real time as well as notifying the residents of waste collection in their areas a few minutes before collection via an SMS platform. In developing countries particularly in Zimbabwe where internet tariffs are a bit expensive, it might be difficult for the majority of the residents to access the internet to check the solid waste collection timetable and any changes to the usual collection cycles that are posted on the solid waste collection information management system dashboard by the administrator. Nevertheless, the web platform for posting their feedbacks is cheaper than travelling to the municipal offices or using the voice call/SMS platform.

6 References

Achankeng (2003) 'Globalization , Urbanization and Municipal Solid Waste Management in Africa Eric Achankeng , University of Adelaide', pp. 1–22.

ADB (2017) *Integrated Waste Management for Local Governments*.

Adnan, M., Singleton, A. and Longley, P. (2010) 'Developing efficient web-based GIS applications', *UCL Working Papers Series*, 44(153), pp. 0–15.

Ahmed, S. (2009) 'Methods in Sample Surveys'.

Anagnostopoulos, T. (2015) 'Assessing dynamic models for high priority waste collection in smart cities', *Journal of Systems and Software*, 110, pp. 178–192. doi: 10.1016/j.jss.2015.08.049.

Appleton, J. V (2008) 'Analysing Interview Data', *Journal of Advanced Nursing*, 22(13), pp. 993–997. doi: 10.1046/j.1365-2648.1995.22050993.x.

Aquino, C. and Gandee, T. (2016) 'Front-End Web Development', p. 478.

Araque G, J. R. (1994) 'A branch-and-cut algorithm for vehicle routing problems', *Annals of Operations Research*, 50(1), pp. 37–59. doi: 10.1007/BF02085634.

Arebey, M. (2009) 'Solid Waste Monitoring System Integration based on RFID , GPS and Camera', pp. 1–5.

Arribas, C. A. (2010) 'Waste Management & Research information systems'. doi: 10.1177/0734242X09353435.

Asase, M. (2009) 'Comparison of municipal solid waste management systems in Canada and Ghana: A case study of the cities of London, Ontario, and Kumasi, Ghana', *Waste Management*. Elsevier Ltd, 29(10), pp. 2779–2786. doi: 10.1016/j.wasman.2009.06.019.

Ashwin Dhakal (2010) 'Web Gis To Support Irrigation Management', *Earth*, p. 68.

Attride-Stirling, J. (2001) 'Thematic networks: An analytic tool for qualitative research', *Qualitative Research*, 1(3), pp. 385–405. doi: 10.1177/146879410100100307.

Aydin, C., Tarhan, C. and Tecim, V. (2015) 'IT Based Vehicle Tracking System for Effective Management in Public Organizations', *Procedia Economics and Finance*. Elsevier B.V., 33(2004), pp. 506–517. doi: 10.1016/S2212-5671(15)01733-5.

Baghdadi, N., Mallet, C. and Zribi, M. (2018) 'Network Analysis and Routing with QGIS'.

Balaji, S. (2012) 'Waterfall vs v-model vs agile : A comparative study on SDLC', *WATEERFALL Vs V-MODEL Vs AGILE : A COMPARATIVE STUDY ON SDLC*, 2(1), pp. 26–30. doi: 10.1.1.695.9278.

Balde, C. (2014) *E-WASTE MONITOR*.

Bally, L., Brittan, J. and Wagner, K. H. (1977) 'A prototype approach to information system design and development', *Information & Management*, 1(1), pp. 21–26. doi: 10.1016/0378-7206(77)90005-2.

Bassil, Y. (2012) 'A Simulation Model for the Waterfall Software Development Life Cycle', *International Journal of Engineering & Technology*, 2(5), pp. 2049–3444. doi:

10.15680/ijircce.2015.0305013.

Bell, L. (2016) ‘Backend Development’, *George Mason University*.

Benington, H. D. and Royce, W. W. (1983) ‘Waterfall model’, pp. 1–6. doi: 10.1007/978-1-4020-8265-8_200285.

Benjamin, M. (2015) ‘AN INVESTIGATION INTO THE EFFECTIVENESS OF HOUSEHOLD SOLID’, (June).

Bentley, L., Whitten, J. and Dittman, K. (2004) ‘Systems analysis and design methods’. Available at: http://sutlib2.sut.ac.th/sut_contents/60760.pdf.

Bernstein, F. and Federgruen, A. (2014) ‘Operations Research’, 52(6), pp. 868–886.

Bharamagoudar, S. R., Geeta, R. B. and Totad, S. G. (2013) ‘Web Based Student Information Management System’, 2(6), pp. 2342–2348.

Bishop, G. A. (2001) ‘The effects of altitude on heavy-duty diesel truck on-road emissions’, *Environmental Science and Technology*, 35(8), pp. 1574–1578. doi: 10.1021/es001533a.

Bodin, L. (1983) ‘Routing and scheduling of vehicles and crews’, *Computers & Operations Research*, 10(2), pp. 63–211. doi: 10.1016/0305-0548(83)90030-8.

Boehm, B. W. (1987) ‘A Spiral Model of Software Development and Enhancement’, *Computer*, 21(May), pp. 61–72. doi: 10.1109/2.59.

Borkowski (2005) ‘Adaptive Cluster Sampling’, 85(412), pp. 197–210.

Borough, L. and Hamlets, T. (2017) ‘London Borough of Tower Hamlets Waste storage and collection systems supplementary information (2017)’.

Braul, I., Desrosiers, J. and Watson, M. (2011) ‘Frontend Handbook’, *An Analysis of Downstream Changes in Temperature, Electrical Conductivity and Total Dissolved Solids of the Illecillewaet River and Asulkan Brook in Glacier National Park, B.C.*, pp. 1–114. doi: 10.1002/ejoc.201200111.

Bretl, B. (1998) ‘Persistent Java Objects in 3 tier architectures’, *Components*, pp. 1–14.

Buhrkal, K., Larsen, A. and Ropke, S. (2012) ‘The Waste Collection Vehicle Routing Problem with Time Windows in a City Logistics Context’, *Procedia - Social and Behavioral Sciences*, 39, pp. 241–254. doi: 10.1016/j.sbspro.2012.03.105.

Cantelon, M. (2017) ‘Node.js in Action’. Available at: http://toc.dreamtechpress.com/toc_978-93-5119-260-2.pdf.

Carver, J., Seaman, C. and Jeffery, R. (2004) ‘Using qualitative methods in software engineering’, *... Empirical Software Engineering ...*. Available at: http://chess.cs.umd.edu/class/fall2004/cmsc735/CMSC735 11a Qualitative Analysis.pdf.

Castro, A. G. and Monzon, A. (2017) ‘MEASURING THE EFFECTS OF TRAFFIC CONGESTION ON FUEL CONSUMPTION’, 感染症誌, 91, pp. 399–404.

Celano, L. (2014) ‘6 Methods of data collection and analysis’, *Monitoring, Evaluation, Accountability and Learning (MEAL)*, pp. 1–30.

Centers for Medicare & Medicaid Services (2008) ‘Selecting a development approach’, *Centers for Medicare & Medicaid Services*, pp. 1–10. doi: 10.1016/j.csi.2016.06.003.

Chalkias, C. and Lasaridi, K. (2009) 'A GIS based model for the optimisation of municipal solid waste collection: The case study of Nikea, Athens, Greece', *WSEAS Transactions on Environment and Development*, 5(10), pp. 640–650. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-71449113236&partnerID=40&md5=2b62a0a667c0b3241644d767d4b04cc2.

Chatindo, R. G. (2015) *MOBILE APPLICATION SYSTEM FOR SOLID WASTE COLLECTION*. BINDURA UNIVERSITY OF SCIENCE EDUCATION.

Chikobvu, D. and Makarati, F. (2011) 'The Challenges of Solid Waste Disposal in rapidly Urbanizing Cities: A case of highfield suburb in Harare, Zimbabwe', *Journal of Sustainable Development in Africa*, 13(7), pp. 184–199.

Chilela, J. G. (2016) 'Web Geographic Information System for smart campus and facilities management', pp. 1–21.

Chouhan, H. (2017) *6 Reasons to Choose the Bootstrap CSS Framework*. Available at: https://www.ostraining.com/blog/coding/bootstrap/ (Accessed: 26 November 2018).

Coffey, M. and Coad, A. (2010) *Collection of municipal solid waste in developing countries, UN Habitat*. doi: 10.1080/00207233.2013.853407.

Cole, F. (1988) 'Content Analysis: Process and Application', *Clinical Nurse Specialist*, pp. 53–57. Available at: http://journals.lww.com/cns-journal/Abstract/1988/00210/Content_Analysis__Process_and_Application.25.aspx.

Columbia, R., Dwivedi, H. and Godallage, T. (2013) 'Desk review', (May 2012).

Constantine, M. (2014) 'Public Health and Environmental Challenges in Zimbabwe : The Case of Solid Waste Generation and Disposal in the City of Masvingo', 1(2), pp. 68–72.

Conway, J. (2012) 'PostgreSQL Functions By Example What are Functions ?'

Cunningham, R. J. (1989) 'A software engineering perspective', *Journal of Information Technology*, 4(1), pp. 30–40. doi: 10.1057/jit.1989.4.

Deming, W. E. and Ramamoorthy, C. V. (2006) *Software Development Methodology Today, Design for trustworthy software: Tools, Techniques, and Methodology of Developing Robust Software*.

Dennis, A., Wixom, B. and Roth, R. (2012) *System Analysis and Design*. 5th edn. New Jersey: John Wiley & Sons.

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM OF SOUTH AFRICA (2001) 'Working with waste :Guideline on Waste Collection in Guideline on Waste Collection in', p. 91.

Desrosiers, J. (2016) 'A New Optimization Algorithm for the Vehicle Routing Problem with Time Windows Author (s): Martin Desrochers , Jacques Desrosiers and Marius Solomon Published by : INFORMS Stable URL : http://www.jstor.org/stable/171457 REFERENCES Linked references are', 40(2), pp. 342–354.

Desrosiers, J. (2018) 'A New Optimization Algorithm for the Vehicle Routing Problem with Time Windows Author (s): Martin Desrochers , Jacques Desrosiers and Marius Solomon

Published by : INFORMS Stable URL : https://www.jstor.org/stable/171457 REFERENCES Linked references are', 40(2), pp. 342–354.

Devsaran (2015) *10 Best Reasons to Use Bootstrap for Amazing Web Designs | Devsaran*. Available at: https://www.devsaran.com/blog/10-best-reasons-use-bootstrap-amazing-web-designs (Accessed: 26 November 2018).

Dewa, D., Dziva, C. and Mukwashi, K. (2014) 'Exploring Local Governance Challenges in Zimbabwe under the Government of National Unity era and beyond', 2(September), pp. 188–196. doi: 10.14662/IJPSD2014.038.

Earthy, S. and Cronin, A. (2008) 'Narrative Analysis', *Researching Social Life*, pp. 420–439.

El-Sherbeny, N. A. (2010) 'Vehicle routing with time windows: An overview of exact, heuristic and metaheuristic methods', *Journal of King Saud University - Science*. Japanese Association for Dental Science, 22(3), pp. 123–131. doi: 10.1016/j.jksus.2010.03.002.

Elo, S. and Kyngäs, H. (2008) 'The qualitative content analysis process', *Journal of Advanced Nursing*, 62(1), pp. 107–115. doi: 10.1111/j.1365-2648.2007.04569.x.

EUKHOST (2007) *Advantages of PHP Programming – Web Hosting Blog from eUKhost*. Available at: https://www.eukhost.com/blog/webhosting/advantages-of-php-programming/ (Accessed: 26 November 2018).

European Commission (1994) 'Chapter 7 Solid waste management', *Solid Waste Management*, pp. 105–120. Available at: ec.europa.eu/echo/files/evaluation/watsan2005/annex.

Faulin, J. (2011) 'Solving the Capacitated Vehicle Routing Problem with Environmental Criteria Based on Real Estimations in Road Transportation : A Case Study', *Procedia - Social and Behavioral Sciences*, 20, pp. 323–334. doi: 10.1016/j.sbspro.2011.08.038.

Fernandes, A. (2015) 'Vehicle Tracking System using GSM and GPS Technologies', *IOSR Journal of Computer Engineering*, pp. 5–8.

Fischer, M. L. and Jaikumar, R. (1974) 'Practicable . the Copy Furnished', *Aerospace*, (January).

Fisher, M. L. (2018) 'Optimal Solution of Vehicle Routing Problems Using Minimum K-Trees Author (s): Marshall L . Fisher Published by : INFORMS Stable URL : https://www.jstor.org/stable/171617 REFERENCES Linked references are available on JSTOR for this article : You may nee', 42(4), pp. 626–642.

Garry, S. and Harry, R. (2002) *Systems Analysis and Design*. 9th edn. Boston.

Ghiani, G. *et al.* (2013) 'Simultaneous personnel and vehicle shift scheduling in the waste management sector', *Waste Management*. Elsevier Ltd, 33(7), pp. 1589–1594. doi: 10.1016/j.wasman.2013.04.001.

Ghose, M. K., Dikshit, a K. and Sharma, S. K. (2006) 'A GIS based transportation model for solid waste disposal--a case study on Asansol municipality.', *Waste management (New York, N.Y.)*, 26(11), pp. 1287–1293. doi: 10.1016/j.wasman.2005.09.022.

Gilman, E. (2011) 'Fuel consumption based on route choice', *SICE Journal of Control, Measurement, and System Integration*, 4(1), pp. 1–2. Available at:

http://ubicomp.oulu.fi/files/iwsss_17_fuel_consumption.pdf.

Goenka, S. and Mangrulkar, R. S. (2017) 'Robust Waste Collection: Exploiting IOT Potentiality in Smart Cities', *i-Manager's Journal on Software Engineering,* 11(3), pp. 10–18. Available at: http://0-search.proquest.com.pugwash.lib.warwick.ac.uk/docview/1947347060?accountid=14888%0Ahttp://webcat.warwick.ac.uk:4550/resserv??genre=article&issn=09735151&title=i-Manager%27s+Journal+on+Software+Engineering&volume=11&issue=3&date=2017-01-01&atitle=.

Golden, B. L., Magnanti, T. L. and Nguyen, H. Q. (1977) 'Implementing vehicle routing algorithms', *Networks*, 7(2), pp. 113–148. doi: 10.1002/net.3230070203.

Government of Zimbabwe (1983) 'Title 29', *Urban Council'S Act 29_15*, p. 29.

Government of Zimbabwe (2002) 'ENVIRONMENTAL MANAGEMENT ACT'.

Greener, S. (2008) 'An Introduction to Spatial Databases'.

Gregory, J. (2018) *Road quality affects fuel efficiency, greenhouse gas emissions: Study*. Available at: https://www.usatoday.com/story/opinion/2018/09/18/fuel-efficiency-greenhouse-gas-emissions-study-road-quality-construction-column/1330154002/ (Accessed: 19 December 2018).

Gutierrez, J. M. *et al.* (2015) 'Smart Waste Collection System Based on Location Intelligence', *Procedia Computer Science*. Elsevier Masson SAS, 61(October), pp. 120–127. doi: 10.1016/j.procs.2015.09.170.

Güting, R. H. (1994) 'An introduction to spatial database systems', *The VLDB Journal—The International Journal on Very Large Data Bases,* 3(4), pp. 357–399.

Hamer, G. (2003) 'Solid waste treatment and disposal: Effects on public health and environmental safety', *Biotechnology Advances,* 22(1–2), pp. 71–79. doi: 10.1016/j.biotechadv.2003.08.007.

Hannan, M. A. (2011) 'Solid waste monitoring and management using RFID, GIS and GSM', *Journal of Applied Sciences Research,* 7(12), pp. 1961–1964. doi: 10.1109/SCORED.2009.5443382.

Hannan, M. A. (2015) 'A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges', *Waste Management*. Elsevier Ltd, 43, pp. 509–523. doi: 10.1016/j.wasman.2015.05.033.

Hardgrave, B. C. (2011) 'Toward a Contingency Model for Selecting an Information System Prototyping Strategy A CRITICAL ROLE FOR CRITICAL HABITAT IN THE RECOVERY PLANNING PROCESS ? NOT YET', 16(2), pp. 113–136.

Hardy, M. & Bryman, A. (2009) 'Handbook of data analysis', pp. 530–546.

Harwood, T. G. and Garry, T. (2003) 'An Overview of Content Analysis', *The Marketing Review*, 3(4), pp. 479–498. doi: 10.1362/146934703771910080.

Healey, R. G. (1991) 'Database Management Systems', *Geographic Information Systems and Science*, pp. 251–267. doi: 10.1300/J115v06n04_07.

Henderson, R. H. and Sundaresan, T. (1982) 'Cluster sampling to assess immunization coverage: A review of experience with a simplified sampling method', *Bulletin of the World Health Organization*, 60(2), pp. 253–260.

Herman, R. J. (2003) 'Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods'.

Hernandez, B. M. J. (2010) 'Chapter 1 : What is a Relational Database', *Design*.

Hobwana, C. and Ngaza, N. (2018) 'European Journal of Social Sciences Studies CHALLENGES OF WASTE MANAGEMENT IN CHIREDZI , ZIMBABWE', pp. 69–86. doi: 10.5281/zenodo.1341409.

Hoepfl, M. C. (1997) 'Choosing Qualitative Research: A Primer for Technology Education Researchers', *Journal of Technology Education*, 9(1), pp. 47–63. doi: 10.21061/jte.v9i1.a.4.

Huang, X. *et al.* (2003) 'A Three-Tier System Architecture Design and Development for Hurricane Occurrence Simulation'.

Huseyin, C. (2010) 'Introduction to the Transportation Network Design'.

HUVENGWA, I. (2012) 'SOLID WASTE MANAGEMENT: AN URBAN CHALLENGE; A CASE OF MASVINGO'.

Idowu, A. P. (2012) 'Development of A Web based GIS Waste Disposal Management System for Nigeria', (July), pp. 40–48. doi: 10.5815/ijieeb.2012.03.06.

Imam, A. (2008) 'Solid waste management in Abuja, Nigeria', *Waste Management*, 28(2), pp. 468–472. doi: 10.1016/j.wasman.2007.01.006.

Jacelon, C. S. and O'Dell, K. K. (2005) *Analyzing qualitative data.*, *Urologic nursing : official journal of the American Urological Association Allied*. doi: 10.4324/9780203413081.

Jansen, G. (2013) 'Thoughs on RESTful API design'. Available at: https://media.readthedocs.org/pdf/restful-api-design/latest/restful-api-design.pdf.

Jereb, B., Kumperščak, S. and Bratina, T. (2018) 'The impact of traffic flow on fuel consumption increase in the urban environment', *FME Transactions*, 46(2), pp. 278–284. doi: 10.5937/fmet1802278J.

Jerie, S. (2006) 'Analysis of Institutional Solid Waste Management in Gweru, Zimbabwe', *Eastern Africa Social Science Research Review*, 22(1), pp. 103–125. doi: 10.1353/eas.2006.0004.

Jerie, S. and Tevera, D. (2014) 'Solid waste management practices in the informal sector of Gweru , Zimbabwe', *Journal of Waste Management*, 2014(1), pp. 1–7. doi: 10.1155/2014/148248.

Jerie, S. and Tevera, D. (2014) 'Solid Waste Management Practices in the Informal Sector of Gweru , Zimbabwe', 2014.

Jethva, Y. (2016) '3-Tier Architecture', pp. 1–12.

Johansson, O. M. (2006) 'The effect of dynamic scheduling and routing in a solid waste management system', *Waste Management*, 26(8), pp. 875–885. doi: 10.1016/j.wasman.2005.09.004.

Kallel, A., Serbaji, M. M. and Zairi, M. (2016) 'Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia', *Journal of Engineering (United States)*. doi: 10.1155/2016/4596849.

Kambalyal, C. (2010) '3-Tier Architecture', *Retrieved On*, pp. 1–19. Available at: http://channukambalyal.tripod.com/NTierArchitecture.pdf.

Kamble, K. . (2012) 'Smart Vehicle Tracking System', *International Journal of Distributed and Parallel systems*, 3(4), pp. 91–98. doi: 10.5121/ijdps.2012.3410.

Karnatak, H. C. (2016) 'Concept and Applications of Web Gis and Geo - Web Services - Technology and Applications', *SPIE APRS Symposium 2016*, pp. 1–23.

Khan, D. and Samadder, S. R. (2014) 'Municipal solid waste management using Geographical Information System aided methods : A mini review'. doi: 10.1177/0734242X14554644.

Kokila, J. (2017) 'Design and Implementation of IoT Based Waste Management System', 25(5), pp. 995–1000. doi: 10.5829/idosi.mejsr.2017.995.1000.

Kothari, C., Kumar, R. and Uusitalo, O. (2014) *Research Methodology, New Age International*. doi: http://196.29.172.66:8080/jspui/bitstream/123456789/2574/1/Research%20Methodology.pdf.

Kothari, C. R. (2004) *Research Methodology: Methods & Techniques, New Age International (P) Ltd*. doi: 10.1017/CBO9781107415324.004.

Laporte, G. (1992) 'The traveling salesman problem: An overview of exact and approximate algorithms', *European Journal of Operational Research*, 59(2), pp. 231–247. doi: 10.1897/1551-5028(1999)018<0357:AIEOTP>2.3.CO;2.

Larsen, A., Madsen, O. and Solomon, M. (2002) 'Partially dynamic vehicle routing - Models and algorithms', *Journal of the Operational Research Society*, 53(6), pp. 637–646. doi: 10.1057/palgrave.jors.2601352.

Lbath, A. and Pinet, F. (2000) 'The development and customization of GIS-based applications and Web-based GIS applications with the CASE tool AIGLE', *Proceedings of the eighth ACM international symposium on Advances in geographic information systems - GIS '00*, (Vl), pp. 194–196. doi: 10.1145/355274.355307.

leaflet (2017) *Leaflet: Make a web map!* Available at: https://maptimeboston.github.io/leaflet-intro/ (Accessed: 19 December 2018).

Leao, S., Bishop, I. and Evans, D. (2001) 'Assessing the demand of solid waste disposal in urban region by urban dynamics modelling in a GIS environment', *Resources,Conservation and Recycling*, 33(4), pp. 289–313. doi: 10.1016/S0921-3449(01)00090-8.

Lee, C. K. M. and Wu, T. (2014) 'Design and Development Waste Management System in Hong Kong', pp. 798–802.

Levin, M., Duell, M. and Waller, T. (2010) 'THE EFFECT OF ROAD ELEVATION ON NETWORK WIDE VEHICLE ENERGY CONSUMPTION AND ECO-ROUTING', pp. 1–16. doi: 10.1103/PhysRevB.97.045402.

Levy, P. (2012) 'Simple Random Sampling', (1991), pp. 9–37. doi: 10.1002/9781118162934.ch2.

Likotiko, E. D., Nyambo, D. and Mwangoka, J. (2017a) ‘M ULTI -A GENT B ASED I OT S MART W ASTE M ONITORING A ND C OLLECTION’, 7(5), pp. 1–14.

Likotiko, E. D., Nyambo, D. and Mwangoka, J. (2017b) ‘Multi-Agent Based IoT Smart Waste Monitoring and Collection Architecture’, *International Journal of Computer Science, Engineering and Information Technology*, 7(5), pp. 01-14. doi: 10.5121/ijcseit.2017.7501.

Lindley, C. (2013) ‘JavaScript Enlightenment’, pp. 1–141.

Longley, P. A. (2005) *Geographical Information Systems and Science*. 2nd edn. Chicheste: John Wiley & Sons.

MacDonald, S. and Headlam, N. (1999) *Research methods & statistics handbook*, *Statistics*.

Makwara, E. C. and Magudu, S. (2013a) ‘Confronting the Reckless Gambling With People ’ s Health and Lives : Urban Solid Waste Management in’, *European Journal of Sustainable Development*, 2(1), pp. 67–98.

Makwara, E. C. and Magudu, S. (2013b) ‘Confronting the Reckless Gambling With People ’ s Health and Lives : Urban Solid Waste Management in’, pp. 67–98.

Malandraki, C. (2017) ‘Problems : Formulations , Properties and Heuristic Algorithms’, 26(3), pp. 185–200.

Manaf, L. A., Samah, M. A. A. and Zukki, N. I. M. (2009) ‘Municipal solid waste management in Malaysia: Practices and challenges’, *Waste Management*. Elsevier Ltd, 29(11), pp. 2902–2906. doi: 10.1016/j.wasman.2008.07.015.

Mangizvo, R. V (2007) ‘Challenges of solid waste management in the Central Business District of the City of Gweru in Zimbabwe’, *Journal of Sustainable Development in Africa*, 9(3), pp. 134–145.

Mangukiya, Amit., M. V. (2016) ‘ONLINE E-WASTE COLLECTION SYSTEM’, (April).

Mansini, R. and Grazia Speranza, M. (1998) ‘A linear programming model for the separate refuse collection service’, *Computers and Operations Research*, 25(7–8), pp. 659–673. doi: 10.1016/S0305-0548(97)00094-4.

Manus, C. and Coad, A. (2010) *Collection of Municipal Solid Waste in Developing Countries*.

Manyanhaire, I. O., Sigauke, E. and Munasirei, D. (2009) ‘Journal of Sustainable Development in Africa (Volume 11, No.2, 2009)’, 11(2), pp. 126–141.

Mapbox (2018) *Mapbox GL | Mapbox*. Available at: https://www.mapbox.com/mapbox-gl-js/api/ (Accessed: 19 December 2018).

Mapira, J. (2011) ‘Challenges of solid waste disposal and management in the city of masvingo, Zimbabwe’, *Journal of Social Development in Africa*, 26(2), pp. 67–91. doi: 10.4314/jsda.v26i2.

Marshall, M. N. (1996) ‘Sampling for qualitative research Sample size’, *Family Practice*, 13(6), pp. 522–525. doi: 10.1093/fampra/13.6.522.

Mascolo, C. (2009) ‘Software Design Models , Tools & Processes’.

Maulik, S. (2018) *Advantages & Disadvantages of Choosing AngularJS Web*

Development. Available at: https://www.experts-exchange.com/articles/31804/Advantages-Disadvantages-of-Choosing-AngularJS-Web-Development.html (Accessed: 26 November 2018).

Mavropoulos, A., Anthouli, A. and Tsakona, M. (2012) 'Mobile Applications & Waste Management: Recycling, Personal Behavior, Logistics', (May), p. 34.

Medvedev, A. (2015) 'Waste management as an IoT enabled service in Smart Cities', (1). doi: 10.1007/978-3-319-23126-6.

Mehul, R. (2016) *The pros and cons of choosing AngularJS - JAXenter*. Available at: https://jaxenter.com/the-pros-and-cons-of-choosing-angularjs-124850.html (Accessed: 26 November 2018).

Mendel, R. (2004) 'Front End Programming', (2004), pp. 1–23.

MILCHTAICH, I. (2005) 'Network Topology and the Efficiency of Equilibrium *', (749).

Ministry of Local Government Provincial Councils (2008) 'SOLID WASTE COLLECTION AND TRANSPORT : Service Delivery Training Module 1 of 4', pp. 1–63.

Montemanni, R. *et al.* (2005) 'Ant colony system for a dynamic vehicle routing problem', *Journal of Combinatorial Optimization*, 10(4), pp. 327–343. doi: 10.1007/s10878-005-4922-6.

Morrissey, A. J. and Browne, J. (2004) 'Waste management models and their application to sustainable waste management', *Waste Management*, 24(3), pp. 297–308. doi: 10.1016/j.wasman.2003.09.005.

Muchandiona, A. (2013) *Challenges and Opportunities in Solid Waste Management in Zimbabwe ' S Urban Councils Challenges and Opportunities in Solid Waste Management in Zimbabwe ' S Urban*. doi: 10.1161/01.CIR.101.16.1970.

Muchandiona, A. (2013) 'CHALLENGES AND OPPORTUNITIES IN SOLID WASTE MANAGEMENT IN ZIMBABWE ' S URBAN COUNCILS CHALLENGES AND OPPORTUNITIES IN SOLID WASTE MANAGEMENT IN ZIMBABWE ' S URBAN', (September).

Mudzengerere, F. and Chingwenya, A. (2012a) 'WASTE MANAGEMENT IN BULAWAYO CITY COUNCIL IN ZIMBABWE: IN SEARCH OF SUSTAINABLE WASTE MANAGEMENT IN THE CITY', *Journal of Sustainable Development in Africa*, 14(1), pp. 228–244.

Mudzengerere, F. and Chingwenya, A. (2012b) 'Waste Management in Bulawayo Zimbabwe', 14(1), pp. 228–244.

Mulloy, B. and Swiber, K. (2017) 'The New 3-Tier Architecture ':

Musademba, Downmore; Musiyandaka, Shepherd, Muzinda, Andrew; Nhemachena, Barbara ; Jambwa, D. (2011) 'MUNICIPALITY SOLID WASTE (MSW) MANAGEMENT CHALLENGES OF CHINHOYI TOWN IN ZIMBABWE: OPPORTUNITIES OF WASTE REDUCTION AND RECYCLING', 13(2), pp. 168–180.

Musingafi, M. C. C. *et al.* (2015) 'Domestic and Solid Waste Management in Zvishavane Town in Zimbabwe : A Case Study of Mandava Township', 5(12), pp. 17–24.

Narayana, T. (2009) ‘Municipal solid waste management in India: From waste disposal to recovery of resources?’, *Waste Management*. Elsevier Ltd, 29(3), pp. 1163–1166. doi: 10.1016/j.wasman.2008.06.038.

Neumann, P. (2004) ‘Prototyping’, *October*, pp. 1–13.

Neyman, J. (1934) ‘On the Two Different Aspects of the Representative Method : The Method of Stratified Sampling and the Method of Purposive Selection Author (s): Jerzy Neyman Source : Journal of the Royal Statistical Society , Vol . 97 , No . 4 (1934), pp . 558-625 Pub’, *Journal of the Royal Statistical Society*, 97(4), pp. 558–625. doi: 10.2307/2342192.

Ngwenya, P. and Jonsson, L. (2001) ‘Industrial Waste Management in Zimbabwe’, 1(December), pp. 196–199.

Nuortio, T.(2006) ‘Improved route planning and scheduling of waste collection and transport’, *Expert Systems with Applications*, 30(2), pp. 223–232. doi: 10.1016/j.eswa.2005.07.009.

Nyarai, M. P. (2016) ‘Challenges of solid waste management in Zimbabwe : a case study of Sakubva high density suburb’, *Challenges of solid waste management in Zimbabwe : a case study of Sakubva high density suburb*, 3(2), pp. 142–155.

Ogwueleka, T. C. (2009) ‘Municipal Solid Waste Characteristics and Management in Nigeria’, *Journal of Environmental Health Science & Engineering*, 6(3), pp. 173–180. doi: 10.30638/eemj.2016.002.

Ogwueleka, T. C. (2009) ‘Route optimization for solid waste collection : Onitsha (Nigeria) case study’, *Journal of Applied Sciences and Environmental Management*, 13, pp. 37–40.

de Oliveira Simonetto, E. and Borenstein, D. (2007) ‘A decision support system for the operational planning of solid waste collection.’, *Waste management (New York, N.Y.)*, 27(10), pp. 1286–97. doi: 10.1016/j.wasman.2006.06.012.

P. Singh, Y. P., A.K., S. and R.P., S. (2016) ‘Web-GIS based Framework for Solid Waste Complaint Management for Sustainable and Smart City’, *International Journal of Advanced Remote Sensing and GIS*, 5(1), pp. 1930–1936. doi: 10.23953/cloud.ijarsg.71.

Papagelis, M. (2013) ‘WEB APP ARCHITECTURES : Data Independence in Relational Databases’, (Mvc).

Paul, A. (2017) ‘Analysis Of Geographic Information System Using SDLC (System Development Life Cycle)’, (Icetd), pp. 780–789.

php freaks (2011) *Advantages of PHP over JavaScript? - Miscellaneous - PHP Freaks*. Available at: https://forums.phpfreaks.com/topic/251144-advantages-of-php-over-javascript/ (Accessed: 26 November 2018).

Pires, A., Martinho, G. and Chang, N. Bin (2011) ‘Solid waste management in European countries: A review of systems analysis techniques’, *Journal of Environmental Management*. Elsevier Ltd, 92(4), pp. 1033–1050. doi: 10.1016/j.jenvman.2010.11.024.

Polyzos, S. (2017) ‘ScienceDirect The topology of urban road networks and its role to urban mobility’, *Transportation Research Procedia*. Elsevier B.V., 24, pp. 482–490. doi: 10.1016/j.trpro.2017.05.087.

Popa, C. (2017) ‘Smart City Platform Development for an Automated Waste Collection System’, *Sustainability*, 9(11), p. 2064. doi: 10.3390/su9112064.

Pope, C., Ziebland, S. and Mays, N. (2000) ‘Qualitative research in health care Analysing qualitative data’, *Bmj*, 320(January), pp. 114–116. doi: 10.1136/bmj.320.7227.114.

Pouget, S. (2012) ‘Viscous Energy Dissipation in Asphalt Pavement Structures and Implication for Vehicle Fuel Consumption’, *Journal of Materials in Civil Engineering*, 24(5), pp. 568–576. doi: 10.1061/(ASCE)MT.1943-5533.0000414.

Poulsen, O. M. (1995) ‘Collection of domestic waste. Review of occupational health problems and their possible causes’, *The Science of the Total Environment*, 170, pp. 1–19.

Powell, G. (2006) *Beginning Database Design*. Indianapolis: Wiley Publishing.

Prosepk, K. (2017) ‘Research Methodology Haradhan’, (78413).

Qian, J. and Eglese, R. (2016) ‘Fuel emissions optimization in vehicle routing problems with time-varying speeds’, *European Journal of Operational Research*. Elsevier Ltd., 248(3), pp. 840–848. doi: 10.1016/j.ejor.2015.09.009.

Rabl, A., Spadaro, J. V. and Zoughaib, A. (2008) ‘Environmental impacts and costs of solid waste: A comparison of landfill and incineration’, *Waste Management and Research*, 26(2), pp. 147–162. doi: 10.1177/0734242X07080755.

Rada, E. C., Ragazzi, M. and Fedrizzi, P. (2013) ‘Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies’, *Waste Management*, 33(4), pp. 785–792. doi: 10.1016/j.wasman.2013.01.002.

Rahman, M. S. (2016) ‘The Advantages and Disadvantages of Using Qualitative and Quantitative Approaches and Methods in Language “Testing and Assessment” Research: A Literature Review’, *Journal of Education and Learning*, 6(1), p. 102. doi: 10.5539/jel.v6n1p102.

Remigios, M. V (2013) ‘Open burning of municipal solid waste in Senga surburb in the City of Gweru : A salient environmental threat’, 3(1), pp. 105–112.

Sabbas, T. (2003) ‘Management of municipal solid waste incineration residues’, *Waste Management*, 23(1), pp. 61–88. doi: 10.1016/S0956-053X(02)00161-7.

Sakai, S. and Hiraoka, M. (2000) ‘Municipal solid waste incinerator residue recycling by thermal processes’, *Waste Management*, 20(2–3), pp. 249–258. doi: http://dx.doi.org/10.1016/S0956-053X(99)00315-3.

Samson, G. L. (2014) ‘Spatial Databases’, pp. 111–149. doi: 10.4018/978-1-5225-2058-0.ch003.

Sandison, P. (2003) *Desk review of real-time evaluation experience*.

Sang, S. (2016) ‘Java Script Basics and HTML DOM’.

Satzinger, J. W. and Jackson, R. B. (2012) *SYSTEMS ANALYSIS AND DESIGN IN A CHANGING WORLD*.

Schwaber, K. (1997) ‘SCRUM Development Process’, *Business Object Design and Implementation*, (April 1987), pp. 117–134. doi: 10.1007/978-1-4471-0947-1_11.

Shahabi, C. (1994) ‘Introduction to Spatial Database Systems Value of SDBMS’, (October).

Shamieh, C. (2011) *SYSTEMS ENGINEERING*.

Sharholy, M. (2008) ‘Municipal solid waste management in Indian cities - A review’, *Waste Management*, 28(2), pp. 459–467. doi: 10.1016/j.wasman.2007.02.008.

Shasha, D. and Bonnet, P. (2005) *Databse Tuning*, *Technology*.

Shekar, S. and Chawla, S. (2002) ‘Introduction to Spatial Databases’, *Spatial Databases: A Tour*, pp. 21–44. doi: papers3://publication/uuid/E626604D-1F38-4DCD-878A-C1E029178A87.

Shoko, I. (2008) ‘Introduction to Relational Databases’, pp. 1–28.

Simelane, T. and Mohee, R. (2012) ‘Future Directions of Municipal Solid Waste Management in Africa’, *Policy Brief*, (81), pp. 1–6. Available at: e:///C:/Users/library/Documents/No.-81.-Future-Directions-of-Municipal-Solid-waste-Management-in-Africa VIC 7.pdf.

Singh, S. (2012) ‘Simple Random Sampling’, in, pp. 9–37. doi: 10.1002/9781118162934.ch2.

Smith, J., Firth, J. (2011) ‘Qualitative data analysis: application of the framework approach’, *Nurse Researcher*, 2(18), pp. 52–62. doi: 10.7748/nr2011.01.18.2.52.c8284.

Smith, C. (2000) ‘Content analysis and narrative analysis’.

Solanky, V. (2016) ‘An Optimal Transportation Routing Approach Using Open Source GIS for An Optimal Transportation Routing Approach Using Open Source GIS for Shortest Path Evaluation’, (October 2015). doi: 10.13140/RG.2.1.1452.2643.

Soliman, A. M. A. (2006) ‘Effect of Road Roughness on the Vehicle Ride Comfort and Rolling Resistance’, in. doi: 10.4271/2006-01-1297.

Solomon, M. M. (1987) ‘Algorithms for the Vehicle Routing and Scheduling Problems with Time Window Constraints Published by : INFORMS Stable URL : http://www.jstor.org/stable/170697 REFERENCES Linked references are available on JSTOR for this article : You may need to log in to’, *Operations Research*, 35(2), pp. 254–265.

Sparrow, P. (2012) ‘Spiral Model : Advantages and Disadvantages’, *Ianswer4U*, p. 1. Available at: http://www.ianswer4u.com/2011/12/spiral-model-advantages-and.html#axzz3ihy97bFN.

SPSS (2004) ‘Questionnaire design and analysing data using SPSS’, *SPSS Survey Tips*, pp. 1–14. Available at: htp://www.spss.com/PDFs/STIPIr.pdf.

Stephens, R. and Plew, R. (2003) *Begining Datadases*. Sams Publishing.

Sun, R. A. de B. R. A. K. Y. *et al.* (2001) *P RINCIPLES OF Principles of Geographic Information Systems An introductory textbook*. second. Edited by Rolf A. Enschede: ITC.

Supriyadi, S., Kriwoken, L. and Birley, I. (2000) ‘Solid waste management solutions for Semarang’. Available at: http://journals.sagepub.com/doi/pdf/10.1177/0734242X0001800606.

Taiwo, L. B. and Oso, B. A. (2004) ‘Influence of composting techniques on microbial succession, temperature and pH in a composting municipal solid waste', *African Journal of Biotechnology*, 3(4), pp. 239–243. Available at: http://www.academicjournals.org/AJB.

Tanyanyiwa, V. I. (2015) 'Not In My Backyard (NIMBY)? : The Accumulation of Solid Waste in the Avenues Area , Harare , Zimbabwe Abstract ':, 4(2), pp. 122–128.

Teddlie, C. and Yu, F. (2007) 'Mixed Methods Sampling', *Journal of Mixed Methods Research*, 1(1), pp. 77–100. doi: 10.1177/2345678906292430.

Tilahun, N. (2012) 'Qualitative data analysis', *Monash University*, (March), p. 64. doi: 10.1136/ebnurs.2011.100352.

Tilli, T., Faiz, S. and Krichen, S. (2013) 'INTEGRATION OF GIS AND OPTIMIZATION', 2(2), pp. 9–17.

Tobergte, D. R., Curtis, S. and Christofides, N. (1976) 'The vehicle routing problem', *Revue française d'automatique, d'informatique et de recherche opérationnelle. Recherche opérationnelle*, 10(1), pp. 55–70. doi: 10.1017/CBO9781107415324.004.

Training and Research Support Centre (2010) 'Assessment of solid waste management in three local authorities in Zimbabwe REPORT OF A COMMUNITY BASED', (January).

Tsiko, R. G. and Togarepi, S. (2014) 'A Situational Analysis of Waste Management in Harare , Zimbabwe', (April 2012).

Umulisa, C. (2012) 'Sampling Methods and Sample Size Calculation for the SMART Methodology June 2012 Table of Contents', *University*, 2(June), pp. 20–30.

UNICEF (1993) 'Information Managemnt For Municipal Solid Waste Management Services'.

UNICEF (2017) 'Conducting-a-Desk-Review', p. 4.

Vasvari, G. (2015) 'Analysis and observation of road network topology', (September).

Verma, P. and Bhatia, J. S. (2013) 'D Esign and D Evelopment of Gps-Gsm B Ased T Racking S Ystem With G Oogle M Ap B Ased', *International Journal of Computer Science, Engineering and Applications*, 3(3), pp. 33–40. doi: 10.5121/ijcsea.2013.3304.

Vu, H. L. (2018) 'Parameter interrelationships in a dual phase GIS-based municipal solid waste collection model', *Waste Management*. Elsevier Ltd, 78, pp. 258–270.

Wang, H. and Nie, Y. (2001) 'Municipal Solid Waste Characteristics and Management in China', *Journal of the Air & Waste Management Association*, 51(2), pp. 250–263.

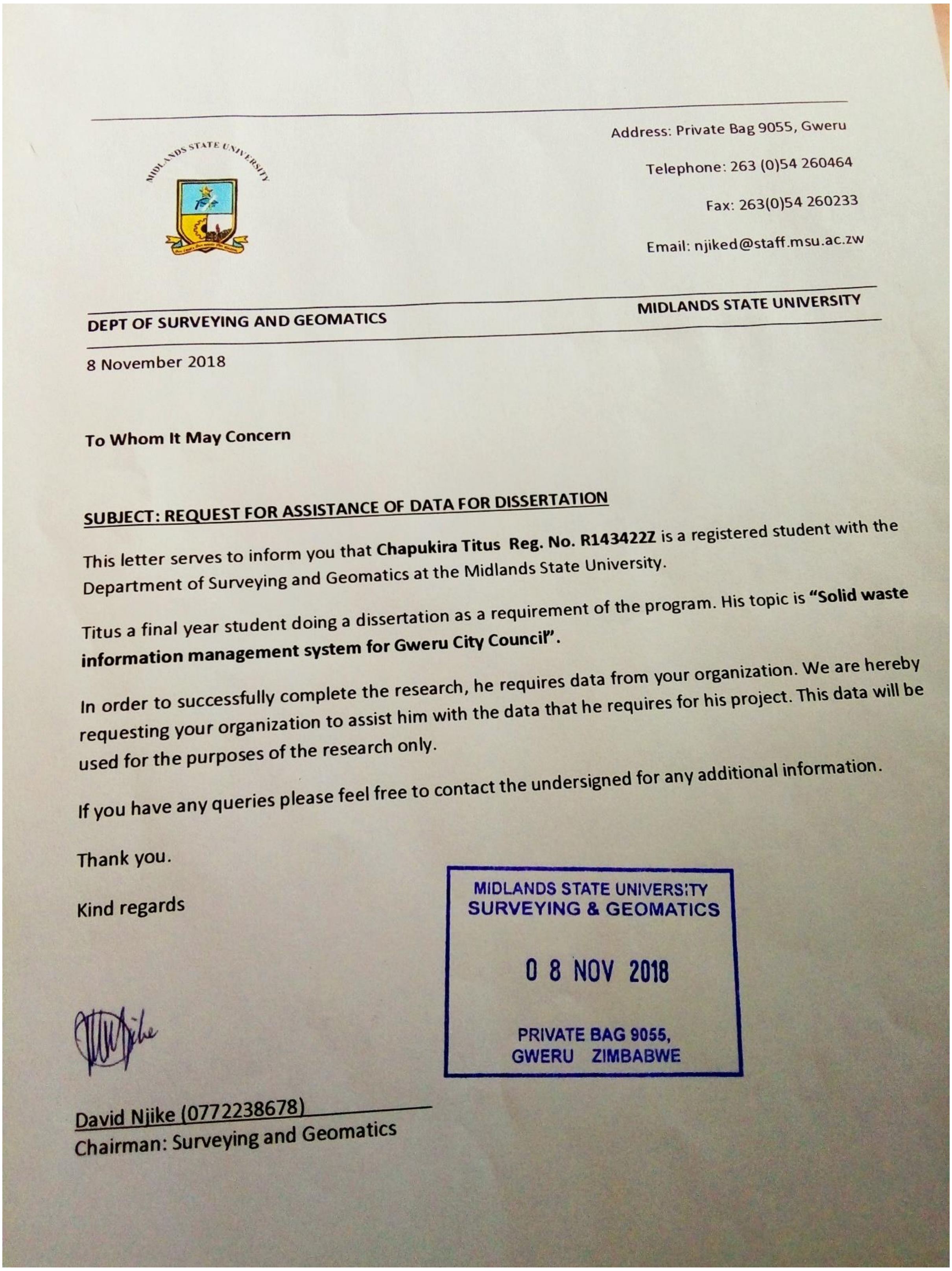
Woods, M. (2011) 'Interviewing for research and analysing qualitative data : An overview', *School of Humanities and Social Sciences, Massey University*, pp. 1–8. Available at: http://owll.massey.ac.nz/pdf/interviewing-for-research-and-analysing-qualitative-data.pdf.

World Food Programme (2009) 'Desk study: literature review and secondary data'.

Young, D. (2013) 'Software Development Methodologies', *Alabama Supercomputer Center*, pp. 1–9. Available at: https://www.asc.edu/sites/default/files/org_sections/HPC/documents/sw_devel_methods.pdf.

Zervas, E. (2011) 'Impact of altitude on fuel consumption of a gasoline passenger car', *Fuel*. Elsevier Ltd, 90(6), pp. 2340–2342. doi: 10.1016/j.fuel.2011.02.004.

7 Appendices



Address: Private Bag 9055, Gweru

Telephone: 263 (0)54 260464

Fax: 263(0)54 260233

Email: njiked@staff.msu.ac.zw

MIDLANDS STATE UNIVERSITY

DEPT OF SURVEYING AND GEOMATICS

8 November 2018

To Whom It May Concern

SUBJECT: REQUEST FOR ASSISTANCE OF DATA FOR DISSERTATION

This letter serves to inform you that **Chapukira Titus Reg. No. R143422Z** is a registered student with the Department of Surveying and Geomatics at the Midlands State University.

Titus a final year student doing a dissertation as a requirement of the program. His topic is **"Solid waste information management system for Gweru City Council"**.

In order to successfully complete the research, he requires data from your organization. We are hereby requesting your organization to assist him with the data that he requires for his project. This data will be used for the purposes of the research only.

If you have any queries please feel free to contact the undersigned for any additional information.

Thank you.

Kind regards

MIDLANDS STATE UNIVERSITY
SURVEYING & GEOMATICS
0 8 NOV 2018
PRIVATE BAG 9055,
GWERU ZIMBABWE

David Njike (0772238678)
Chairman: Surveying and Geomatics

ALL COMMUNICATIONS TO BE ADDRESSED TO THE CHAMBER SECRETARY

CITY of GWERU

CHAMBER SECRETARY'S DEPARTMENT
Municipal Offices
P.O. Box 278 Telephone 263-054-224071-9
Fax 263-054-24309-Gweru, Zimbabwe
E-mail: *gweruchambersec@comone.co.zw*

PROGRESS

If calling or phoning this matter.
Please ask for
MR NEMUSESO

Your Ref:
Our Ref: JN/nmd/Personnel

06 November 2018

Chapukira Titus
Midlands State University
P. Bag 9055
GWERU

Dear Sir/Madam

RE: REQUEST TO CARRY OUT AN ACADEMIC RESEARCH IN GWERU CITY

I refer to your letter dated 08 November 2018 requesting to carry out a research and I am pleased to inform you that your request was considered and permission has been granted.

Please be kindly advised that permission is granted on the following conditions:

1) That you do not publish the name of Council officials.
2) That you also seek police clearance in the case that you want to interview residents.
3) That Gweru City Council shall not be liable of any action arising from your research.
4) That you undertake to deposit of the said research which shall be submitted to the Town Clerk's office.

V.D CHIKWEKWE
CHAMBER SECRETARY

cc: *Human Resources Manager*
File

CITY OF GWERU
13 NOV 2018
CHAMBER SECRETARY
P.O. BOX 278

USERS' REQUIREMENTS COLLECTION GUIDE FOR SOLID WASTE COLLECTION INFORMATION MANAGEMENT SYSTEM

The significant goal is to document the problems, limitations, opportunities, requirements and priorities of the organisation and the users of the system.

INTRODUCTION

Researcher: Chapukira Titus Munoda

I am a final year student at Midlands State University for a BSc (Honours) degree in Surveying and Geomatics. I am undertaking a research on developing a solid waste collection information management system for Gweru city council. The proposed system aims at optimising solid waste collection by making use of the available resources efficiently and effectively. May you kindly assist by responding to the following questions about planning and scheduling for human resource and equipment before, during and after waste collection activities, issues concerning hardware and software utilization, the sharing of data between and crosswise over departments. This survey will be used for academic purposes only and all responses will be treated confidentially.

DEPARTMENTAL FUNCTIONS

The respondent will be requested to describe his or her activity capacities within the framework of his/her job description, the department structure and the principal activities that define their view of the proposed system.

Management

1. What are the main functions of your department?
2. How many employees are in your department?
3. What specifically, is your function within the department?
4. How many collection vehicles do you have and what are their types?

ACTIVITIES

This section identifies the departmental activities, the information flows within and across departments, and the associated problems if any.

Management

5. How do you create shifts and schedules for both the personnel and equipment?

6. What do you consider when assigning collection vehicles to a specific ward/suburb?

7. How were waste collection and disposal routes generated?

8. What factors were considered in generating these routes?

9. Do you have maps that show routes and in what format are they?

10. How do you know if the waste collection vehicle is on the designated route and, what tools and techniques do you use to keep track of its location?

11. What types and formats of data do you use in all your activities and where do you get it from?

12. Where do you store this data and in what formats?

13. What tools and techniques do you employ to manipulate this data?

14. How you retrieve this data from the storage facilities mentioned above and what challenges do you encounter if any, in retrieving this data?

15. Do you share this data with any other departments? If so, briefly describe the data types, formats and medium for data dissemination?

16. What problems if any, do you face when sharing this data with other departments?

17. What type of reports do you generate and how do you convey them to the interested departments/parties/individuals?

18. What type of computers do you have?

19. Which software packages do you currently use in your department and for how long have they been in use?

20. Is there any hardware and/or software resources that you do not have but which you feel can greatly assist you to execute your job more effectively?

21. How do you want your methods for data acquisition, storage, manipulation, analysis and dissemination to be incorporated into the proposed information management system?

Drivers

22. What do you use to navigate the predetermined routes (map/navigation device/human memory)?

23. What challenges are you facing if any by using the above-mentioned criterion?

24. Do you try to optimise routes amid waste collection and disposal? If so, what factors do you consider when optimising these routes?

25. After emptying your truck at the disposal facility, what means do you use to return back to your last location?

26. How do you report the progress of solid waste collection to the supervisor?

27. How do you report needed repairs or servicing of waste collection vehicles to the supervisor?

RESIDENT QUESTIONAIRE

Researcher: Chapukira Titus Munoda

I am a final year student at Midlands State University for a BSc (Honours) degree in Surveying and Geomatics. I am undertaking a research on developing a solid waste collection information management system for Gweru city council. May you kindly assist by responding to the following questions in the questionnaire by ticking and or providing information in the appropriate box or allocated space. This survey will be used for academic purposes only and all responses will be treated confidentially.

1. Location ………………………………………………………….
2. How often is waste collected?

☐ Once a week ☐ Once a month ☐ Not at all collected

3. Where do you temporarily store your waste?

☐ Plastic bins ☐ Galvanised metal bin ☐ Sacks/Plastic bags ☐ Others

4. If the answer is others above please justify.

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

5. When bins are not collected in time, how do you manage your uncollected waste?

☐ Put in supplementary sacks/plastic bags

☐ Throw away at closest dump site/open space

☐ Burn

6. Does the city council communicate why they did not collect waste?

☐ Yes ☐ No

7. If the answer is yes from the above question, what platforms/media do they use?

……
……
……
……

8. How do you convey your queries/complaints to the city council with regards to the solid waste collection?

☐ Visit the townhouse

☐ Via phone calls

☐ Do nothing

9. What other platforms would you want the convey your queries/complaints to the city council through?

……
……
……
……

10. Does the current waste collection system enable you to check the collection timetable and any changes to the normal collection cycles?

☐ Yes ☐ No

11. Would you like to be notified when the waste collection vehicle has been dispatched to collect waste in your area?

☐ Yes ☐ No

12. If the answer above is yes, through what platforms would you want to receive these notifications?

……
……
……
……