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Optimization of Supply Chain Network in Solid Waste Management Using a Hybrid Approach of Genetic Algorithm and Fuzzy Logic: A Case Study of Lagos State

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ABSTRACT

A strategic shift towards sustainable, appropriate supply chain networks and data-driven decision-making in solid waste management in rural and urban areas can drastically reduce environmental pollution. This study utilizes a hybrid strategy of genetic algorithms and fuzzy logic to improve the supply chain network in solid waste management in Lagos State. In this research, four local governments in Lagos State are taken as a case study to help Identify solid waste in those selected areas, acquire data to better understand the supply chain network in solid waste management, and use the data acquired to model for the algorithm. A series of 30 iterations were carried out using a fitness parameter of frequency, price range, and means of disposal to determine who should be given utmost importance in the chain. Supply chains often exhibit inadequacies that may be enriched using Artificial Intelligence (AI) tools. The optimization model is flexible and useful, so everyone involved in the chain can coexist harmoniously. One of the reasons causing these inadequacies in proper waste management is a poorly planned supply chain network. It was concluded that the scavengers must be recognized as major participants in the movement of waste from houses to these provided refuse bins, with their frequency increased to 6 times daily with dustbins ranging from 9-20 be provided on each street which the private service participants (PSP).

INTRODUCTION

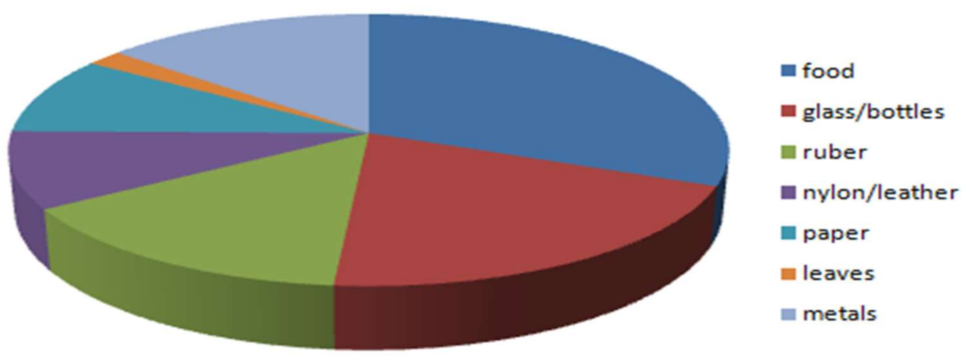
Solid waste management is becoming more than just an environmental concern, with the world's solid waste estimated at 2.01 billion tons and Lagos at 14,000 metric tonnes daily. One of the most significant environmental issues, air pollution, is mostly a concern in urban areas. It is challenging to monitor atmospheric pollution, especially particulate matter and nitrogen oxides, and this problem must be solved for both health and wealth. Waste is defined as any material that has been discarded and is no longer useful to humans. Waste can be made up of any material, including solid, liquid, organic, toxic, or biodegradable. While some garbage can be recycled, other garbage cannot. The term "solid waste" refers to a collection of trash from a variety of sources, including household, institutional, industrial, commercial, and demolition sites (as well as waste from public spaces and hazardous waste) (British Columbia Government 2018). The options include house-to-house collection, community bins, curbside pickup, self-delivery, and hired or delegated service (Olberg et al. 2018). All of these factors contribute to the rapid accumulation of municipal solid waste in every state's waste management system due to uncontrolled population growth, rapid industrial growth, and rising community living standards. 1.3 billion tons of municipal solid waste (MSW) are generated every day, according to Singh et al. (2011) an estimate that is equivalent to two-thirds of a kilogram or ten times the weight of an adult's body in a year. As of February 2021, more than 50 million tons of hazardous chemicals have been disposed of worldwide. Global garbage production is expected to reach 3.4 billion tons by 2050, according to current projections. According to a survey of 151 large cities worldwide, insufficient solid waste disposal is the community's second most serious issue after unemployment (Elahi 2009).

Waste management is an important part of any developing or industrial society, and its generation and disposal are influenced by factors such as population growth, societal awareness, and the government's response and approach. It could be argued that the amount of waste produced does not always equate to a problem, but rather the government's, individual's, and waste management force's response to the accumulated waste. Compilation of almost all waste produced globally isn't technically difficult, but it is mostly solid, and one of the issues that arise in this regard is organizational issues. For example, the means of waste collection and transportation are weighed in societies where proper and adequate structured management companies are present. Chemical, physical, and product analyses are also performed regularly on appropriate waste samples. But in places like Nigeria, especially Lagos state, the management of waste disposal isn't good enough; meanwhile, the problem with solid waste has reached an alarming level. Lagos, Nigeria's most populous state, is home to a large percentage of the country's population. In 2021, the population of Lagos' metropolitan area was 14,862,000, an increase of 3.44 percent from 2020. As of 2020, Lagos' metro area had a population of 14,368,000, an increase of 3.34 percent from 2019. Lagos State's population is expected to rise, and with it, an efficient waste management system is needed. This is because poor solid waste management has many undesirable characteristics that our society cannot tolerate.

EARLIER STUDIES

One of the most significant and newly emerging potential difficulties in the majority of large cities is the availability of land for effective trash disposal. Landfill dumping remains the primary method of trash disposal despite some efforts to reduce and reclaim garbage (Ramu et al. 2023). Owing to this problem, some researchers conduct research and experiment to recover waste heat from any resources to be combined with an application to decrease energy usage (Ramadan et al. 2017). Every household or commercial space may employ air conditioning for thermal comfort and to maintain indoor air quality (Wu et al. 2020). In developing nations, improper municipal solid waste disposal poses serious environmental and health risks (Ayomoh et al. 2008). The life cycle analysis (LCA) approach is useful for estimating greenhouse gas emissions from different waste management activities (Ali et al. 2016). The promotion of waste management laws and regulations was done to help with guidance and to lessen the continual dumping of waste into rivers, waterways, and illegal dump sites (Abila & Kantola 2013). Environmental quality is a prerequisite for an increase in per capita well-being over time, and the sustainable management of waste approach seeks to achieve this (Bari et al. 2012, Ayininuola & Muibi 2008). Human beings are exposed to toxic chemicals through various pathways (Ogarekpe et al. 2023).

There is a global need for effective waste management, necessitating intensive research and development efforts to examine innovative applications for sustainable and environmentally sound management (Oyebode 2013, Oyebode & Otoko 2022). Engineering intervention and strategic groundwater monitoring surrounding landfills are required for environmental sustainability, pollution reduction, and public health as urbanization and population growth continue in the megacity (Oyebode et al. 2023). Waste is a byproduct of life that can be produced by municipal, industrial, familial, individual, and developmental activities like civil engineering construction projects. To promote public health, economic prosperity, and effective energy systems, the management of solid wastes must be effective (Oyebode 2018, 2019). Waste incineration is the principal method for managing medical waste in poor nations like Nigeria, with the pathogen removal from the waste stream and trash volume and reactivity reduction having positive economic effects (Oyebode et al. 2022, Oyebode & Coker 2021). A key assurance of social and economic sustainability is the availability of water resources. Enhancing water's ecological carbon sequestration capacity directly reacts to the double carbon objective. Water quality evaluation significantly impacts human life and development (Guojiao et al. 2023).



Source: (Khair et al. 2019)

Fig. 1: Compositions of household wastes.

In general, waste can be classified as solid, liquid, or gaseous (Javourez et al. 2021). Solid wastes: Urban wastes, industrial wastes, agricultural wastes, biomedical wastes, and radioactive wastes are all examples of these (Samson et al. 2011). Fig. 1 gives the Compositions of household wastes.

Solid Waste Management

The system that oversees the collection, source separation, storage, transportation, treatment, and disposal of solid waste is known as solid waste management (Ahsan et al. 2014). The selection and design of landfill sites is an important step in waste disposal because it allows landfill gas to be extracted as a source of energy that can be used for various energy-producing purposes, generating revenue for the landfill (Kofoworola 2007). We have no choice but to seek a technical method of solid waste management system by using a modern and integrated concept of SC due to the amount of waste generated in Lagos state and Nigeria's inability to collect proper data due to various factors. As a result, waste reduction, recycling, and recovery, as well as appropriate waste treatment methods, more environmentally friendly technology, and appropriate final disposal, should all be considered and encouraged when designing SWM systems (Kofoworola 2007). Fig. 2 presents the waste management cycle.

Solid Waste Management in Lagos State

The Lagos State Waste Disposal Board, now known as the Lagos State Waste Management Agency (LAWMA), was founded by Lagos State (Afon 2007). The organization is tasked with properly managing the garbage of the state's 14 million citizens and providing a clean environment through transportation, waste disposal site management, and, more recently, recycling. As a result, LAWMA embarked on a public-private partnership project to manage the system. It is open to the public in the sense that LAWMA regulates both residents and private partners. While the PSP is in charge of service delivery, the LAWMA sets rates for households and businesses. Charges for garbage collection are based on direct charges to families and other businesses; the amount to be paid for rubbish collection is determined by the location and kind of households and establishments rather than the volume of waste generated (Anestina et al. 2014). Under state legislation, all Lagos citizens are required to use the services to keep the state clean. Due to financial constraints, this scenario has been exacerbated by some resident households' unwillingness to pay for garbage disposal services. One of the reasons why people in the country, particularly in Lagos State, are unwilling to pay is that the Waste Management Board was founded as a non-profit organization, and its services are considered a public good that attracts little or no cost (Anestina et al. 2014)

The state government has contracted solid waste collection and disposal to private sector operators to maintain a clean Lagos at no additional expense to the government (Idowu et al. 2011). Conservation efforts can only be a long-term success if local people embrace their goals and actions (Anestina et al. 2014).

The supply chain (SC) is the network that connects purchasing, shipping, and processing of raw materials and distributing and delivering goods to customers (Nan et al. 2021). The primary goal of a supply chain is to improve a system's operating efficiency (Gu et al. 2021). SC design is a strategic problem whose solution significantly impacts the SC's performance. It includes decisions about the number and location of production facilities, the amount

Source: (Alli et al. 2016)

Fig. 2: Waste management cycle.

of capacity at each facility, the assignment of each market region to one or more locations, and sub-entity, component, and material supplier selection (Ambe 2012). Supply chain optimization uses the most efficient methods for collecting and transporting solid waste. Transporting raw materials, commodities, and information from start to finish is critical for global trade, as is reverse logistics (moving waste) (MacArthur 2016).

Network of Supply Chain

The term "network" is important since it implies that most SCs are more sophisticated than a chain and that flows between entities are an integral feature of the SC (Santabarbara-Ruiz et al. 2015). Managers in a supply chain network (SCN) are responsible for making sustainable strategic decisions for the system. Supply chain management is the process of developing, executing, and operating a supply chain network system to fulfill consumer demand while lowering the total cost of the network's operations (Gurtu & Johny 2021).

Elements of a Supply Chain

All of the functions that begin with receiving an order and end with satisfying the customer's request are included in the elements of a supply chain. These responsibilities include planning, sourcing, manufacturing, delivering, and returning (Santabarbara-Ruiz et al. 2015).

Design and Modeling of a Supply Chain

Multi-stage supply chain design and analysis models may be separated into four groups by modeling technique. The nature of the inputs and the study's goal influence the modeling technique in the situations shown below.

The four categories are as follows:

- Deterministic analytical models, which have known and stated variables,
- Analytical stochastic models, in which at least one variable is unknown and is assumed to follow a certain probability distribution,
- business models
- A simulation model aims to determine which tactics are the most successful in smoothing demand fluctuations (Fayezi & Zomorrodi, 2015).

Optimization (Mathematical Optimization)

Mathematical optimization is selecting the optimal element from a group of alternatives based on criteria. It is frequently utilized when a choice incorporating several factors must be made quickly and efficiently.

The Main Components of Mathematical Optimization Decision variables are physical quantities the decision-maker may control and represent by mathematical symbols.

The objective function defines the criterion for assessing the solution. It is a mathematical function of the choice variables that transforms a solution into a numerical evaluation.

Constraints are a collection of functional equality or inequalities that indicate physical, economic, technological, legal, ethical, or other limitations on the numerical values that can be assigned to decision variables.

The inefficiency of MSW management in Nigeria can be attributed to an improper supply chain, which includes how waste is generated, collected, separated, sorted, distributed, processed, renewed, if necessary, reused, and re-disposed (Sabbas et al. 2003), as the efficiency of MSW management can be improved by supply chain management technique optimization (Mamashli & Javadian 2021).

Optimization of the Supply Chain Network

Supply chain optimization uses technology and resources such as blockchain, artificial intelligence, and the Internet of Things to improve supply chain efficiency and performance (Kadad et al. 2020). Silos (data visibility), client demands, competitive advantages, agility, and sustainability are all addressed in a well-designed supply chain (IBM). Within a successful supply chain optimization, there are three stages.

- Supply chain design describes network design activities such as where facilities are situated, how waste and products flow between them, and strategic objectives such as demand forecasting, supply establishment, and industrial operations planning and scheduling.
- Supply chain management involves making a comprehensive plan for supply chain development, planning inventory, and coordinating assets to get customers the most products, services, and information as quickly as possible.
- Managing the supply chain is focused on execution-oriented applications and systems, such as real-time decision support, supply chain visibility, other management systems, warehouse and inventory management, global trade management, and other execution-oriented applications.

Genetic Algorithm (GA)

The genetic algorithm is a stochastic optimization approach derived from natural selection and the survival of the fittest (Ray et al. 2021). A genetic algorithm (GA) is a meta-heuristic inspired by natural selection that belongs to the wider family of evolutionary algorithms in computer science and operations research (EA). Genetic algorithms depend on biologically inspired operators, including mutation, crossover, and selection, to develop high-quality solutions to optimization and search problems. A population of potential solutions to an optimization issue is developed toward superior answers in a genetic algorithm (Joshi 2021).

Genetic Algorithm Working Principle

GA falls within the category of evolutionary algorithms based on Darwin's theory of evolution. Initially, the genetic algorithm has a population of solutions (represented by chromosomes) (Crowl et al. 1991). A population's solutions are chosen and processed to create a new population. The belief that the new population would perform better than the previous one motivates the planned development of a new population. The fitness of the solutions chosen to create new solutions (offspring) is determined. They will be more capable of passing on their traits to the following generation if they are better suited. It is repeated until a pre-defined criterion (for example, the number of populations or the best solution improvement) is met (Gupta et al. 2019).

Genetic Algorithm Applications and Uses

a) Engineering design, traffic, and shipping routing, and robotics are just a few real-world uses of genetic algorithms (Suman et al. 2018).
b) Engineering design to make the design cycle quicker and more cost-effective, engineering designs rely on modeling and simulations.
c) Many sales-based organizations employ traffic and shipment routing to save time and money.
d) Robotics, GA, is being utilized to develop learning robots that will act like people and do tasks like preparing our meals and doing our washing.
e) Financial markets are used to forecast the performance of publicly traded stocks in the future.
f) System engineering is the process of doing multi-objective activities, such as developing turbines that generate electricity.
g) Aeronautical engineering to create supersonic aircraft wing shapes that minimize aerodynamic drag at supersonic cruising speeds, subsonic drag, and aerodynamic load.

The Benefits and Drawbacks of Genetic Algorithms (GAs)

The Benefits of Genetic Algorithms:

1. GAs are capable of addressing issues with a large number of viable solutions.
2. GAs investigate all of their options before deciding on the greatest fit.
3. Genetic algorithms are adaptable and can rapidly adjust to changes.
4. GA's selection process is non-biased and open-minded.

The Drawbacks of Genetic Algorithms:

1. Finding the best way out of hard, high-dimensional, multimodal situations often requires expensive fitness function assessments.
2. Genetic algorithms do not scale effectively as the complexity of the problem increases.
3. The "better" answer is just superior to the alternatives. As a result, the stop condition isn't always obvious.
4. GAs often tend toward local optima or random places instead of the problem's global optimum.
5. GAs can't handle issues if the only fitness criterion is a single right or wrong answer.
6. Other optimization methods may work better than genetic algorithms regarding how quickly they find the best solution to an optimization problem or issue.

Supply Chain Network Optimization Using a Genetic Algorithm

A genetic algorithm is employed in SC to help filter out all the undesired disruptions that would lead to the SC's ineffectiveness by selecting the best ways to address a given problem using a "survival of the fittest" strategy.

Fuzzy Logic-Meaning and History

The truth value of variables in fuzzy logic can be any real number between 0 and 1, making it a type of many-valued logic. It deals with partial truth, where the true value might be between true and false. The truth values of variables in Boolean logic, on the other hand, can only be the integer values 0 or 1. The concept of fuzzy logic is founded on individuals making judgments based on inexact and non-numerical data. Fuzzy models or sets are mathematical representations of ambiguity and imprecise data (hence the term "fuzzy"). These models can identify, express, manipulate, understand, and utilize ambiguous and uncertain facts and information.

Fuzzy Logic's History

With Lotfi Zadeh's proposal of fuzzy set theory in 1965, the term fuzzy logic was coined. However, fuzzy logic has been investigated as infinite-valued since the 1920s, especially by Ukasiewicz and Tarski.

Applications of Fuzzy Logic

It's utilized in control systems to allow specialists to input broad guidelines like "raise the train's brake pressure if you're close to the target station and traveling rapidly," which can then be quantitatively improved within the system.

Japan was home to several of the first effective uses of fuzzy logic. The first prominent use was on the Sendai metro train, where fuzzy logic improved the ride's economy, comfort, and accuracy (Emokhare & Igbape 2015). It's also been used by the Institute of Seismology Bureau of Meteorology in Japan for handwriting recognition in Sony pocket computers, helicopter flight aids, subway system controls, improving automobile fuel efficiency, single-button washing machine controls, automatic power controls in vacuum cleaners, and early earthquake detection.

Artificial Intelligence

When studied, AI and fuzzy logic are the same things. Neural networks have a hazy logic at their core (Bechtler et al. 2001). A neural network will take several valuable inputs, weigh them differently concerning one another, and arrive at a decision that is usually also valuable. There are no sequences of either-or judgments in that process, which describes non-fuzzy mathematics, practically all computer computerized systems of programming, and digital electronics. In the 1980s, academics were split on whether "common sense" models or neural networks were the most successful method of machine learning. The former method necessitates massive decision trees and binary logic compatible with the hardware. Although physical devices are confined to binary logic, AI can do computations via software. This is how neural networks function, resulting in more accurate simulations of complicated situations. A wide range of electrical devices quickly used neural networks.

Medical Decision-Making

In medical decision-making, fuzzy logic is a crucial notion. Because medical and healthcare data might be subjective or ambiguous, fuzzy logic-based techniques in this sector have a lot of promise to help (Wang et al. 2017).

F fuzzy logic may be employed in various ways within the medical decision-making framework. Medical image analysis, biomedical signal analysis, or signals, and feature extraction selection of images or signals are examples of such aspects.

Computer-Assisted Diagnosis Using Images

In medicine, image-based computer-aided diagnosis (CAD) is one of the most prevalent domains where fuzzy logic is used. CAD is a computerized system of interconnected tools that can help doctors make better diagnostic decisions. For example, if a clinician discovers an aberrant lesion still in its early stages of development, they may employ a CAD method to describe and identify the lesion's nature. Fuzzy logic can be a good way to characterize the major features of this lesion (Yanase & Evangelos 2019).

Fuzzy Logic for Supply Chain Optimization

The necessary flow is established in the supply chain regardless of the connection, proving the most effective method for achieving the desired result.

Supply Chain Network Optimization Using a Hybrid Approach

Because of the intricacy of their hybridization and the inadequacies of each system, the hybridization of multiple functions associated with an ideal supply chain network has not been adequately discussed in earlier research publications. This justifies the urgent need to create a model to address these flaws.

Fuzzy Logic Hybridization Genetic Algorithm Working Principle

Even though some systems are very complicated and can't be described well with just one AI tool, it's becoming more common to use a combination of fuzzy logic, neuro-computing, and evolutionary algorithms to get a better picture.

State and local government environmental protection organizations in Nigeria are grappling with a growing problem: waste management. A rapid increase in the amount of solid waste produced has outpaced the agencies' ability to increase their financial and technological resources to keep up with it (Ogwueleka 2009).

MATERIALS AND METHODS

Description of Area of Study

Lagos is Nigeria's most populous metropolis, with about 20 million people. According to population, it is Nigeria's most populous state but is Nigeria's smallest state by area; it is located in the southwest and covers 3577 square miles. Lagos has a population density of approximately 5032 people per square kilometer and is one of the world's fastest-growing metropolitan areas, growing at an annual average rate of around 4 percent (Ayeni 2017). About 70% of Nigeria's commercial activity occurs here, and it has an excellent location, which explains the state's large population (ibid). Approximately 37% of Lagos' total land area is devoted to the city's 20 Local Government Areas (LGAs). However, over 85% of the population lives in these areas.

Alimosho LGA, Eti-Osa LGA, Oshodi-Isolo LGA, and Ibeju-Lekki LGA families were surveyed in this study. Two years ago, 11,456,783 people lived in Alimosho LGA, the state's largest and most populous LGA. Now, there are 287,958, 1,621,789, and 288,743 people in Eti-Osa LGA, Oshodi-Isolo LGA, and Ibeju-Lekki LGA (Lagos Bureau of Statistics, 2010). Private operators are located in Alimosho, whereas garbage disposal sites and scavengers are found within Ibeju-Lekki Local Government Area. As a result, all the homes in the city were represented by those who responded. Fig. 3 presents the map of the location of the study in Lagos State.

Methodological Framework

An example of a case study methodology is used to describe how this research was conducted. Data collection is an organized collection of data about an individual or individuals, a social situation, or issues through various means and organized in a way that provides a better understanding of the study topic. In addition to being used to study complex phenomena, it also serves as a way for theories to be applied. For a more thorough understanding of the research topic, it's the systematic gathering and analysis of information about a specific individual or individuals, as well as a social situation or issues. Due to its focus on solid waste management in Lagos State (Nigeria), the case study method is appropriate for this study. Data were gathered for the study using a variety of methods. Because Lagos is Nigeria's most populous city, it was chosen as a case study for this research. Researchers looking to better manage garbage collected from city residents could serve as a model for similar work being done in other cities across the country, as the state appears to be setting an example for development initiatives elsewhere. While many studies have focused on the state's solid waste disposal issues, the sector's major players have received insufficient attention. Characterization and supply chain analysis of solid waste for all trash generated are both included in this study. Hybrid genetic algorithms and fuzzy logic algorithms are proposed to help with the supply chain.

Data Collection and Methodology

The approach used in this research is essentially a qualitative method that focuses on the quality of data obtained and analyzed rather than the quantity of study to help find answers to research questions by studying society and its inhabitants to achieve its associated goals. Primary and secondary data were collected from various sources, including field observation and interviews with various stakeholders in Lagos, including homes, private operators, LAWMA staff,

Fig. 3: Map of Lagos State (Google Maps).

Fig. 4: Household waste.

Fig. 5: Scavengers on the site.

and scavengers. A thorough review of relevant literature gathered secondary data. Fig. 4 presented various Household Waste, and Fig. 5 presented typical Scavengers on Site.

Materials

To collect data from interviews in the field, researchers often use a tape recorder, which allows them to focus on the interviewee's response and follow up on points of interest; they can also identify any inconsistencies in the interviewee's answers if necessary. A camera and the same method were used to monitor the garbage disposal site. A camera and a pair of gloves were used to spy on the house. This study relied heavily on a camera to capture visual representations of its subject matter and findings to aid in its presentation and comprehension. Photographing various interesting things in the field, including domestic solid waste storage, collection, disposal, and landfill activities, was possible. After completing the fieldwork, all recorded responses and photographs were categorized for analysis.

Data Analysis

Qualitative data analysis can be approached in a variety of ways. An in-depth examination of data to discover and interpret trends is known as content analysis. Content analysis is the detailed and in-depth examination of data to identify and interpret trends. A Google questionnaire form was utilized for the household interviews in this study, with graphs and charts created for each respondent's response. A PSP and LAWMA operator reply Excel spreadsheet was employed to tabulate the responses for the scavengers. Following the receipt of the responses, a C++ program was utilized to assist in the execution of the Fuzzy logic and Genetic algorithm iterations.

Modeling with Fuzzy Logic

A fuzzy-genetic algorithm is employed in providing suitable optimized solutions.

The fuzzy inference system (FIS) and genetic algorithm are synergized such that the fuzzy inference takes the members of the population as input values and provides an output value that serves as the fitness of the individuals in the population.

The FIS serves the fitness function; hence, it must be built within the boundaries of the definition of a good or poor solution. The Matlab fuzzy logic designer was used to build the fuzzy inference system for each local government area. However, these were implemented in C++ for the benefit of computational speed while continuously iterating through generations of the genetic algorithm.

It is important to define all linguistic variables and the boundaries of the membership functions before building the FIS. This leads to the following:

- The input variables and linguistic variables
- The boundaries of the membership functions
- The Fuzzy Inference System

Input variables and linguistic variables:

To optimize waste management, the genetic algorithm seeks to provide a good solution consisting of the number of refuse bins required to manage the waste produced and how frequently the waste should be removed.

Hence, the input variables to the FIS are 'frequency' and 'number of refuse bins.' The genetic algorithm represents the genotypes using real numbers. Therefore, no conversion is required before passing individuals through the FIS.

Boundaries of the membership function:

a. The frequency input variable consists of two membership functions, namely, poor and good.

b. This variable ranges from 1 to 7 since it describes the number of times the waste is removed in a week.

c. The frequency is 100% poor at the point for which, after the consecutive value of frequency, the waste generated in the remaining days of the week fills up the provided refuse bin.

   If the waste distribution at 'the max' number of refuse bins is 25 bags per day, and the capacity of the refuse bin is 100 bags. It will take 4 days to fill up the bin. Hence, the frequency value '3' is 100% poor. This is because after taking out the refuse for 3 consecutive days, the refuse bin gets full before the next week. Though this consecutive combination is only a probability, it is considered.

d. The input variable, 'number of refuse bins,' has 2 membership functions, namely, poor and good.

e. The number of refuse bins required is 100% poor when the distribution of daily generated waste exceeds or fills the provided bins in a single day, considering the capacity of the bins provided.

   If the total generated waste is 250 bags daily, and the capacity of the bin is 100 bags. If only 2 bins are provided, the daily distribution is 125 bags, which exceeds the capacity of the bin. Hence, the input value 2 is 100% poor.

f. The number of refuse bins required is 100% good at the point where the daily distributed waste takes 5 consecutive days to exceed or fill the bin.

   If the total generated waste is 250 bags daily and the capacity of the bin is 100 bags. It will take 5 days to exceed the capacity using 10 bins.

g. The output value, the fitness value, spans a scale of 1-10, having 2 membership functions, namely, poor and good. They span from end-to-end meetings at 50%.

Fuzzy Inference System:

Generally, there are three popular types of fuzzy inference methods: Mamdani fuzzy inference, Sugeno fuzzy inference, and Tsukamoto fuzzy inference. Fuzzifying the crisp input values into membership values according to appropriate fuzzy sets is the same in all three types. However, differences occur in integrating rules into a single precise value.

The Mamdani inference is widely used, as it is straightforward and less complex and is used in this project to build fuzzy inference systems. In this inference type, the consequent of the IF-THEN rule is defined by a fuzzy set, and a corresponding value reshapes the output fuzzy set of each rule.

Mamdani-Type Fuzzy Inference Process:

The Mamdani-type fuzzy inference process consists of five steps:

- Fuzzify input variables
- Apply fuzzy operator
- Apply implication method
- Apply aggregation method
- Defuzzification

The input variables and output variables both have 2 membership functions. Hence, complete and symmetric rules are used to avoid disturbance from rules.

IF-THEN rules:

a. If (frequency is poor) and (the number of refuse bins is poor) then (fitness is poor)
b. If (frequency is good) and (the number of refuse bins is good), then (fitness is good.)

The THEN-part (implication) of the fuzzy operator reshapes the fuzzy set of the consequent part according to the result associated with the antecedent. The AND method is set to 'min,' and the aggregation method is set to 'max.' The mean of the maximum defuzzification method is chosen, as it has the characteristic of spanning through to the ends of the output range.

Due to the difference in the population of the considered local government areas, and thus the difference in waste generated, different fuzzy inference systems were built for each local government area.

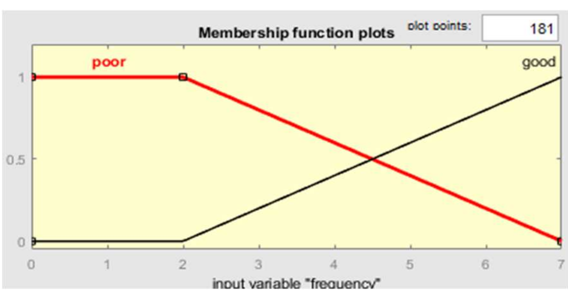


Fig. 6: Frequency membership function plot.

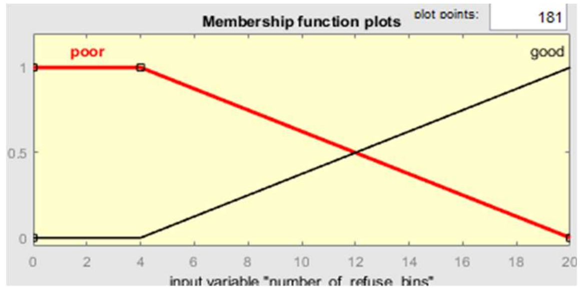


Fig. 7: Number of refuse bins' membership function plot.

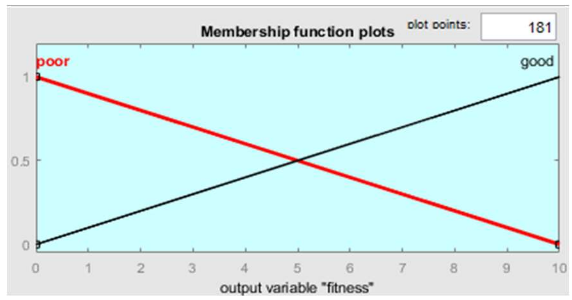


Fig. 8: Output (fitness) membership function plot.

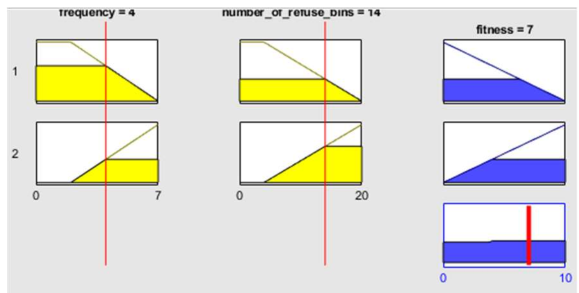


Fig. 9: Implication and aggregation process.

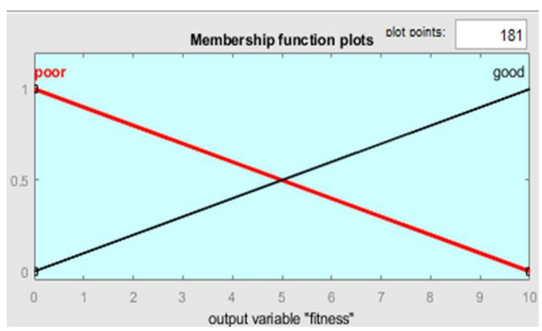


Fig. 10: Output (fitness) membership function plot.

Fig. 6 presents the frequency membership function plot, Fig. 7 presents the Number of refuse bins' membership

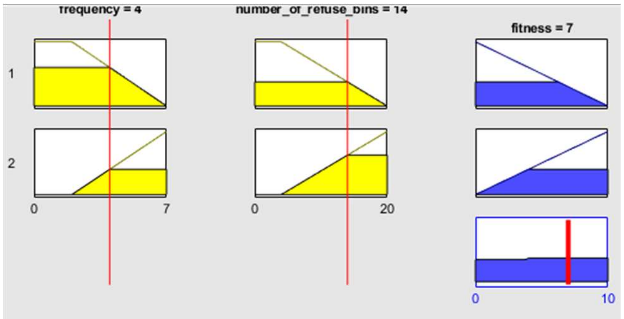


Fig. 11: Implication and aggregation process.

function plot, Fig. 8 presents the Output (fitness) membership function plot, Fig 9: Implication and aggregation process, Fig. 10 presents the Output (fitness) membership function plot and Fig. 11 presents the Implication and aggregation process. It indicates the membership function plots for the inputs, outputs, implication, aggregation, and input-output surface peculiar to each LGA. The membership function plot for frequency input is the same for all LGAs and the output membership function plot. The Fuzzy Inference System

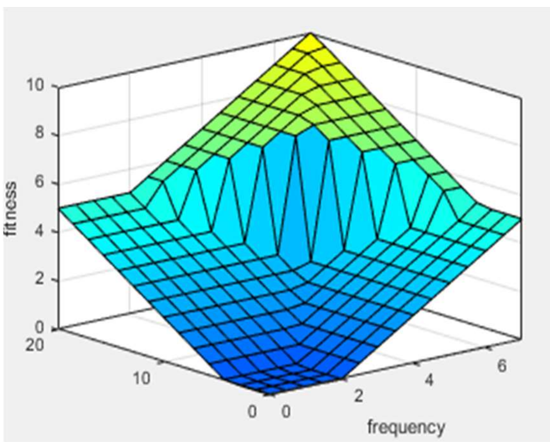


Fig. 12: Input-Output Surfaces.
(Fuzzy Inference System for Oshodi-Isolo LGA: Population-1621789, Average daily waste-48 bags)

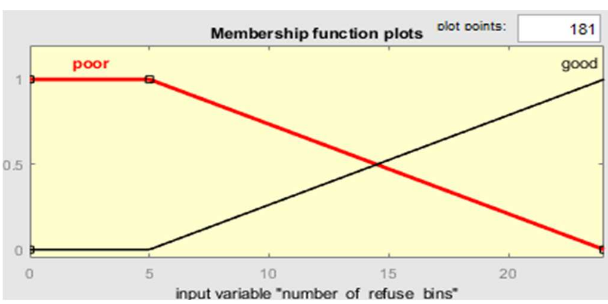


Fig. 13: 'Number of Refuse Bins' Membership Function Plot.

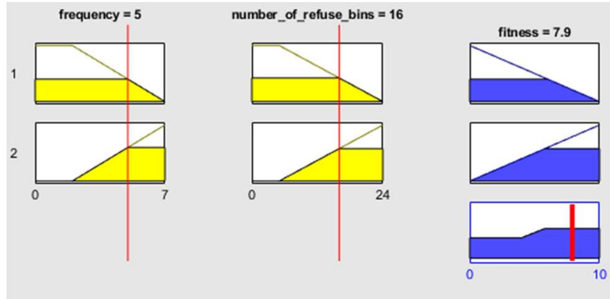


Fig. 14: Implication and aggregation process.

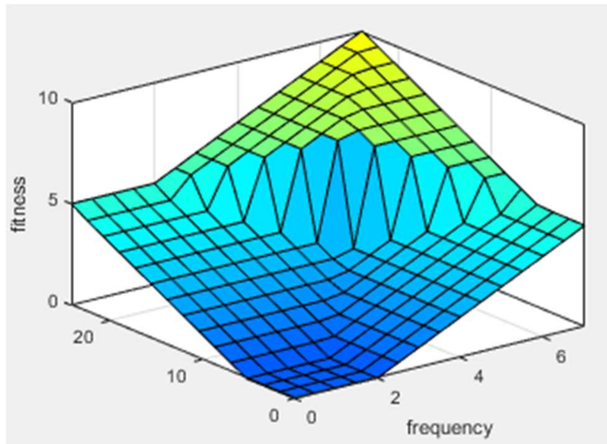


Fig. 15: Input-Output surfaces.
(Fuzzy Inference System For Eti-Osa LGA: Population-287958, Average daily waste-30 bags)

for Alimosho LGA has a population of 11,456,783 and an average daily waste of 212 bags.

Fig. 12 presents Input-Output Surfaces. The Fuzzy Inference System for Oshodi-Isolo LGA: Population-1621789, Average daily waste-48 bags. Fig. 13 presents the Number of Refuse Bins' Membership Function Plot. Fig. 14 presents the Implication and Aggregation Process, and Fig. 15 presents the Input-Output surfaces for the Fuzzy Inference System For

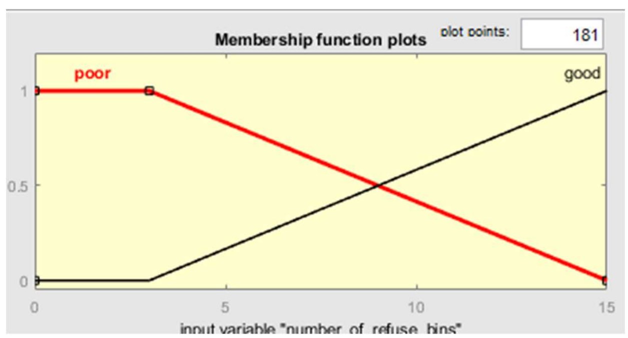


Fig. 16: 'Number of Refuse Bins' Membership Function Plot.

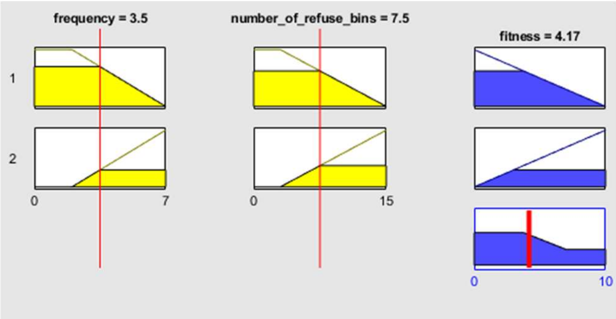


Fig. 17: Implication and Aggregation Process.

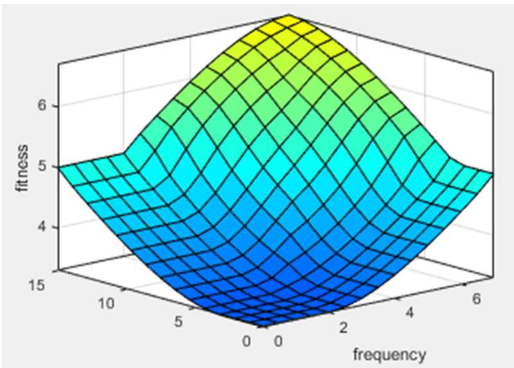


Fig. 18: Input-Output Surface.
(Fuzzy Inference System For Ibeju-Lekki LGA: Population-288,743, Average daily waste-21 bags)

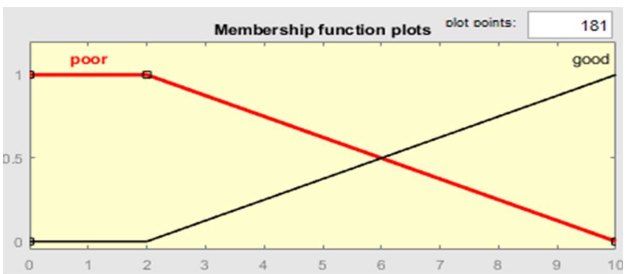


Fig. 19: 'Number of refuse bins' membership function plot.

Eti-Osa LGA: Population-287958, Average daily waste-30 bags.

Fig. 16 presents the number of Refuse Bins' Membership Function Plot, Fig. 17 presents Implication and Aggregation Process, Fig. 18 presents the Input-Output Surface for the Fuzzy Inference System For Ibeju-Lekki LGA: Population-288,743, Average daily waste-21 bags and Fig. 19 presents the Number of refuse bins' membership function plot for various aspects of the study area.

While the FIS provides the fitness of each solution (members of the population), the genetic algorithm selects the best solutions (individuals) in the entire population through a selection process, performs crossover to create new solutions (offspring), and mutates randomly selected members of the population to maintain diversity. This process is recursively for a specified number of iterations or until some other criteria are attained. In this case, the GA is allowed to run until convergence is attained.

The GA used in this project follows the outlined steps:

- Population Initialization
- Obtain fitness
- Selection process
- Crossover
- Mutation

The GA is manually initialized with 10 random individuals whose fitness is evaluated by the FIS. Selection is carried out using the rank selection method. Beginning at the top, individuals are selected according to their expected count. The size of the population is maintained; hence, once the number of individuals required is reached, the remaining individuals are removed from the population. The best individuals in this new generation are selected, and a randomly selected genotype is exchanged (crossed over) to create offspring that replace the parents. Finally, individuals are randomly selected from the resulting population, and a randomly selected genotype is changed to maintain diversity and prevent premature convergence. Genotypes are represented as real numbers; therefore, mutation is achieved by simply increasing or decreasing a random genotype within the boundaries of its membership function. The GA was implemented in C++ for the benefit of computational speed.

RESULTS AND DISCUSSION

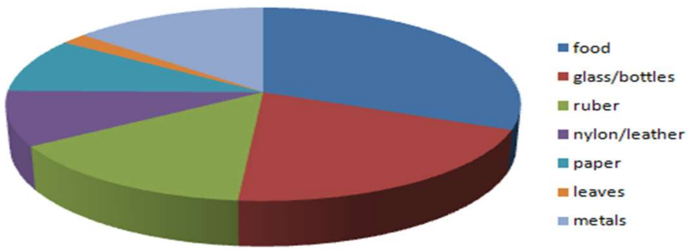
Data obtained from the field with regard to their different solid waste management practice was analyzed, and the results generated are presented in this section using charts and graphs.

Composition of Household Waste in Selected Neighborhoods in Lagos State

From the questions carried out during the research work, each household has approximately at least 25% food, 20% glass/bottles, 15% rubber, 15% metals, 10% papers, 10% nylon/leather, and 5% leaves (Fig. 20).

The Supply Chain Network in the Selected Areas

Any households interviewed did not recycle, although some reuse their waste, and no segregation is done before disposal. Some households prefer to give their waste to scavengers



Source: (Mukhtar et al. 2019)

Fig. 20: Composition of Household Waste.

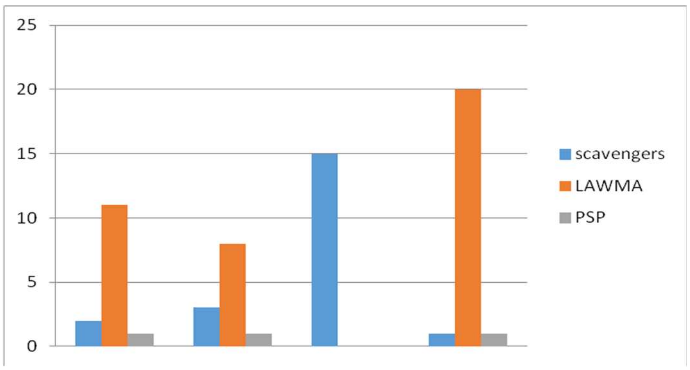


Fig. 21: Preferences of households on personnel for waste disposal.

because it can be sold to itinerant scavengers at a fair price. In addition to selling at a fair price, the scavengers revealed that the metals were piled up, sent to local fabrications, and converted to new items such as metal pots and kettles. While some individuals don't even know what the PSP operators are, those with an idea have no interest in them. Some say it is due to the prices allocated to their waste or their frequency of appearance (Fig. 21).

The GAs were set to stop if the change in average fitness was negligible after several iterations. The Fuzzy-GA provided the following solutions after converging (Fig. 22). The solution consists of how frequently waste should be removed from the provided bin, the number of bins required in the LGA, and the fitness value of each proffered solution (Figs. 23-25, Tables 1-4).

Table 1: Alimosho LGA Fitness Variables.

Frequency of waste removal	Number of bins required	Fitness
7	16	8.75
6	20	9
6	18	9
7	18	9.4
7	19	9.7
7	20	10

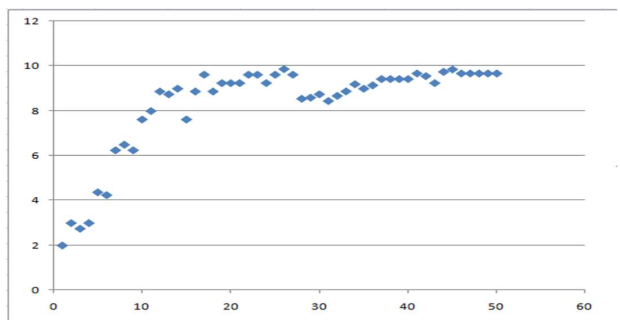


Fig. 22: Scatter plot of Average Fitness for Alimosho.

Table 2: Oshodi-Isolo LGA Fitness Variables.

Frequency of waste removal	Number of bins required	Fitness
6	20	9
7	24	10
7	19	8.7
7	21	9.25
6	19	8.7

CONCLUSIONS

While carrying out the research, it was observed that the bulk of the waste produced in households was 25% food, 20% glass/bottles, 15% rubber, 15% metals, 10% papers,

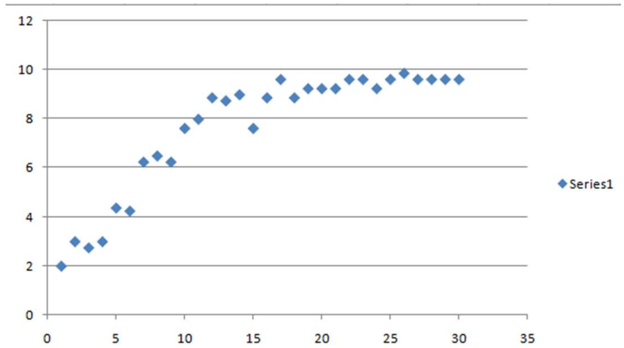


Fig. 23: Scatter plot of Average Fitness for Oshodi-Isolo.

Table 3: Eti-Osa Fitness LGA Variables.

Frequency of waste removal	Number of bins required	Fitness
5	10	7.95
7	15	10
6	13	9
7	14	9.6

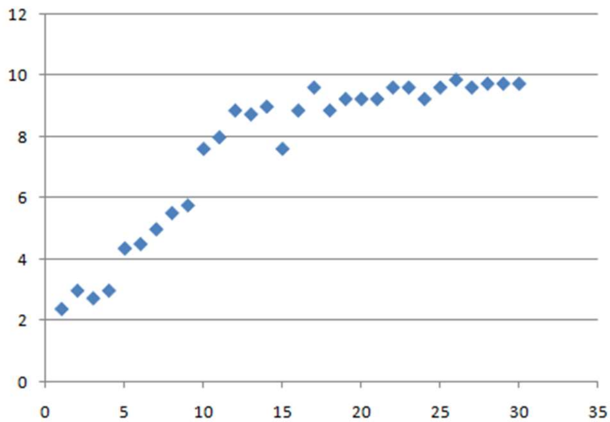


Fig. 24: Scatter Plot of Average Fitness for Eti-Osa.

Table 4: Ibeju-Lekki Fitness Variables.

Frequency of waste removal	Number of bins required	Fitness
7	10	10
5	7	8
6	8	8.75
6	9	9
7	9	9.4

10% nylon/leather, and 5% leaves. Of which the household does no proper sorting. Also, most correspondents prefer the inclusiveness of the scavengers due to various reasons ranging from frequency of appearance to price. Some households do not know what the PSP is about, and the data

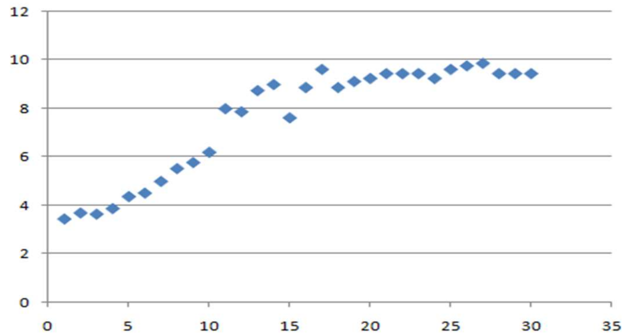


Fig. 25: Scatter plot of average fitness for Ibeju-Lekki.

was then used in modeling the Fuzzy-GA. The Fuzzy-GA used in this optimization exercise performed efficiently, iterating for at least 30 generations for each LGA. The proffered solutions are peculiar to each LGA and are all options for optimized solutions within the boundaries of the objectives. These solutions not only optimize but preserve the existing waste management supply chain, such that the scavengers can participate by moving the waste from houses to these provided refuse bins. The PSP is involved in moving the waste from the provided bins to the already existing dump sites, where LAWMA handles it with just the appropriate number of workers and materials required for the work allotted to it. Though the provided solutions stand out by fitness values, the best solution should be chosen based on other objectives such as feasibility, cost of implementation, and so on.

RECOMMENDATIONS

The households that are the major waste generators do not practice waste segregation and recycling. Waste segregation is fundamental for successful management, but due to the probability of financial constraints, the most basic starting point will be the separation of the household itself. This could be done by imploring the household to have at least two waste receptacles, such as wheelie bins, so that organic wastes are put in one, and inorganic waste is put in the order. The LAWMA, as a way of encouragement, could probably provide these waste bins so that if the rules are not followed, sanctions and fines should be placed on those who fail to obey. These methods not only help to separate the waste but also make the job of the workers easier. From the analysis carried out results gathered, it is obvious that all the personnel involved in the waste management have no proper relationships, resulting in improper waste management. For sustainable waste management to occur, all the individuals have to play a strategic role in the sense that the scavengers playing the key roles in this link must be properly inculcated into the flow by formally employing the scavengers to work hand in hand with the PSP and in-turn the PSP works with the LAWMA official so that the supply chain leaves no loopholes for mismanagement. Scavengers available in Lagos state should be properly integrated into the system. Such that an association is created for them where it is easier to take a record of the areas each of the scavengers belongs to so when issues arise in those areas, they will be attended to efficiently and easily.

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