Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

The Application of Genetic Algorithm for the Optimization of Solid Waste Management System in Port Harcourt Metropolis

Emine, Awoala Joybel[1, a], Nwosu, Harold Ugochukwu[2, b] and Ukpaka, Chukwuemeka Peter[3, c]

[1]Department of Mechanical Engineering, Faculty of Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.
[2]Department of Mechanical Engineering, Faculty of Engineering, University of Port Harcourt, Choba, Port Harcourt, Nigeria.
[3]Department of Chemical and Petrochemical Engineering, Faculty of Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria.
[a] awoalajoybel@yahoo.com, [b] hu.nwosu@uniport.edu.ng, [c] chukwuemeka24@yahoo.com

ABSTRACT
Solid waste has turned out to be a global challenge facing Port Harcourt cosmopolis. A justifiable solid waste handling structure which secures environmental safety and human health becomes a critical target for Port Harcourt cosmopolis. Waste management is about the assembling, conveying and disposal of waste from the factors that generates the waste. Over 60% of resources for waste management is waste spent on the collection and evacuation phase, hence optimizing this phase is crucial. The study aims to use Genetic Algorithm methodology to deal with the nonlinear optimization model to maximize the reliability of the system with operation cost, fixed cost, vehicles of different capacities, taking into cognizance past data from Rivers state waste management agency and related literatures. The algorithm was tested in a simplified real case study from 2016 to 2020 of Port Harcourt cosmopolis to optimize the operation cost required to operate the heterogonous fleet of vehicles for waste disposal. The probability plot shows reliability numbers of 93% for 2016, 91% for 2017, 90% for 2018, 91% for 2019 and 89% for 2020 scenarios. These results revealed scenarios with more trucks and higher capacity with lesser waste load tend to have a higher reliability than scenarios with the same waste load or more. Pursuing this goal which pertains to solving the optimization problem using genetic algorithm, was accomplished. It is therefore recommended that Genetic Algorithm optimization technique should be considered as an alternative applicable to maximize the reliability of the system regarding the arrangement of diverse types of vehicles for waste management system.

KEYWORDS: Solid Waste Management System, Genetic Algorithm, Reliability, Optimization Problem, Waste Collection, Evacuation Phase.

Cite This Paper: Emine, A. J., Nwosu, H. U. & Ukpaka, C. P. (2022). The Application of Genetic Algorithm for the Optimization of Solid Waste Management System in Port Harcourt Metropolis. *Journal of Newviews in Engineering and Technology*. 4(3), 93 – 103.

1.0 INTRODUCTION
Nigeria is saddled with the menace of environmental waste management especially solid waste, and it is common in the major cities such as Port Harcourt cosmopolis due to the absence of effective waste management system. More so, lack of statistics on solid waste, inadequate financial resources, and skills within the cosmopolis and government authorities have prompted counterproductive organization for solid waste management (Onokerhoraye, 1985; PAI Associates, 1982). This has also hugely put-up random discarding of waste on the roads, stream channels, bush lands and open spaces (Ekere, 2003; Falomo, 1995), thus deforming the topography of the city, giving rise to flooding, and spreading of vector borne

diseases. Data shows that the per capital waste generation in Port Harcourt cosmopolis ranges from 0.66 – 1.25kg/cap/day and the property of the waste comprises of organic matter, plastics, metal, nylon, glass, and others (Abah & Ohimain, 2010; Ayotamuno & Gobo, 2004; Ibiebele, 1986; Igoni *et al.*, 2007).

Solid waste includes all solid material that the process no longer considers of any adequate worth to retain (Tchobanoglous *et al.*, 1993; Thurgood *et al.*, 1995). It encompasses but is not limited to commercial and industrial, construction and hazardous waste. An exposition by Kofoworola (2007) defined waste management as the orderly and methodical channeling of waste via pathways to make sure that it is discarded with consideration to tolerable communal health and environmental protection. Okecha (2000) affirmed that solid waste has become a constantly occurring feature in our urban habitation and the difficulties faced in evacuating them cannot be put aside. Hence the inhabitants are faced with health challenges arising from the presence of this waste. The health effects of these left out and decayed rubbish cannot be ignored, although their impact is profound (Oyeniyi, 2011). According to a United Nations report in August 2004, developing countries are positively progressing in ensuring access to clean drinking water but lagged in sanitation goals. Ongoing urbanization puts pressure on the significance of effective waste collection. Urban habitation must employ ways to optimize the receipt of collection (Belien *et al.*, 2011).

Waste management is about the collection, transportation, and disposal of waste from the factors that generate the waste. Waste collection is a difficult problem that must be aware of many agents that influence the collection, hence making this process effective is a herculean task. This is because this type of problem does not have an exact solution in a feasible time. Over 60% of resources for waste management is waste spent on the collection and evacuation phase (Karadimas *et al.*, 2007)

The most recent Solid Waste Management Act in Port Harcourt is the Rivers State Waste Management Act 2014 which gives the Rivers State Waste Management Agency the gross power and authority for proper waste management (Okoli *et al.*, 2020). It also gives the agency the authority to apply waste separation at inception, foist waste management bills, handle waste fecundating and recycling activities and for proper disposal of waste in Land fill site. Although policy execution is a big problem for any government, it is very necessary to understand ground issues before any decision is enforced to the community. In Port Harcourt cosmopolis, MSW management is still struggling to get its feat. The organisational and policy framework where they are found are not in line with international best practices. Also, the existing solid waste policies in the state are not implemented and enforced to the later. In solid waste management system how to evaluate the reliability of the system and how much regime, price, are appropriate to put in place a dependable structure is a major concern in addressing the issues of solid waste management in the cosmopolis. This brings about having an algorithm to deal with this problem in a feasible time, leading the researchers to develop heuristic and meta-heuristic algorithm to address the problem in a smart way.

Punajaya and Hanggara (2020) optimized the number of waste transporters by applying GA, in her study GA can optimize the number of Batam City transporters based on number of collection points per district and distance between collection points and final disposal site. Bhargava *et al.* (2019) in their works used GA to determine cost-effective routes for solid waste collection to reduce distance travelled by waste collection trucks, considering the

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

collection capacity of the trucks, waste generated in bins, traffic conditions and time constrains. The goal of the current paper is to explore the possibility of using GA approach to optimize the reliability of solid waste management system in Port Harcourt cosmopolis, with multiple trucks of different capacities, yearly waste loads for the period under review (2016 to 2020), operational cost, fixed cost, taking into cognizance past data from Rivers State Waste Management Agency and reputable literatures. The algorithm concern is about serving the edges, differently from the usual serving system where traditional methods fail (Mulligan & Brown, 1998).

2.0 MATERIALS AND METHODS

2.1 Data Collection Sources

The sources of data for this study were from annual reports of finance and solid waste management unit of Rivers state waste management agency, academic journals and publications, data were also utilized. This information is shown in Tables 1 - 9.

Table1: Population Projection Data

Scenarios	Value
2016	2,467,000
2017	2,596,000
2018	2,731,000
2019	2,873,000
2020	3,020,000

(Source: UNP, 2017)

Table 2: Yearly Waste Generation Load

Scenarios	Value (tonnes)
2016	930,009.7
2017	975,966.2
2018	1,026,719.5
2019	1,080,104
2020	1,138,479.6

(Source: Ayotamuno & Gobo, 2004)

Table 3: Land Fill Capacity (Waste per capita)

Scenarios	Value (tonnes)
2016	2,541
2017	2,673.9
2018	2,812.9
2019	2,959.2
2020	3,110.6

(Source: Ayotamuno & Gobo, 2004; Rawtec, 2015)

Table 4: Vehicle Types

Scenarios	Types
2016	A, B, C
2017	A, B, C
2018	A, B, C
2019	A, B, C
2020	A, B, C

(Source: RIWAMA, 2020a)

Table 5: Vehicle Capacity (tonnes)

Scenarios	Capacity (tonnes)
A	20
B	15
C	30

(Source: RIWAMA, 2020a)

Table 6: Maximum Number of Vehicles for each Scenario

Scenarios	Type A	Type B	Type C
2016	200	100	300
2017	200	100	300
2018	200	100	300
2019	200	100	300
2020	200	100	300

(Source: RIWAMA, 2020a)

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

Table 7: Fixed Cost ₦/year

Scenarios	Type A	Type B	Type C
2016	26,970,281	23,343,244	44,640,466
2017	29,474,194	24,008,781	47,724,772
2018	33,984,416	27,105,396	51,027,959
2019	35,859,453	29,054,798	52,493,054
2020	38,025,219	34,951,324	68,308,776

(Source: RIWAMA, 2020b)

Table 8: Operation Cost ₦/tonnes

Scenarios	Type A	Type B	Type C
2016	29	25.1	48
2017	30.2	24.6	48.9
2018	33.1	26.4	49.7
2019	33.2	26.9	48.6
2020	33.4	30.7	60

(Source: Yang et al., 2016).

Table 9: Waste Budget

Scenarios	Amount (#)
2016	2,100,000,000
2017	2,200,000,000
2018	2,400,000,000
2019	2,580,000,000
2020	3,000,000,000

(Source: RIWAMA, 2020b)

2.2 METHODS

2.2.1 Research Design

The data engaged historical research design. All data were analyzed using genetic algorithm-based optimization.

2.2.3 Data Analysis.

The data sources relied on two major agents; waste generated and system capacity. Genetic algorithms have been used to solve complex assignment problems in literature (Okafor *et al.*, 2019). Python programming language and MATLAB software were utilized to conduct complex mathematical operation for the research.

2.3.1 Data Formulation Problem

The solid waste management problem was formulated based on Cheng *et al.*,2018 as depicted in equation (1) and the reliability is optimized by maximizing the reliability index of the system in equation (1) as the objective function subject to constraints in equations (5), (6), (7) and (8).

Recall $\beta = {}^{\mu_y}/_{\sigma_y}$ (1)

$$\mu_{y=} \sum_{i\varepsilon v} \mu_{rti} v_i \, \mu_{ri} - \mu_L > O \quad (2)$$

$$\sigma_y^2 = \sum_{i\varepsilon v} \left[(\mu_{rti} v_i)^2 \sigma_{\mu_{ri}}^2 + (\mu_{ri} v_i)^2 \sigma_{rti}^2 \right] + \sigma_L^2 \quad (3)$$

$$\beta = \frac{\sum_{i\varepsilon v} \mu_r v_i \, \mu_{ri} - \mu_L > O}{\sum_{i\varepsilon v} [(\mu_{rt} v_i)\sigma_{ri} + (\mu_{rt} v_i)\sigma_{ri}] + \sigma_L} \quad (4)$$

Maximizing β subject to the following constraints

$$\sum_{i\varepsilon v} v_i \, D\mu_{rti} \, v_i + \sum_{i\varepsilon v} v_i \, u_f \le max_c \quad (5)$$

$$\sum_{i\varepsilon v} v_i \, \mu_{rti} \, \mu_{ri} \le L_c \quad (6)$$

$$v_i \le max_{vi} \; v_i \, \varepsilon v \quad (7)$$

$$\sum_{i\varepsilon v} v_i \le N_v \quad (8)$$

Thus,

$$\mu_{y=} \sum_{i\varepsilon v} \mu_{rti} v_i \, \mu_{ri} - \mu_L > 0 \quad (9)$$

$$\sigma_y^2 = \sum_{i\varepsilon v} \left[(\mu_{rti} v_i)^2 \sigma_{\mu_{ri}}^2 + (\mu_{ri} v_i)^2 \sigma_{rti}^2 \right] + \sigma_L^2 \quad (10)$$

Where

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

max_c is maximum cost encompassing fixed cost and operation cost (₦),

D is average distance between the collection points and the landfill areas,
μ_y is Mean Probability Function
δ_y is Standard Deviation Function

N_v is maximal number of available vehicles in total,
max_{vi} is maximal number of type $i\varepsilon$ vehicles
μ_f is fixed cost of type $i\varepsilon$ vehicles (unit: ₦) represents the parameters while
v_i is Number of each type of vehicles used in the system been the variables.
β is Reliability Index

L is Estimated Waste Load

μ_r is Mean of the Waste Load

δ_i is Standard Deviation of Waste Load

δ_r is Standard Deviation of Resistance

r is Capacity of the vehicles

r_{ti} is Total Routes which can be made by $i\varepsilon v$ vehicles

max_{vi} is Maximum number of type $i\varepsilon$ vehicles

V is Variable linked to the set of Vehicle types

Lc is Landfill Capacity

Equation (1) is the objective function from which the reliability index is been optimized,
Equation (5) establishes that the associated cost does not exceed the maximum cost,
Equation (6) is the capacity constrain of the landfill,
Equation (7) establishes that the number of each vehicle type used does not exceed the available number.
Equation (8) establishes that the number of all vehicles engaged in the system is not more than the total number.

2.3.2 Solution Encoding of solid Waste Management system.

This comprises of two codes, the main code py and ga.py code. The main code is the code that processes the input of the vehicle types, waste data and number of years in the analysis. The result from the genetic algorithm is then returned to back to the main py code.

2.3.3 Population Size

A population size of 600 was used for the research.

2.3.4 Crossover

A crossover chance of 1.0 was used, this works as a breeding operation.

2.3.5 Mutation

The mutation operator conducts random changes to the produced offspring using simple mutation conditions. The values within the solution network were randomly produced with a mutation rate of 0.2.

2.3.6 Genetic Algorithm

The genetic algorithm for this research is shown in the following stages.
Stage 1; Chromosomes and genes constitute a crucial step in GA. In this case the chromosomes represent the number of vehicle types and number of vehicles, while the genes represent the truck capacities and overall cost of vehicle selection.
Stage 2; Begin with randomly generated initial population of size.
Stage 3; Allocate the fitness value of solution by conducting the following steps.
Step 3.1; Evaluate the fitness of the solution.
Step 3.2; Evaluate the selection probability of each result as follows.
Step 3.3; Conduct cross over and mutation on the selected parents focused on selection chance. The operation crossover selects two

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

trucks. Next to generate the children, copy the first part of the parent first parent and insert in the offspring, then get the second part of the other parent and insert in the offspring The remaining loading trucks are trucks in the same order that they occur in the other parent. Finally, in the mutation, randomly select two loading trucks and swap their positions.
Step 3.4; Compute the fitness of the two offspring generated by equation (10)

2.3.7 Termination Criteria

In this research the termination criteria are chosen to be 100. This means that the program will stop after 100 iterations.

3.0 RESULTS AND DISCUSSION

The relationship between the overall cost and overall capacity for the case study scenarios is depicted in Figure 1. The GA iterations were done 100 times. The results at iteration 50 for 2016, with minimum capacity optimization of 5000T and a minimum cost optimization of #8950, for 2017 it is 5400T minimum capacity optimization and a minimum cost optimization of #9500, the 2018 scenario is 5250T minimum capacity optimization with #9600 as its minimum cost optimization and 5250T minimum capacity optimization with #9000 as minimum cost optimization, for 2019 and for 2020 it is 4100T minimum capacity optimization and #6000 as its minimum cost optimization.

Figures 2, 3, 4,5,6 shows the trends of number of vehicles and the cost of vehicle selection for all the scenarios. The results of GA at iteration 1, shows that 81 vehicles of A, 25 vehicles of B and 134 vehicles of C with an overall cost of #9406 for 2016, 84 vehicles of A, 15 vehicles of B and 21 vehicles of C with an overall cost of #3888 for 2017, 82 vehicles of A, 37 vehicles of B and 49 vehicles of C with an overall cost of #3717 for 2018, 38 vehicles of A, 70 vehicles of B and 132 vehicles of C with an overall cost of #9410 for 2019, 143 vehicles of A, 61 vehicles of B and 156 vehicles of C with an overall cost of #15909 for 2020 is needed for the operation of the three types of vehicles with their associated amounts. This is the cost at the first iteration of the algorithm. This cost can change depending on the iteration.

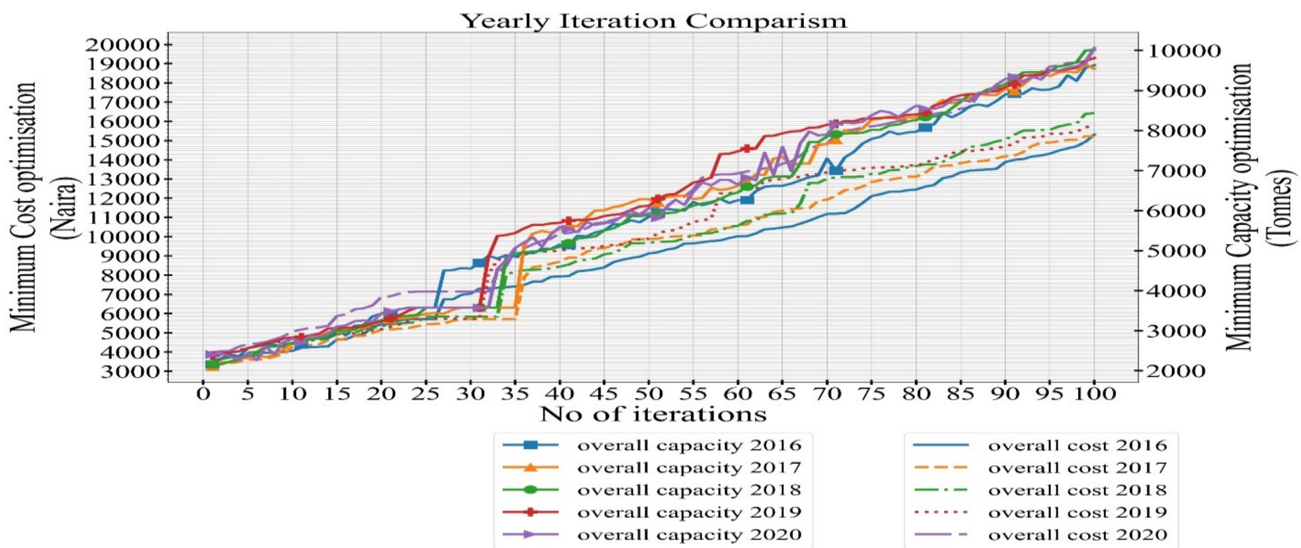

Figure 1: GA Cost and Capacity Comparison Result

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

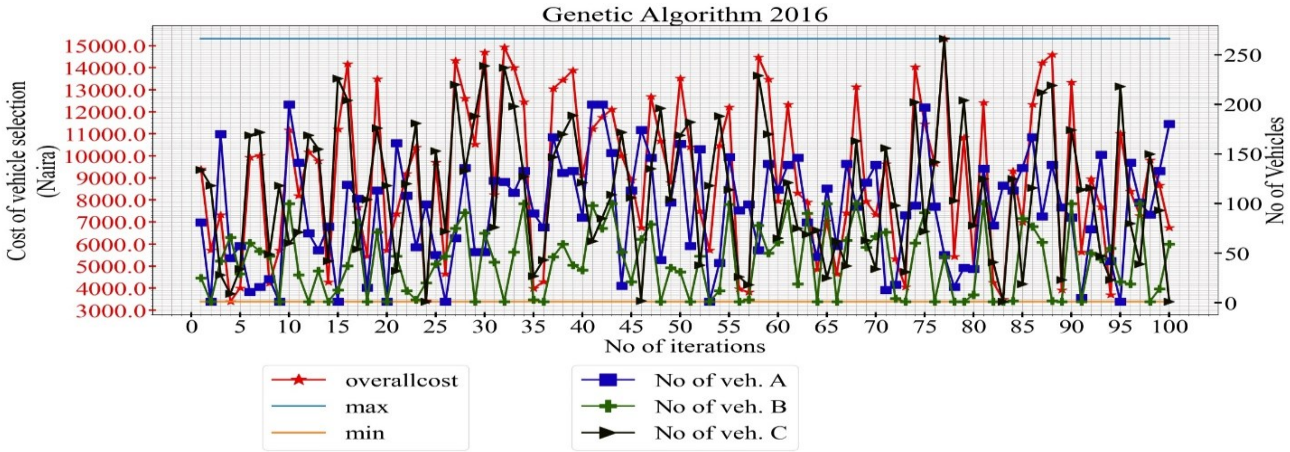

Figure 2: Genetic Algorithm Fitness Curve for 2016 Scenario

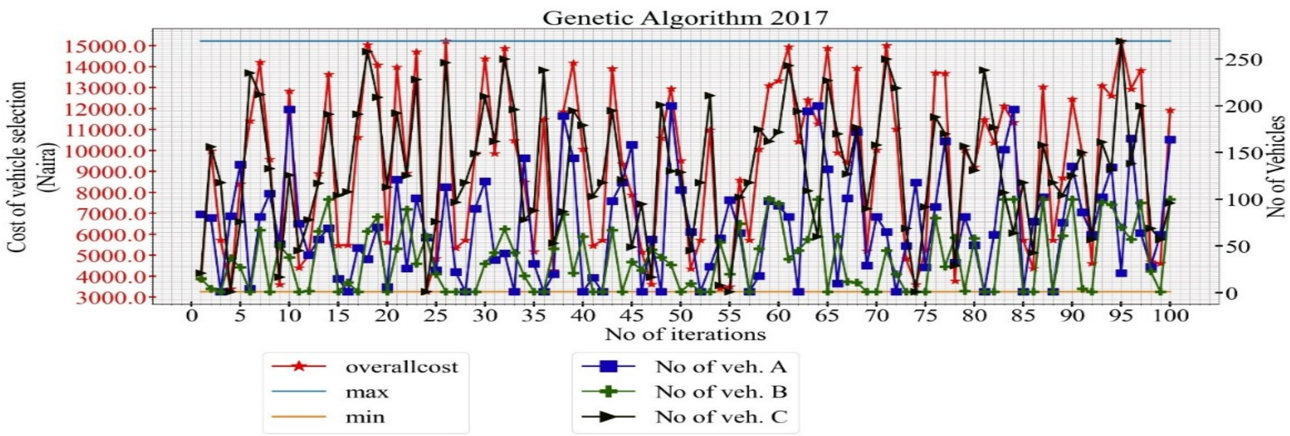

Figure 3: Genetic Algorithm Fitness Curve for 2017 Scenario

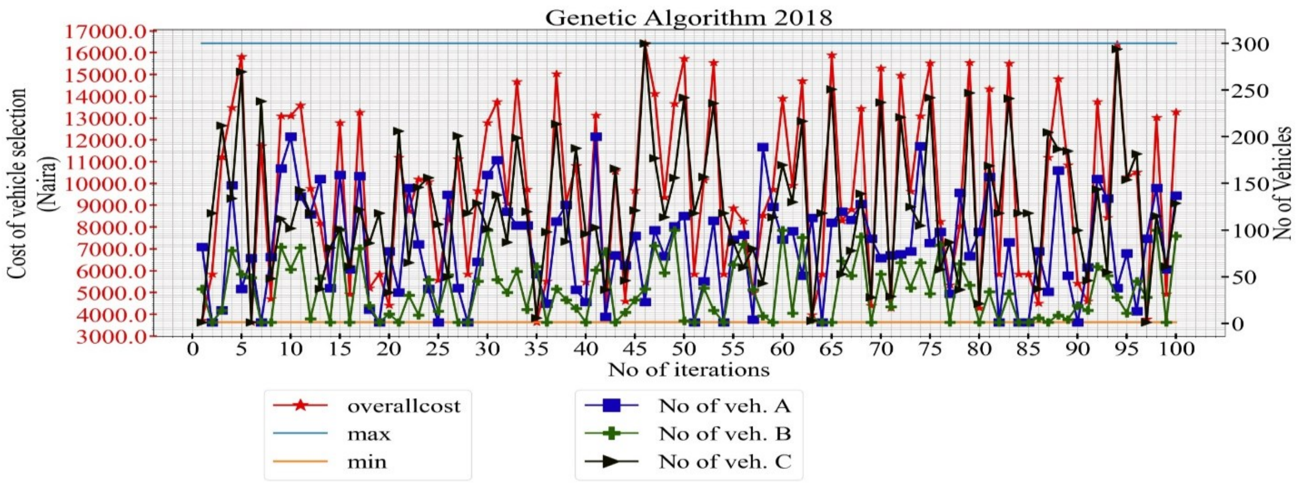

Figure 4: Genetic Algorithm Fitness Curve for 2018 Scenario

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

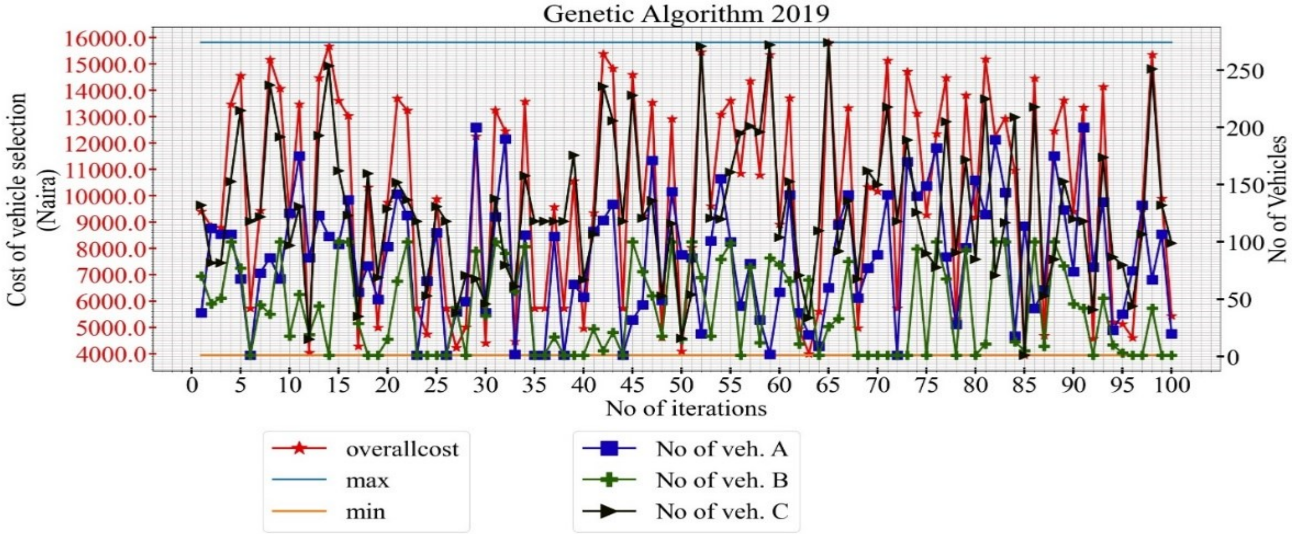

Figure 5: Genetic Algorithm Fitness Curve for 2019 Scenario

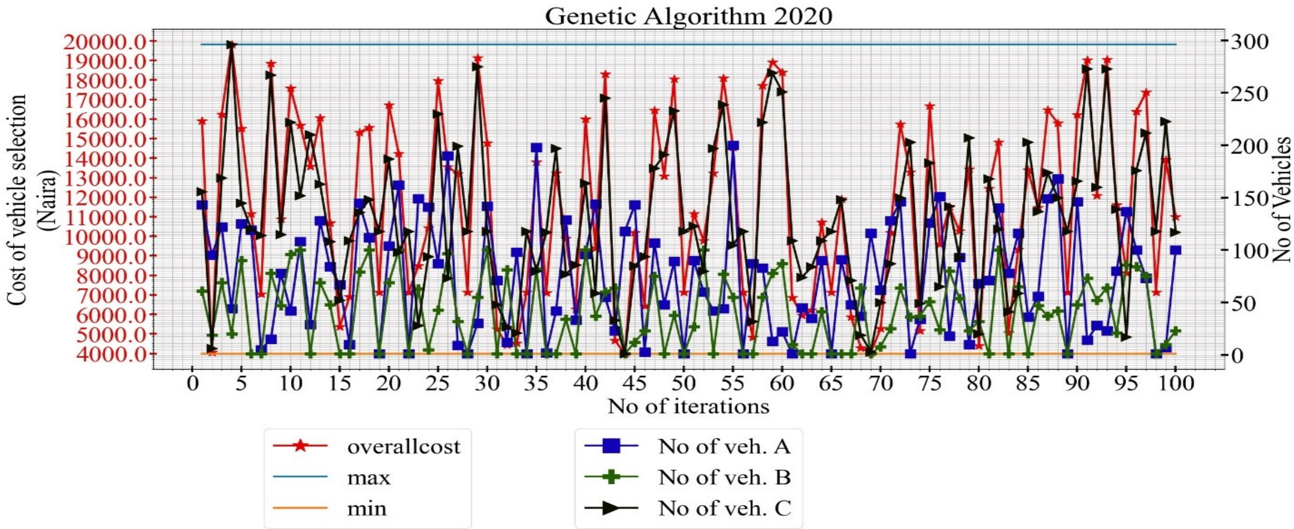

Figure 6: Genetic Algorithm Fitness Curve for 2020 Scenario

The results from the probability plot in Figure 7 shows reliability numbers of 0.93 for 2016, 0.91 for 2017, 0.90 for 2018, 0.91 for 2019 and 0.89 for 2020 scenarios. From the results it shows that scenarios that have more trucks and higher capacity with lesser waste load tend to have a higher reliability than scenarios with the same waste load or more. It is apparent from literature that if the reliability is greater than 70% then the system is reliable for the condition analyzed. The combination was analyzed using the probability plot.

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

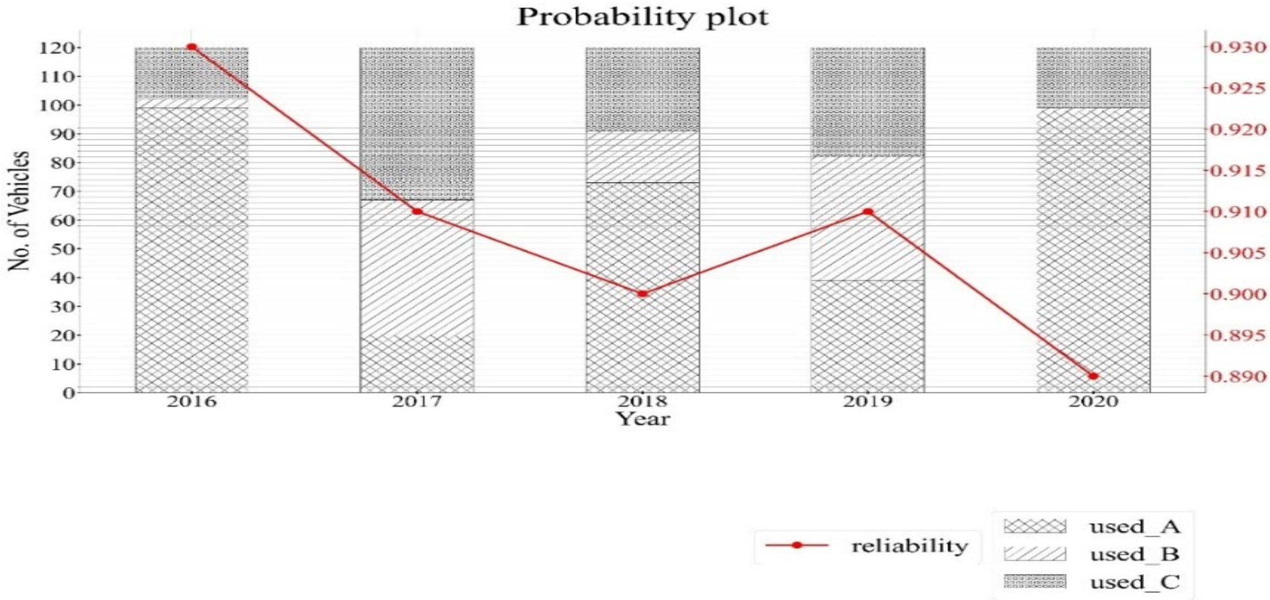

Figure 7: Probability plot for Genetic Algorithm

4.0 CONCLUSION

In this study the assignment problem for solid waste road management system in Port Harcourt cosmopolis was considered using three types of vehicles; A, B and C to dispose waste within the period of 2016 to 2020 in PortHarcourt cosmopolis. Genetic Algorithm was used for optimization of the total cost required to operate the three vehicles for waste disposal. This goal, which pertains to solving the optimization problem using genetic algorithm was accomplished. It was observed that the scenarios with more trucks and higher capacity with lesser waste load tend to have a higher reliability than scenarios with the same waste load or more. It is therefore recommended that genetic algorithm optimization technique should be considered as an alternative applicable to maximize the reliability of the system regarding the arrangement of diverse types of vehicles for waste management system.

5.0 ACKNOWLEDGEMENTS

The authors are immensely grateful to the Rivers State Waste Management Authority for making available records to the actualization of this research, and to Dr. B. Nkoi of Mechanical Engineering Department of Rivers State University for his invariable contributions in co-supervising the research.

ABBREVIATION

Abbreviation	Description
GA	Genetic Algorithm
MATLAB	Matrix Laboratory
MSW	Municipal Solid Waste
PAI	Personal Actively Intelligence
RIWAMA	Rivers State Waste Management Agency
UNP	United Nations Population

REFERENCES

Abah, S. O., & Ohimain, E. I. (2010). Assessment of Dumpsite Rehabilitation Potential using the Integrated Risk Based Approach: A Case Study of Eneka, Nigeria. *World Applied Sciences Journal*, *8*(4), 436-442.

Ayotamuno, J. M., & Gobo, A. E. (2004). Municipal Solid Waste Management in Port Harcourt, Nigeria. *Management of Environmental Quality*. 15(4), 389-398

Belien, J., De Boeck, L., & Van Ackere, J. (2011). Municipal Solid Waste Collection and Management Problems: A Literature Review Transportation Science.. Retrieved from https://dorg/10.1287/trsc.1120.0448. [Accessed 4th April 2020]

Bhargava, K., Gupta, R., Singhal, A., & Shrinivas, A. (2019). Genetic Algorithm to Optimize Solid Waste Collection. *Preceedings at the 3rd international Conference on of Recent Trends in Environmental Science and Engineering held* 10-12 June 2019, Ottawa.

Cheng, C., Zhang, L., & Thompson, R. G. (2018). Reliability Analysis for Disaster Waste Management systems. *Waste Management*, 78(1), 31-42.

Ekere, T. (2003). *Planning a Solid Waste Management System in Obio Akpor Local Government Area of Rivers State*. MPhil Thesis, Rivers State University of Science and Technology, Port Harcourt.

Falomo, A. A. (1995). City Waste as a Public Nuisance. Paper Presented at *the Annual Conference of Nigerian Environmental Society,* Lagos.

Ibiebele, D. D. (1986). Rapid Method for Estimating Solid Wastes Generation Rate in Developing Countries. *Waste Management and Research*, 4(4), 361 - 365.

Igoni, A. H., Ayotamuno, M. J., Ogaji, S. O. T., & Probert, S. D. (2007). Municipal Solid-Waste in Port Harcourt, Nigeria. *Applied Energy*, 84(6), 664-670.

Karadimas, N. V., Papatzelour, K., & Loumos, V. (2007). Genetic Algorithm for Municipal Solid Waste Collection and Routing Optimization.International Federation for Information Processing. Nigeria. *Theory to Applications*, 84, 223-232.

Mulligan, A. E. & Brown, L.C. (1998). Genetic Algorithm for Caliberating Water Quality Models. *Journal of Environmental Engineering,124(3) 202-211*.

Okafor, E.G., Ubadike, O.C., Anene, N.H., Uhuegho, K.O., & Soladoye, M.A. (2019).Study of Fleet Assignment Problems using a Hybrid Technique based on Monte Carlo Simulation and Genetic Algorithm. *Nigerian Journal of Tecnology*. *38*(3), 756, 762.

Okecha, S. (2000). *Pollution and Conservation of Nigeria Environment,* (1st Ed).T'Afriqua International Association WA: Owerri

Okoli, C., Egobueze, A., & Briggs, D. (2020). Waste Management Policy Implementation in Nigeria: A Study Of Rivers State Waste Management Agency. *International Journal of Advanced Research,* 8(2), 755, 765.

Onokerhoraye, A. G. (1985). Case Studies of Urban Slums and Environmental Problems in Nigerian Cities. *National Seminar on Environmental Issues And Management in Nigeria development, Benin City*

Oyeniyi, B. A. (2011). Waste Management in Contemporary Nigeria: the Abuja example. *International Journal of Politics and Good Governance*, 2(2.2), 1-18

PAI Associates. (1982). Solid Waste Management in Fifteen Cities and Urban Areas in Nigeria. In: *PAI Associates International for Federal Ministry of Housing and Environmen*t: Lagos.

Purnajaya, A.R., & Hanggara, F.D (2020). Optimization of Municipal Solid Waste Transporter in Batam City using Genetic

Journal of Newviews in Engineering and Technology (JNET)
Vol 4, Issue 3, December 2022
Available online at http://www.rsujnet.org/index.php/publications/2022-edition
e- ISSN: 2795-2215

Algorithm. *Preceedings at the 4th international Conference on Computing and Applied Informatics held* 26-27 November 2019, Medan.

Rawtec, R. (2015). *Disaster Waste Management Scoping Study:*Technical Report Office of Green Industries. Environemntal Protection Authority and Zero Waste, South Australia

Rivers State Waste Management Agency (RIWAMA), (2020a). Audit Report. Retrieved from www.riversstate.gov.ng. [Accessed 18th November, 2020].

Rivers State Waste Management Agency (RIWAMA), (2020b). Financial Annual Report. Retrieved from www.riversstate.gov.ng. [Accessed 18th November, 2020].

Tchobanoglous, G., Theisen, H., & Vigil, S. A. (1993). *Integrated Solid Waste Management: Engineering Principles and Management Issues*. McGraw Hill Inc., New York.

Thurgood, M., Bonnefoy, X., & World Health Organization (1995). *Solid Waste and Health.* Copenhagen: WHO regional office from Europe. 20.

United Nation Population (UNP), (2017). United Nation Population Estimates and Projections of Major Urban Agglomerations. Retrieved from http://www.citypopulation.de/world/agglomeration.html. [Accessed 5th November, 2020].

Yang, Y., Perera, L., Thompson, R., & Liu, Z. (2016). *Determining Optimal Toll Levels for City logistics.* Australian Road Research Board Conference, 27th, 2016, Melbourne, Victoria.