A Hybrid Service for Enhanced Route Optimization in Waste Management

Ebubechukwu D. Onuegbu *, Udoka F. Eze, Emmanuel C. Amadi, Anthony I. Otuonye

Abstract— Due to the growth in population, there has been an increase in trash generated, which has led in the late emptying of waste bins, resulting in an unclean environment, air pollution, and other issues in waste management. A route optimizer has been designed to help reduce the time and cost associated with emptying of waste bin. The proposed model was analyzed and developed using the prototyping approach. This is due to the fact that it aids in the early detection of problems, stimulates immediate user input, and makes identifying missing functionality simple. Data was gathered using a key informant interview approach, observation, and published studies. The proposed route optimizer was created using the Dijkstra-Ant Colony algorithm. Overall, the Dijkstra-Ant Colony algorithm demonstrated that visiting a place with a full waste bin took less time. Key informant interview technique, observation of previous methods, online repository and published related works were used in data gathering. JavaScript, Hypertext preprocessor (PHP), Hypertext Markup Language (HTML), Cascading Stylesheet (CSS), MySQL and C++ were used to develop the front and backend of the application. Different algorithms like: Dijkstra, Floyd Warshall, ant colony, genetic algorithms alongside the proposed hybrid algorithm were used for route optimization on our test data, and the Dijkstra-ant colony algorithm produced the best result amongst them. The proposed model was tested on different routes and it produced a better result than the existing system. The proposed approach is therefore recommended for integration into waste management systems and logistics services based on its effectiveness.

Index Terms— Waste Management, Solid Waste Management, Garbage, Waste Bin, Route Optimization, Optimizer, Waste Collection, Waste Collection Vehicle.

1 Introduction

WASTES are items that are worthless or unwanted generated from society's actions [1]. Without a well-designed waste management plan, we will not be able to achieve effective and efficient waste management [1]. Waste management concerns are ubiquitous, and their impact on the environment and public health can be seen in many poor countries. In any city, waste management is an important aspect of urban and environmental planning [1].

Waste management is becoming a global concern as a result of high population expansion due to rural-urban migration, limited public knowledge, and changes in consumption patterns [2].

Sustainable development, namely in terms of environmental quality and protection, is currently a critical priority for the European Union (EU). One of the United Nations' (UN) goals, according to the Division for Sustainable Development (DSD), is to ensure sustainable consumption and production [3].

The volume of rubbish produced continues to expand at a faster rate than the agencies' ability to enhance the resources required to handle this growth [4]. Urban garbage generation is expected to climb to 2.2 billion tons by 2025 as a result of fast population expansion and urbanization [5]. Global waste management is predicted to increase at a 6.2 percent annual rate by 2023, according to Allied Market Research in Portland, Oregon, with particularly significant growth in the growing Asia Pacific area [5]. This industry grew by more than 30% in Europe in 2016. Because of sophisticated infrastructure and robust demand in numerous sectors, growth is likely to continue to accelerate.

Waste management, also known as garbage administration, arose from the need for a controlled generation of waste in society. Waste management, according to [6], is "the systematic, deliberate control of the generation, storage, collection, transportation, separation, processing, recycling, recovery, and disposal of solid waste in a sanitary, aesthetically acceptable, and cost-effective manner."

A task linked with waste management is solid waste collection, which is one of the biggest issues faced by garbage collection businesses and municipalities [7]. In recent years, rising fuel prices, the impact of excessive garbage on the environment and health, rising operational costs, and an increased regulatory burden have all prompted waste collection authorities to optimize their waste collection routes. Solid waste transportation accounts for roughly 70 to 80 percent of overall waste collection operational expenditures [8]. As a result, even minor improvements to the collecting routes will result in significant cost reductions. These savings could have a positive impact on individual household fees, corporate profit margins, and municipal budgets.

2 RELATED WORKS

A methodical outline of the review done on carefully chosen literature on route optimization for waste management is shown in Table 1.

TABLE 1
SUMMARY OF SOME RELATED WORKS

Research Title	Author (S)	Techniques	Result
Waste Management System Using IoT	Adam et al [9]	Spiral	Real-time monitoring of the contents of the waste bin using sensors, and displaying container status using colors, as well as analysis of the

			sensed contents to determine the optimized distribution of the Waste bins.
Multi-Agent-Based IoT SMart Waste Monitoring and COllection.	Likotiko et al [10]	Prototyping, Dijkstra's algorithm, multi-agent model, Netlogo	Developed a prototype of a multi-agent model for waste monitoring and collection. Proposed a multi-agent model that consists of three main agents- citizen, waste bin and agent. Dijkstra's algorithm and the Netlogo were used to achieve route optimization.
Real-time bin status monitoring for solid waste collection route optimization.	Mamun et al [11]	Rapid Application Development (RAD), Integer Linear programming (ILP)	Development of a system that uses Integer Linear programming (ILP) model for dynamic route optimization. Used six (6) sensors viz: accelerometer, hall effect, humidity, temperature, load cell, and ultrasonic sensors. The Integer Linear programming (ILP) model was used for dynamic route optimization.
Internet of Things based Waste Management System for Smart Cities : A real-time route optimization for waste collection vehicles.	Mishra et al [12]	Prototyping	Classification of waste based on the material (i.e. metallic, biodegradable and non-biodegradable)
Internet of Things for Smart	Nishikant et al [13]	Spiral, Priority Schedul	In addition to the ultrasonic sensor, two IR sensors placed at

Waste Management		ing	the middle of the bin and topmost part of the bin are employed to identify the level of waste in the waste bins Priority Scheduling was used to empty the waste-filled waste bins.
Efficient Garbage Management System for Smart Cities.	Nagalingeswari et al [14]	Prototyping, Thingspeak server, Dijkstra Algorithm	Thingspeak server was used to post the information generated from the bins. Dijkstra Algorithm was employed to calculate an optimal route to be followed by garbage collection vehicles.
Technology Enabled Smart Waste Collection and Management System using IoT	Susila et al [15]	Rapid Application Development (RAD), Spatial Poisson quantity detection algorithm	Developed a system that uses a two-tier method to ensure that every waste bin is emptied at least once in three days, irrespective of its fill level.
Waste Management System Using IoT-Based Machine Learning in University. 2020.	Khoa et al [16]	low-cost design circuit, Long-range radio third-generation (LoRa) technology, the logistic regression function	Proposed a system that could optimize the collection of waste with the shortest path by combining machine learning and graph theory. The system delivered better operations for optimizing employee use, reducing operating costs, and timely data gathering.
IoT-Based Framework for Smart Waste Monitoring	Abba and Chinaka [17]	Arduino IDE and embedded C	We have proposed a system for real-time monitoring and control of waste disposal.

and Control System : A Case Study for Smart Cities		programming language, hypertext preprocessor PHP scripting programming language, Proteus 8.0 professional simulation software	

3 METHODOLOGY

3.1 Software Methodology Adopted

Prototyping software development methodology was adopted. It was chosen because it aids in the early detection of faults, fosters immediate user input, and facilitates the identification of missing features. The steps are: gathering requirements, fast design, prototyping, user evaluation, refining prototype, and engineering the product.

3.2 Assumptions

During the course of this project, the following assumptions were made:

1. There isn't a single bump on the road or path.
2. There is no traffic congestion.
3. The vehicles have the same carrying capacity.
4. The weight of rubbish in a bin is proportional to the bin's filling level.
5. There will be no divided collection.

3.3 System Architecture

The organization, performance, and interpretations of an information system are defined by system architecture, which is a conceptual model. The system components and sub-systems that are brought together to implement the system are sometimes contained in a system architecture. The architecture of the proposed system is illustrated in Figure 1

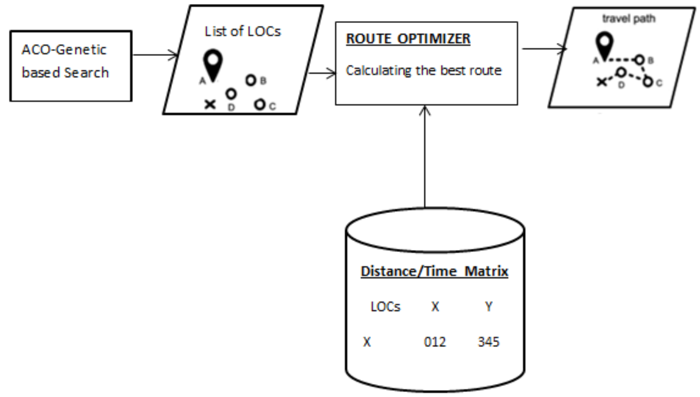

Figure 1: Diagram of the system architecture

3.3 USE CASE DIAGRAM

The interaction of a user with a system is depicted or represented in a use case diagram. The relationship between the various sorts of users of a system is usually depicted in a use case diagram shown in figure 2. It includes a route optimization model and the identification of the two (2) active key players (administrator and client). The actions they can handle or do on the proposed information system, as well as the users' relationships, are also revealed.

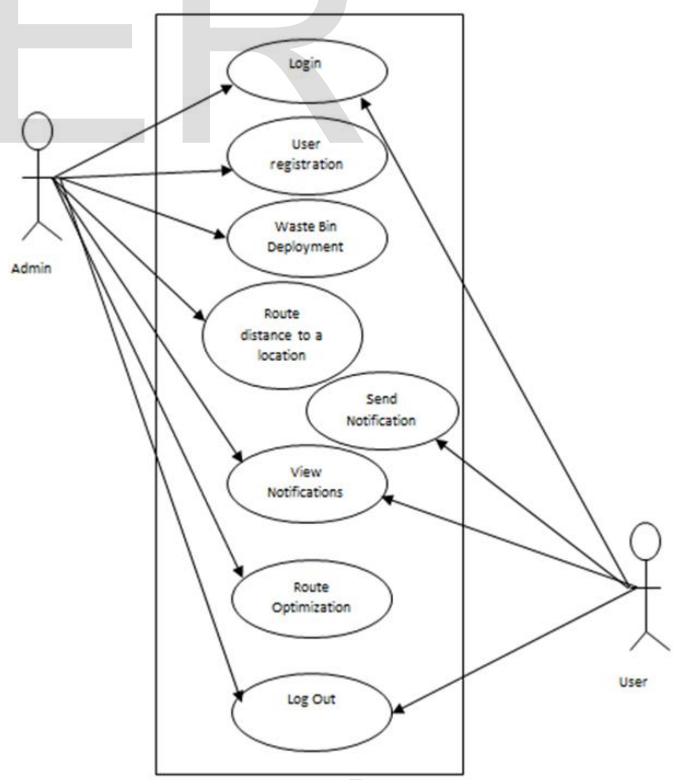

Figure 2: Use case diagram for the proposed System

3.5 Sequence Diagram

A sequence diagram depicts the preparation of object interactions in chronological order. A sequence diagram shows parallel upright lines that represent the various items or processes that interact with one another, and horizontal arrows that indicate the messages that the objects exchange in the order in which they occur. The proposed system's sequence diagram is shown in Figure 3

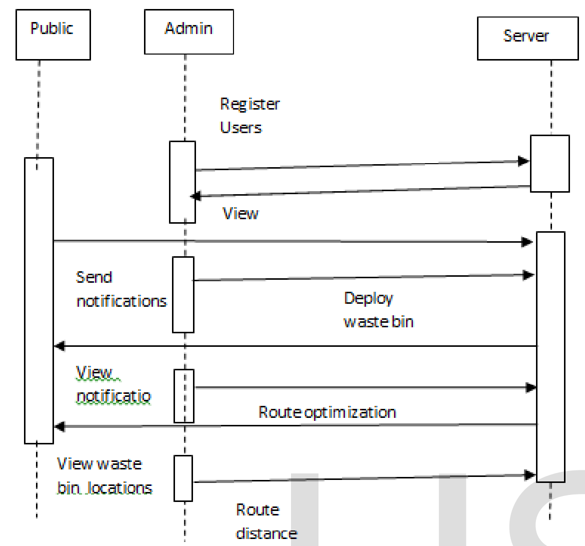

Figure 3: Sequence diagram of the proposed system

3.6 Flowchart design

A flowchart can simply be referred to as a diagrammatic representation of a step by step method of providing a solution to a given problem or task. Figure 4 below shows the process flowchart for the proposed route optimizer.

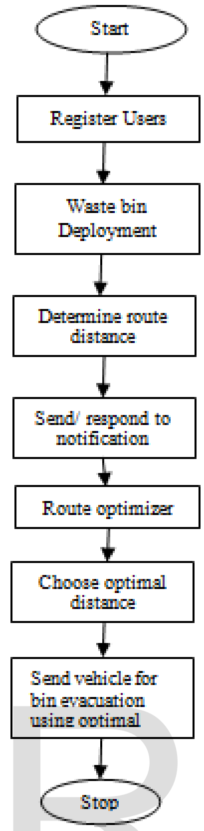

Figure 4: Process flowchart for the proposed route optimizer

3.7 Entity Relationship diagram

Entity Relationship diagram is a specialized graphics that illustrate the interrelationship between entities in a database.

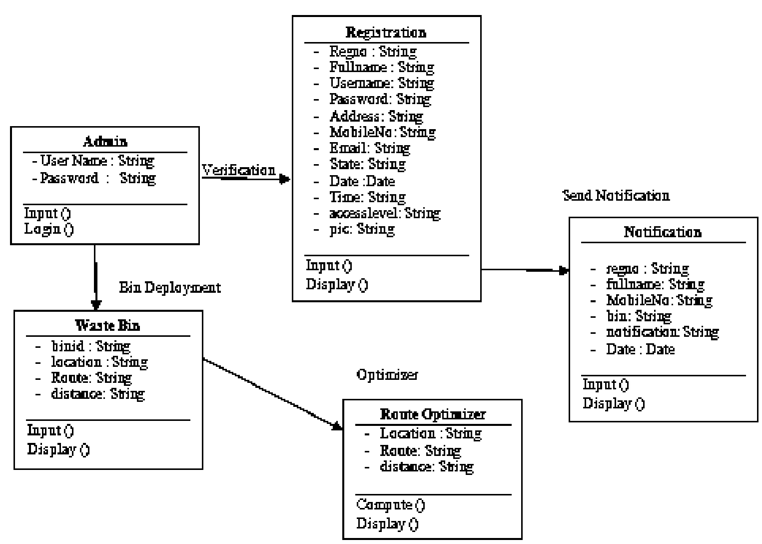

Figure 5: Database specification entity relationship diagram

3.8 Data Flow Diagram (DFD) of the Proposed System

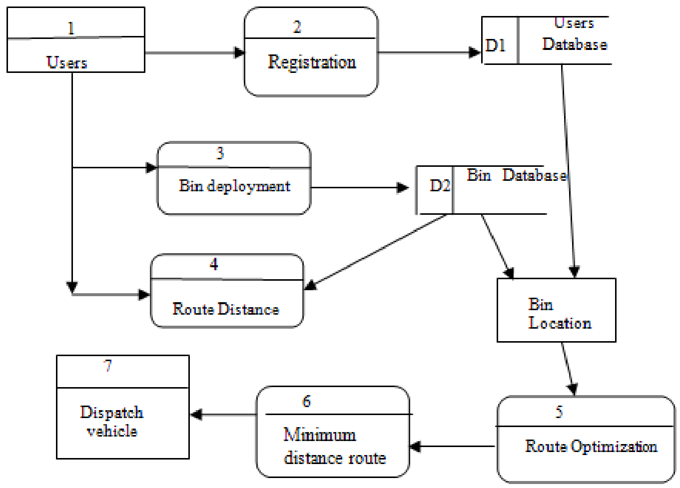

Figure 6: Data Flow Diagram Of the proposed system

The data flow diagrams (DFDs), as shown in figure 6 shows the movement of data in any process or system. Using rectangles, circles, and arrows as well as small text labels, it displays data inputs, outputs, storage sites, and the paths between them.

3.9 High-level Model of the Proposed System

The proposed system will incorporate all the processes and procedures described and some other very important features to enhance the operations of a typical waste management agency as illustrated in figure 7.

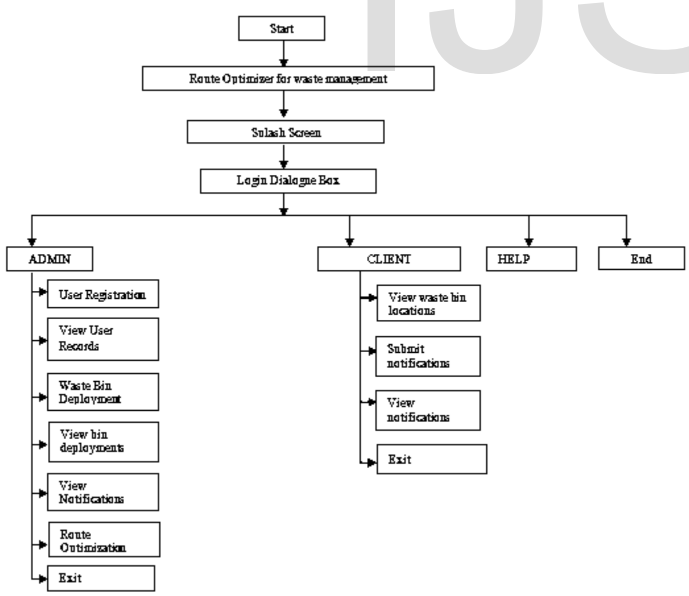

Figure 7: High-Level Model of the Proposed System

3.10 Activity Diagram of the Proposed System

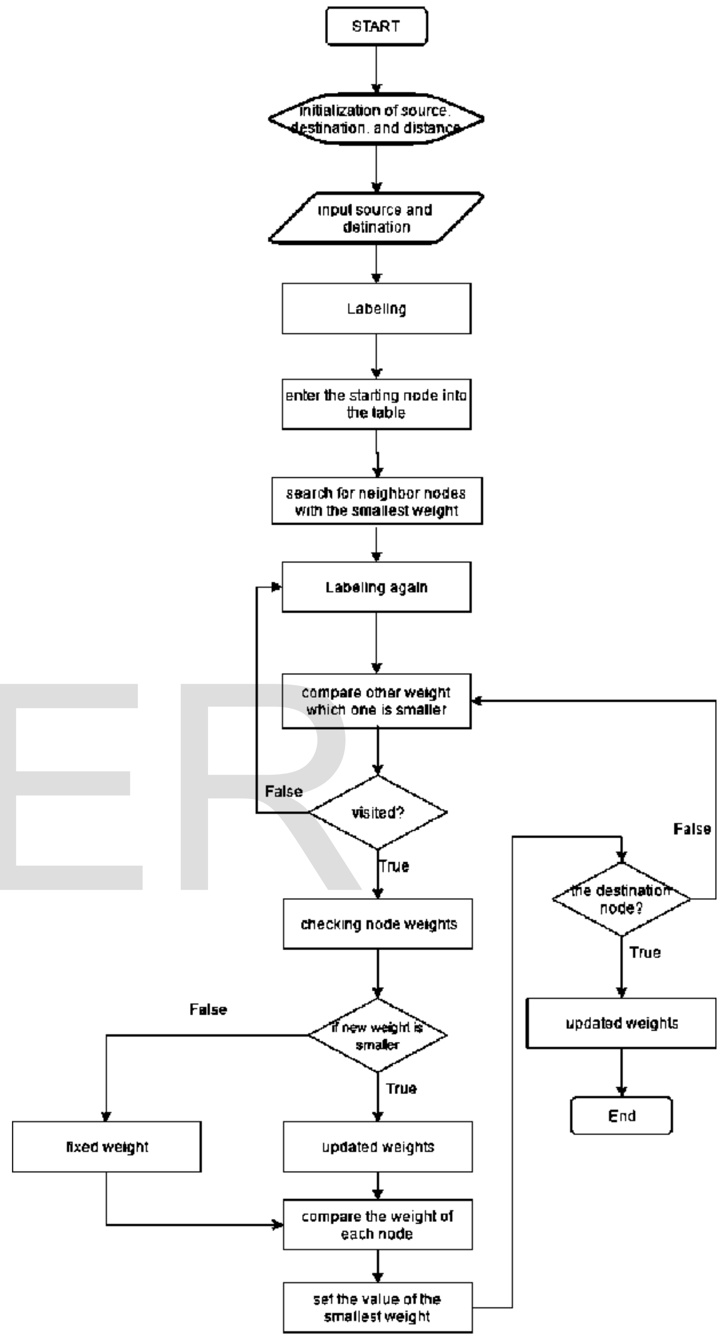

Figure 8: Activity Diagram of the Proposed System

3.11 The proposed algorithm

By integrating the Dijkstra and ant colony algorithms, a hybrid algorithm is presented. To begin, the Link Method was utilized to create the truck's environment model, and the Dijkstra algorithm was used to plan the truck's first course. The traditional ant colony algorithm was optimized and improved using a nodes random selection mechanism and a combination of local and global pheromone renewal. Finally, an upgraded ant colony method was used to optimize the Dijkstra algorithm's starting path in order to effectively avoid obstacles.

1. Dijkstra Algorithm

Step 1: Draw a line from the beginning vertex (location) to the end vertex (location).
Step 2: Mark this vertex (position) as the current one.
Step 3: Locate all vertices (paths) that lead to the present vertex (location).
Step 4: Determine their distances to the finish line.
Step 5: Make a note that the present vertex (location) has been visited.
Step 6: Assign current status to the vertex (position) with the shortest distance.
Step 7: Repeat steps 2–6 until the shortest distance to the destination is determined.

2. Ant Colony Algorithm

Step 1: Place ants in various areas and set pheromone intensities on the edges.
Step 2: Make the first element of each ant's tabu list its starting place.
Step 3: According to the probability p, each ant moves from one position to another (i, j).
Step 4: All ants have completed their trip after n moves; their tabu lists are full, so compute Lk and Tkij. Update pheromone strengths by saving the shortest path identified and emptying tabu lists.
Step 5: Iterate until your tour counter reaches its maximum value or until all ants begin to follow the same path.

3.12 Program Development

A large number of programming languages were examined in the development of this software. Online database access, data transmission via networks, database security, database retrieval online, multi-user network access, online data collection, and other considerations were all taken into account. The front end was developed using HTML (hypertext markup language). This is because it allows for the creation of a simple and straightforward user interface for accessing the database, and HTML documents may be viewed in any browser. The m**iddle end:** PHP and javascript allow content entered in a generated graphical user interface to be linked to a database. The b**ack end:** The implementation of the algorithm was done in C++. Mysql was chosen for database design and query because it is a simple, low-cost database language that can run on a variety of operating systems including Windows, Linux, Unix.os/2, and others, is secure, and has a wealth of technical support available on the internet. Most importantly, it can handle large databases. The decision to use PHP-MySql and Java Script was taken to help us meet the above-mentioned goals. Furthermore, PHP-MySql is extremely user-friendly and allows for the creation of a programmatically alterable interface. In addition, the MYSQL database is a powerful database that can provide database integrity, security, and scalability.

4 Result and Discussion

4.1 Functional Interfaces

The experimental results derived from the implementation of the proposed model are presented in this chapter. The forms shown here are the ones that the user uses to input data into the proposed system. The diagrams below show how each of these forms will function in the new system. The new system's input/output design is as follows:

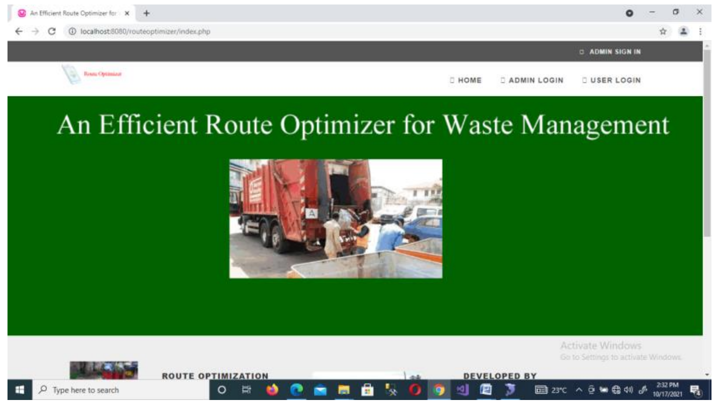

Figure 9: Home Page / Landing Page

The application's Landing Page, shown in Figure 4.1, is a single web page that appears when a web application is opened. This page offers information about the web application as well as login instructions.

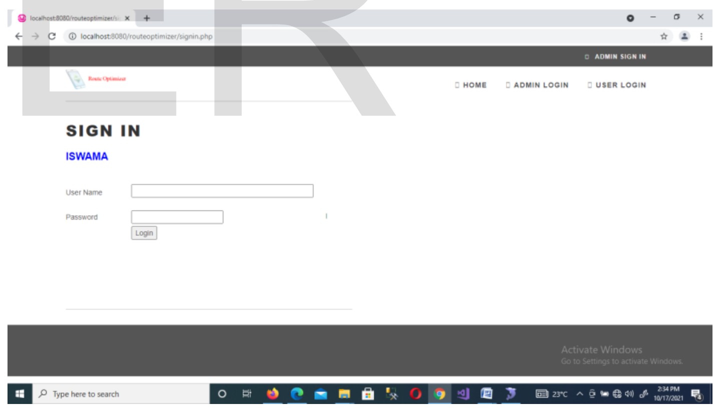

Figure 10: Login Form

The login form, as shown in figure 10, enables a user to log in to the main menu of the program. Each user access is authenticated in this module.

The login form, as shown in figure 10, enables a user to log in to the main menu of the program. Each user access is authenticated in this module.

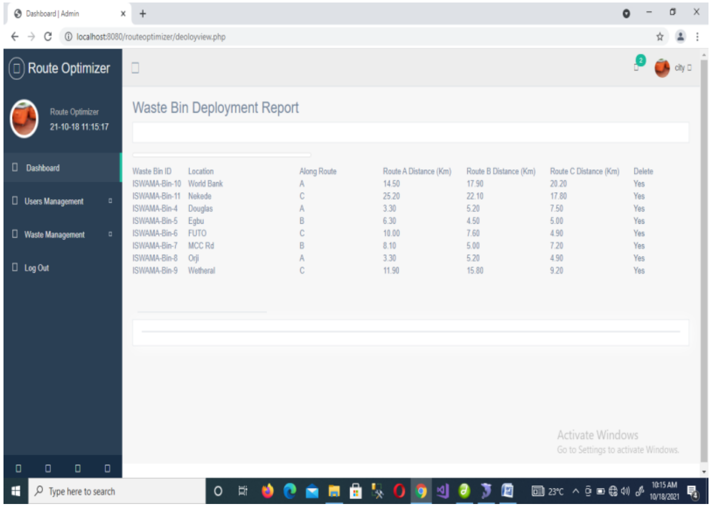

Fig 11: Waste Bin Deployment Location and Distance Report

Figure 11 is a report that displays all the locations where the waste bin is deployed with the various routes to the location and their distance in km.

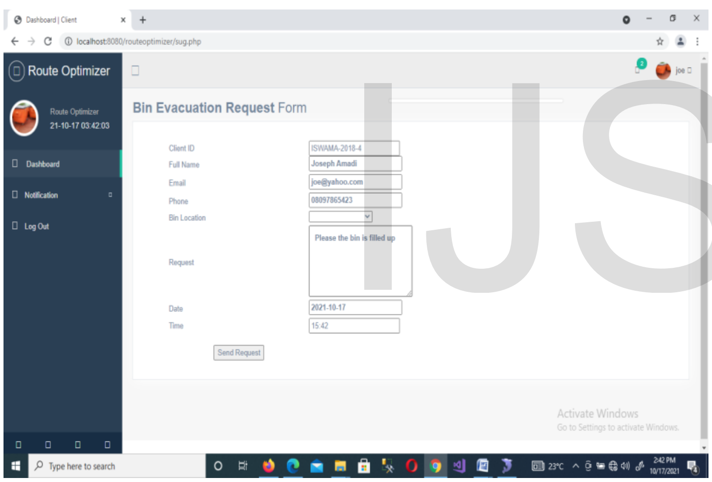

Fig 12: Waste Bin Evacuation Request Form

Figure 12 shows the waste bin evacuation request form and is used by the clients to notify the admin that a waste bin is filled up and need to be evacuated.

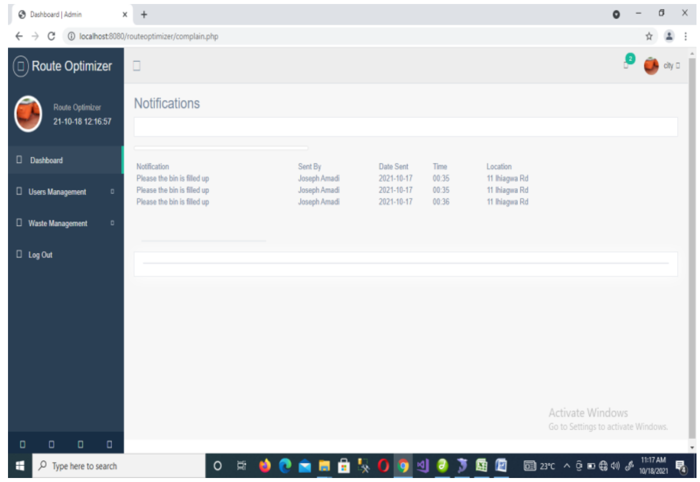

Fig 13: Waste Bin Evacuation Request Notifications

Figure 13 is a report that displays all the locations where the waste bin is filled up and needs to be evacuated.

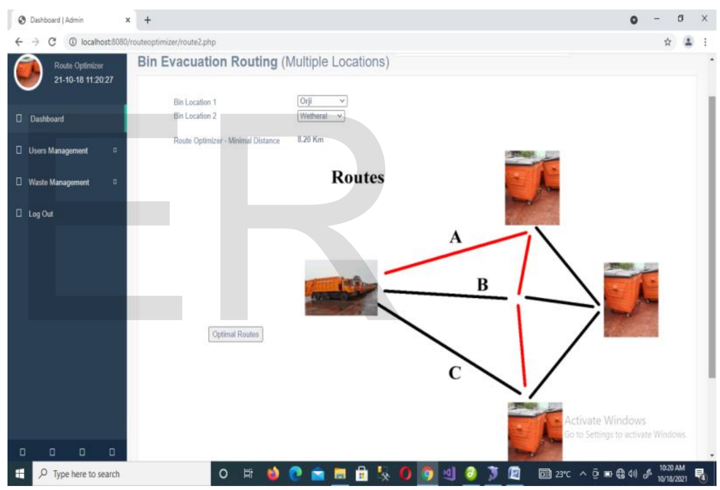

Figure 14: Multiple Locations Waste Bin Evacuation Route Optimization

Figure 14 shows a route optimizer for numerous waste bin locations that must be evacuated by the same vehicle. The red line in figure 14 depicts the vehicle's optimum route to the first waste bin location and the second location. The optimal movement distance is 5.50 kilometers. There are alternative ways to the same destination, as shown in the diagram, but the chosen path is the one with the shortest transportation distance. Any change in the distance between the various routes will select the vehicle's route depending on the optimal distance.

4.2 Performance Evaluation

1. Software performance: The software performance was tested using the accuracy of route optimization. Table 2 shows the performance grading of the proposed system. During the testing, 20 different route optimization procedures were performed to see to see how it can

accurately identify the shortest route, 18 of which gave an accurate result. This implies that our algorithm is 90% accurate.

TABLE 2
PERFORMANCE RESULTS OBTAINED

Technique Applied	Efficiency of the route optimizer
Dijkstra-Ant Colony Algorithm	90%

2. Comparison of the performance of the proposed hybrid (Dijkstra-ant colony) algorithm other algorithms:

Different algorithms like: Dijkstra, Floyd Warshall, ant colony, genetic algorithms alongside the proposed hybrid algorithm were used for route optimization on our test data, and the Dijkstra-ant colony algorithm produced the best result amongst them. The optimized distance generated using each of the algorithms are shown in were plotted Table 3 and figure 15 below.

TABLE 3
COMPARISON OF THE PERFORMANCE OF THE PROPOSED SYSTEM WITH OTHER ALGORITHMS

Technique Applied	Optimized Distance (km)
Dijkstra	6
Floyd Warshall	6.5
Ant Colony	6.8
Genetic	7
Dijkstra-Ant Colony Algorithm	5.5

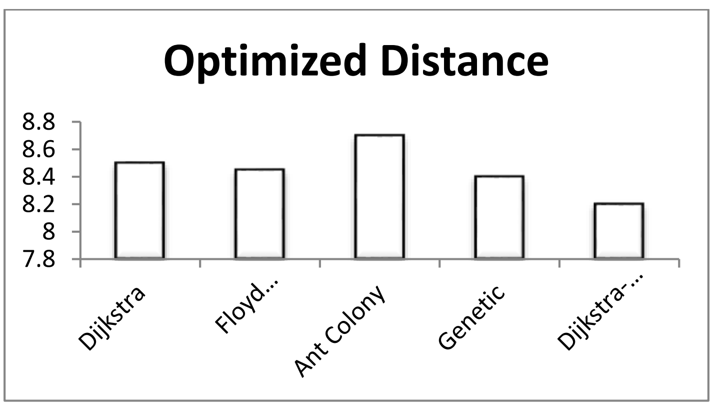

Fig. 15: Comparison of the performance of the proposed system with others

3. Comparison of the proposed system with the existing system :

   The proposed was tested on different routes in within Owerri and it produced a better result. Figure 16 below show the side by side comparison of the results obtained on each of these locations with that of the existing system.

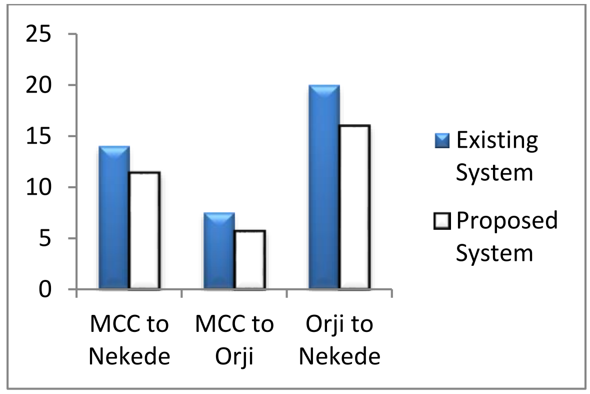

Figure 16 Comparison of the proposed system with the existing system

5 CONCLUSION

5.1 Conclusion

The logistics part of waste management relies heavily on transportation. It's one of the most important aspects of any waste management system. As a result, the routes must be optimized. The existing waste management system was found to have major concerns with inefficient and untimely trash bin emptying. The proposed system aids in the reduction of environmental pollutants, air pollution, manpower, time, and cost.

To enable me achieve the objectives of the study, I created and developed an efficient route optimizer utilizing the Dijkstra-Ant Colony algorithm to minimize or eliminate the untimely waste disposal concerns connected with the present waste management system.

5.2 Recommendations

The suggested route optimizer was created utilizing a prototype software development technique, which aids in early error detection, stimulates quick user feedback, and makes it simple to identify necessary functionalities. We recommend the following for optimal use of the proposed route optimizer:

1. Organizations' adoption of the route optimizer for commercial purposes.
2. This system can be scaled up and deployed with internet of things (IoT) devices to give smart cities with a more dependable and efficient smart garbage collection and management system.

5.3 Contribution to Knowledge

The following are some of the ways that this research on route optimization using a Dijkstra-ant colony algorithm contributes to knowledge:

1. The knowledge gained from this research has contributed in the construction of a workable model for improved route optimization utilizing a hybrid algorithm that combines the advantages of both algorithms.
2. The knowledge gathered from this research project will aid in the effective implementation and use of the prototype model that has been built.

5.4 Future works

Future research work should consider the following;

1. A priori strategy that generates planned routes for phlebotomists to take when visiting patients should be examined, together with a recourse rule designed to address the eventuality that all demand cannot be met in a hospital.
2. A robust precedence-constrained asymmetric Travelling Salesman Problem solution methodology for handling demand uncertainty in same-day delivery networks.

Acknowledgment

Thank you to the management of the Federal University of Technology, Owerri, and the Tertiary Education Trust Fund (TETFUND) Nigeria for giving the finances required for carrying out this research, which will aid in achieving efficient service delivery in waste management.

REFERENCES

[1] A. Kadafa, "Solid waste management practice of residents in Abuja municipalities (Nigeria)." *Journal of Environmental Science, Toxicology and Food Technology*, *11*(2), 87–106. https://doi.org/10.9790/2402-11020187106, 2017.

[2] P. S. A. Mahajan, A. Kokane, A. Shewale, and M. Shinde, "Smart waste management system using IoT." *6495*(4), 93–95, 2017.

[3] R. Giurea, I. Precazzini, M. Ragazzi, M. I. Achim, L. Cioca, F. Conti, V. T. Id, and E. C. Rada. "Good practices and asustainable municipal solid waste management in the tourist sector." 1–12. https://doi.org/10.3390/resources7030051, 2018.

[4] S. Praneetha, L. P. Magulur, and M. Symala, "Solid waste management in smart cities using IoT." *Journal of Geography and Regional Planning*, *118*(7), 635–640, 2018.

[5] K. Pardini, J. J. P. C. Rodrigues, S. A. Kozlov, N. Kumar, and V. Furtado, "IoT-based solid waste management solutions : A Survey." *Journal of Sensor and Actuator Networks*, *5*(8). https://doi.org/10.3390/jsan8010005. *International Journal of Computer Science and Engineering (SSRG-IJCSE)*, *April*, 24–29, 2019.

[6] A. O. Adeniran, "Inventory analysis of solid waste management in ikorodu community inventory analysis of solid waste management in Ikorodu." 2016.

[7] I. Markov, S. Varone, H. E. D. G. de Genève, and M. Bierlaire, "Vehicle routing for a complex waste collection problem." *The 14th Swiss Transport Research Conference*, 2014.

[8] G. Tavares, Z. Zsigraiova, V. Semiao, and M. D. G. Carvalho, "Optimisation of MSW collection routes for minimum fuel consumption using 3D GIS modelling." 2009.

[9] M. Adam, M. E. Okasha, O. M. Tawfeeq, M. A. Margan, and B. Nasreldeen, "Waste management system using IoT." *2018 International Conference on Computer, Control, Electrical, and Electronics Engineering, ICCCEEE*, 1–4. https://doi.org/10.1109/ICCCEEE.2018.8515871, 2018.

[10] E. D. Likotiko, D. Nyambo, and J. Mwangoka, "Multi -agent based IoT smart waste monitoring and collection." *7*(5), 1–14, 2017.

[11] M. A. A. Mamun, M. A. Hannan, A. Hussain, and H Basri, "Real time bin status monitoring for solid waste collection route optimization." *IET Conference Publications*, *2014*(CP649). https://doi.org/10.1049/cp.2014.1077, 2014.

[12] A. Mishra, N. Ghosh, and P. Jena, "Internet of things based waste management system for smart cities : A real time route optimization for waste collection vehicles." *4*, 496–503, 2019.

[13] A. Nishikant, R. Mukherjee, R. Gupta, S. P. Singh, and Shashikant, "Internet of things for smart waste management" *1. 8*, 33–36, 2017.

[14] K. Nagalingeswari, and K. P. Satamraju, "Efficient garbage management system for smart cities." *International Journal of Engineering Trends and Technology*, *50*(5), 260–265. https://doi.org/10.14445/22315381/ijett-v50p242, 2017.

[15] N. Susila, S. Anand, G. R. Elwin, and T. Sujatha, "Technology enabled smart waste collection and management system using IoT." *119*(12), 1283–1295, 2018.

[16] T. A. Khoa, C. H. Phuc, P. D. Lam, L. M. B. Nhu, N. M. Trong, N. T. HoangPhuong, N. Van Dung, N. Tan-y, H. N. Nguyen, and N. D. D. Minh, "Waste management system using iot-based machine learning in university." https://doi.org/https://doi.org/10.1155/2020/6138637, 2020.

[17] S. Abba, and I. L. Chinaka, "IoT-Based Framework for Smart Waste Monitoring and Control System : A Case Study for Smart Cities." *Engineering Proceedings*, 1–10. https://doi.org/10.3390/ecsa-7-08224, 2020.