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Refining Dijkstra's Algorithm: Employing Smart Solutions for Efficient Waste Management and Pollution Mitigation

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Abstract:- This study explores the application of Dijkstra's algorithm to enhance waste disposal management systems, focusing on optimizing routing for efficient waste disposal. By modeling waste disposal pathways, the research aims to identify the shortest and most cost-effective routes, thereby reducing both pollution and operational costs. The analysis demonstrates that Dijkstra's algorithm can effectively streamline waste collection processes in Abakaliki, Ebonyi State, Nigeria, enabling the waste management board to minimize distance, time, and expenses associated with waste transportation. The developed model is both scalable and adaptable, promoting the integration of Geographic Information Systems (GIS) and real-time data for dynamic route optimization. The findings suggest significant potential for this approach not only in waste management but also in other domains such as traffic management and urban planning. This paper advocates for further exploration of user-friendly interfaces and alert systems to enhance operational efficiency. This research highlights the overall transformative potential of Dijkstra's algorithm in improving the sustainability and effectiveness of municipal services.

Keywords:- *Waste Management, Waste Disposal, Waste Pollution, Geographic Information System (GIS), Geospatial, Technology, Information And Communication Technology (ICT) Application, Dijkstra's Algorithm, Shortest Path And Machine Learning.*

I. INTRODUCTION

Municipal waste-related environmental contamination typically poses serious threats to Nigeria's environment, the non-disposal of municipal garbage in numerous Nigerian cities cause serious harm to residential and business zones. As Africa's most populous country, Nigeria faces challenges in managing the large volumes of waste generated daily due to human and industrial activities. Many cities lack effective waste disposal systems, leading to serious environmental issues. (Amuda et al., 2014).

Municipal waste management encompasses the collection, transportation, processing, resource recovery and disposal of trash. There are a number of waste management organizations that are currently operating in the states under legislation that provides them with the authority to handle waste. While the oldest observable issue is that the rate of waste collection and evacuation frequently lags behind the rate of waste generation, leading to the accumulation of solid waste, the current issues include funding, the fact that government agencies also engage in unacceptable waste disposal practices, and the fact that Nigeria is generally underinvesting adequately in cutting- edge waste management technologies such as recycling facilities or plants. This has made open dumping, open burning, unregulated landfills, and dumping into drain channels, streams and rivers the most frequently used option/method of disposing waste due to poor effectiveness and efficiency in disposal of the waste. The repercussions of this issue include excess of littered garbage that introduces smell, unsightly view, and health risks for both hygiene and sanitation hazards (Chukwuogo et al. 2024).

The link between waste generators (residential, commercial, and industrial facilities) and the waste management needs to be properly controlled to guarantee an efficient system and this contact point is waste collection and transportation. Numerous aspects of the Waste Management System (WMS) can be improved, including the route optimization (to determine the best route), labor costs (to determine how many workers will be required for the waste collection), schedule (to determine the best time for the waste collection), and the number and type of waste collection trucks required (among other factors). The focal point of this research was on route optimization and vehicle need optimization.

Dijkstra's algorithm is a very popular algorithm in computer science used to solve the single- source shortest paths for a given graph with non-negative edge weights (Dijkstra, 1959). In our model, we formulated the route from the garage, dumping station and the bins as the computer networking node problem. The link- cost of the routes were then calculated based on the bins' status (fill levels), distance and road congestion. The shortest path will then be displayed for the garbage truck to follow for the waste collection.

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This study explored the simulation of an optimized routing system for waste collection by leveraging the computational efficiency of Dijkstra's algorithm which was applied in route optimization and data analysis using practical scenario and information gotten from Ebonyi State Ministry of Environment. The research investigated how optimized routes can lower fuel consumption and consequently, reduce greenhouse gas emissions and air pollution, contributing to more sustainable waste management practices. The environmental advantages align with global sustainability goals, making this study highly relevant in contemporary discussions on climate change and urban sustainability.

Finally, this study sets the stage for future research by identifying areas for further investigation. This includes exploring advanced techniques such as machine learning for predictive analytics, and multi-objective optimization models for real-time data collection and analysis. By highlighting these future research directions, the study ensures the continued evolution and improvement of waste management optimization techniques.

II. LITERATURE REVIEW

Gazder U. (2018) offered a structured approach to improving the efficiency of waste collection through optimized routing. The primary strength of his paper lay in its development of a comprehensive framework for route optimization. By presenting a systematic approach, the paper provided valuable insights into how solid waste collection routes can be optimized to enhance operational efficiency and reduce costs.

Melo et al. (2017) presented an innovative approach to enhancing garbage collection efficiency through the application of genetic algorithms (GAs). One of the key strengths of the paper was its introduction of a robust optimization technique, the genetic algorithm, to address the complexities of garbage collection routing.

Gilardino et al. (2017) used Life Cycle Assessment (LCA) technique and heuristic approach to solve the vehicle routing problem. By merging these methodologies, the authors offered a comprehensive framework that addressed both operational efficiency and environmental impacts, making their approach highly relevant for the specific context of Lima, Peru. They considered the available working time of each collection truck to assign them collection routes and minimized the number of compactor trucks. The study's strengths includes its detailed methodology and the actionable insights it provided for optimizing waste collection routes and reducing environmental impacts.

Akhtar et al. (2017) proposed a modified Backtracking Search Algorithm (BSA) to solve vehicle routing problem models with the smart bin concept to find the best-optimized waste collection route solutions. The study provided a significant contribution to the optimization of solid waste collection routes through the application of advanced algorithms. The primary strength of the study was its use of the Backtracking Search Algorithm (BSA) in conjunction with the Capacitated Vehicle Routing Problem (CVRP) framework. This approach is noteworthy for its ability to offer innovative solutions to the complex problem of route optimization in waste collection. By employing the BSA, the authors presented an effective method for improving route efficiency, which can lead to cost reductions and enhanced operational effectiveness.

Xue and Cao (2016) presented a well-structured approach to optimizing waste collection routes using advanced routing algorithms. They proposed an ant colony optimization (ACO) based multi-objective routing model coupled with Dijkstra's algorithm to find the best route from these waste-generating points to the dumping station considering travel time, accident probability (black spots), and population exposure. The study's primary strength lay in its application of sophisticated optimization techniques to a real-world scenario, providing practical solutions for improving efficiency in waste collection operations. The case study in Singapore added significant value by demonstrating the applicability of these techniques in a developed urban setting, showcasing how theoretical models can be effectively implemented in practice. The paper's use of detailed data and advanced algorithms, such as the Vehicle Routing Problem (VRP) with specific constraints, ensured that the proposed solutions were both theoretically sound and practically relevant.

Zhang and Wang (2020) research paper integrated social equity considerations into the optimization models used for planning waste collection routes. By doing so, they aimed to address disparities in service provision that can arise from purely cost-driven models. Their model incorporated constraints that ensure more balanced service levels across different neighborhoods, taking into account factors like population density, socio-economic status, and specific community needs. This approach helped to prevent scenarios where lower-income areas might receive less frequent or lower-quality waste collection services.

Kabir and Sadiq (2021) delved into the integration of advanced optimization techniques to improve waste collection efficiency. They focused on creating a robust hybrid model that leverages the strengths of genetic algorithms and neural networks to optimize waste collection routes, incorporating multiple constraints and objectives. The hybrid model combined the global search capabilities of genetic algorithms with the predictive power of neural networks.

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Markovic et al. (2021) developed a comprehensive hybrid model to address the challenges of vehicle routing in waste collection systems. The study integrated Dijkstra's algorithm with other advanced optimization techniques, including machine learning and multi-objective optimization, to enhance the efficiency and robustness of logistics operations. The research primarily focused on the vehicle routing problem within the context of waste collection, aiming to optimize routes to minimize costs and environmental impact while ensuring timely waste collection.

III. METHODOLOGY

Object Oriented Analysis and Design Methodology (OOADM) is used in this research to organize requirements around objects which integrated both behaviours (processes) and states (data) modeled after real world objects that the system interact with.

The data used for this project were gathered from both primary and secondary sources. Three methods of fact-finding techniques was applied for this research; Interview method, Examination of documents, and Journals, Conference papers and articles. The requirement gathering process primarily employed a descriptive research approach, relying heavily on secondary data sourced from online platforms, conference proceedings, journals, and publications. Additionally, email communication with researchers and practitioners in ICT and waste disposal management contributed to the information collection. This process involved gathering both primary and secondary data, with datasets obtained from the Ebonyi State Waste Management Board. Data collection included interviews with relevant staff, focusing on disposal routes, waste hazards, and challenges in effective waste management.

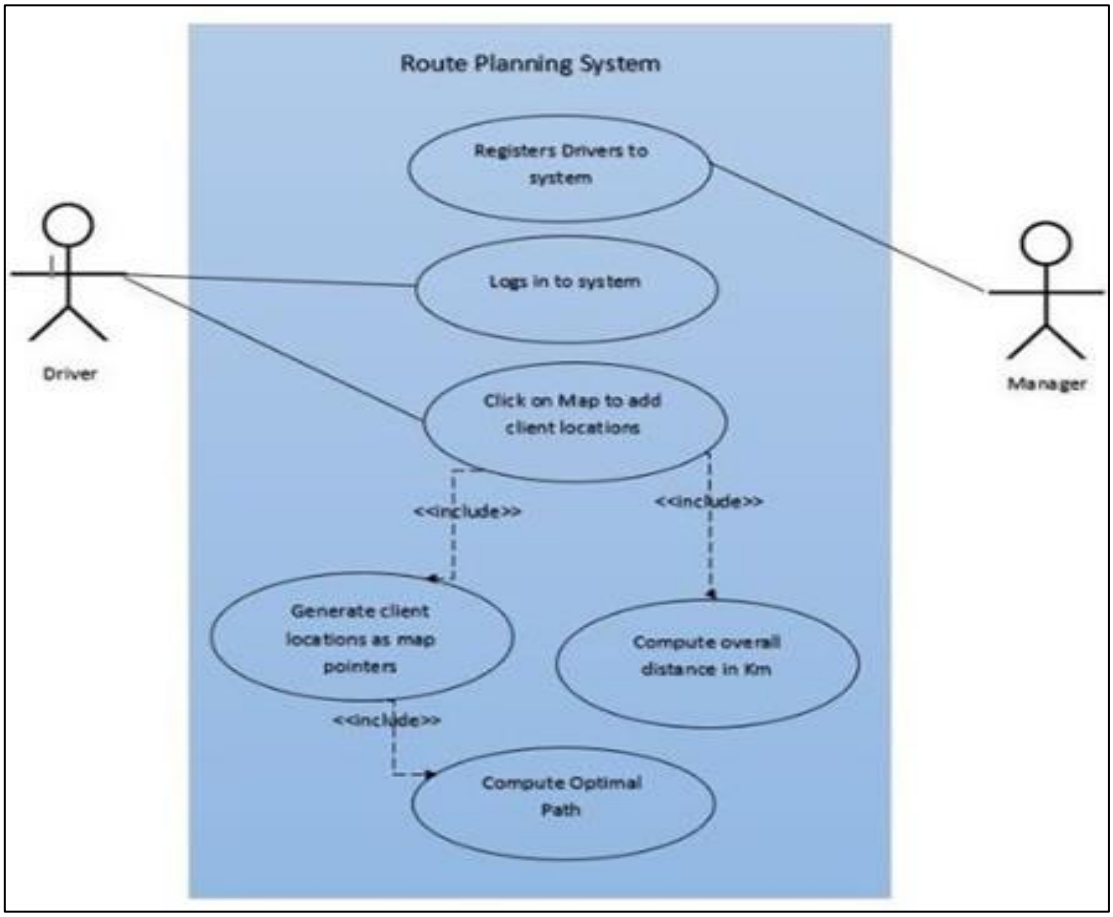

Fig 1: Use Case Diagram of the System

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IV. SYSTEM ANALYSIS AND DESIGN

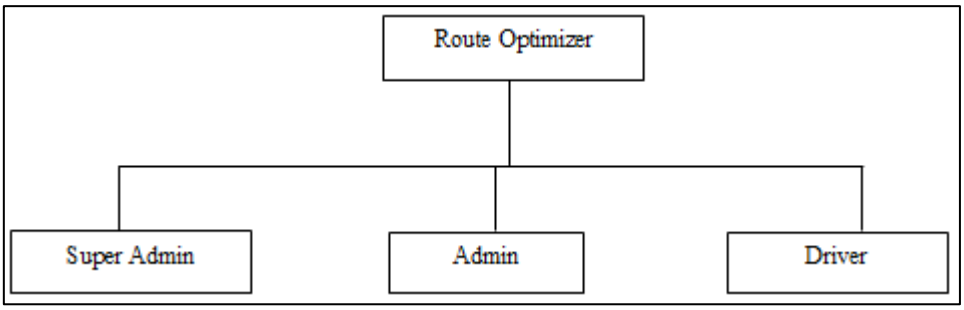

Fig 2: Use Case Diagram of the System

❖ *Menus and Sub-Menus of the New System:*

The new system has three menus – Super Admin (is the system manager at headquarter level) having access to functions of the system, Admin (is the system manager at sub-stations level) which has same access with the Super Admin except the access to manage other users, and Driver (is the drivers manning the garbage trucks) who's access is limited to finding and navigating best possible and shortest routes to pick up the bins that are filled and the exact locations of the bins as shown in figure 2.

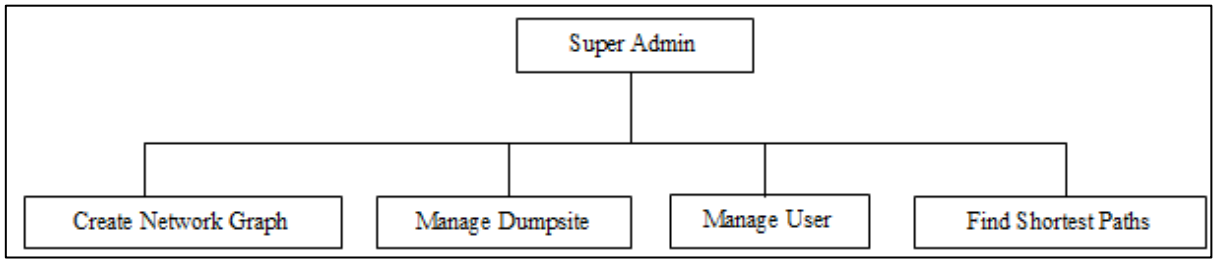

Fig 3: Sub-Menus of the Super-Admin Module (Menu)

- Create Network Graph: This sub-menu is used to create predefined paths, specify and manage source (sub-station) and destination (dumpsites and recycle station).
- Manage Dumpsite: the location and status of all approved dumpsites, recycle stations and waste bins are added, managed, and tagged from this sub-menu, linking them with the sensors embedded in the actual waste bins which monitor the status bins.
- Manage User: login profiles are created for various personnel with their designations assigning to them the level of access required to carry out their duties effectively through this sub-menu.
- Find Shortest Path: this sub-menu function is used to compute all available paths through all filled bins, accounting for traffic, bad roads, etc. advising the user on the best possible route to take based on all the parameters factored.

V. CONCLUSION

The research highlighted the major factors constraining the effective disposal of waste, leading to waste build up, which in turn causes environmental hazards. The developed route optimizer model successfully addressed these challenges faced in the management of waste disposal. Waste disposal routes were optimized using sensors to check the degree of fill of the bins, internet of things (IoT) for the weighted vans and Geographic Information System (GIS) to check and redirect route in cases of road congestions, giving 16% - 23% shorter routes than the traditional routing. This would facilitate the effective and efficient delivery of the same task under less time, maximizing man power and saving resources in the process.

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