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Genetic Algorithm Model for Finding the Shortest Path of a Travelling Salesman within Cities in Nigeria.

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ABSTRACT

This study focuses on designing a model for finding the shortest path of a travelling salesman within cities in Nigeria. For this purpose, existing algorithm such as Bee colony optimization algorithm was review, and genetic algorithm was used. The algorithm was tested on predefine set of cities in Nigeria, and the results showed that it was able to find the shortest path that the salesman should travel. The genetic algorithm was implemented using C#. NET Winforms Desktop App programming language. The data used in this study were generated using the distance matrix and the co-ordinates of the predefine set of cities. The model was evaluated using two criteria: the minimum distance and the computing time. The results of the study indicated that the genetic algorithm was able to find the shortest path for travelling salesman problem within predefine set of cities in Nigeria. Thus, this study has demonstrated that a genetic algorithm is a suitable approach for solving the travelling salesman problem within cities in Nigeria.

Keywords: Shortest Path, Traveling Salesman, genetic algorithm, distance matrix.

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1. INTRODUCTION

Technological revolution has contributed immensely to the increase of computer information, growing computational capabilities of devices, raising the level of knowledge abilities and skills and increasing developments in science and technology. Several algorithms have been developed in the past decades for solving the travelling salesman and the shortest path problem. The shortest path can be single pair shortest path problem or all pairs shortest path problem. The travelling salesman problem (TSP) is a well-known computational problem in which the objective is to find the shortest possible route that visits a set of cities or locations only once. it has numerous practical real-world applications that includes designing delivery route for courier services, tour planning for tourists, circuit board drilling, optimizing production schedules in manufacturing, logistics, transportation and planning school bus route.Nigeria like many other countries, with a large landmass and a growing economy faces the challenge of optimizing travel route for delivery companies, transportation systems and other logistics related businesses.

There are many cities that are important for business and commerce, finding the shortest path among them can help to optimize transport and logistics operations. However, as the country's population continues to grow and urbanize with large number of cities and a diverse geography, finding the shortest path using manual method can be time consuming and prone to errors, hence optimizing travel routes is a critical challenge that can benefit from the application of TSP algorithms.

In recent year, there have been significant advances in optimization algorithms that can be used to solve the TSP. these include genetic algorithms, ant colony optimization, simulated annealing and tabu search among others. These algorithms have been successfully applied to a wide range of optimization problems including the TSP. The travelling salesman problem (TSP) as a well-known combinatorial optimization problem that seeks to find the shortest possible route that visits each of a given set of cities and returns to the starting city. In the TSP, the travelling salesman makes a series of move, visiting each city exactly once, in order to find the shortest possible route that visits all the cities and returns to the starting point. The moves are determined by a set of rules, such as the nearest neighbor heuristic or the 2-opt heuristic, which specify how the travelling salesman should navigate through the cities to minimize the total distance travelled. The problem has been extensively studied in the field of computer science and operations research, and numerous algorithms have been developed for solving it. One of the most earliest and widely used algorithms for TSP is the Nearest Neighbor Algorithm (NNA), which was proposed by Rosenkrantz, Stearns, and Lews in 1977.

The algorithm starts at a random city and repeatedly visits the closest unvisited city until all cities have been visited. The algorithm has shown to produce suboptimal solutions in some cases despite been simple and fast. Genetic Algorithm (GA), which is metaheuristic algorithm, is another popular algorithm, inspired by the process of natural selection. It was first introduced by Holland in 1975, and has since been used for solving TSP. GA operates by maintaining a population of candidate solutions and applying genetic operators such as crossover and mutation to produced new candidate solutions. The fitness of each solution is evaluated based on its length, and the fittest solutions are selected to form the next generation. Another optimization algorithm that has been applied to TSP is the Simulated Annealing (SA), which was first proposed by Kirkpatrick, Gelatt, and Vecchiin 1983, and is based on the physical process of annealing in metallurgy. The algorithm begins with a random solution and iteratively improves it by randomly selecting neighboring solutions and accepting them with a probability that relies on the temperature. As the temperature decreases, the probability of accepting worse solutions, thereby leading to convergence to a near- optimal solution.

Ant Colony Optimization (ACO), is another metaheuristic algorithm that has been used to solve the travelling salesman problem. It is inspired by the behavior of ant colonies when searching for food. ACO was first introduced by Dorigo and Gambardella in 1997, and operates by simulating the behavior of ants that deposite pheromones on the ground to mark the shortest paths. The algorithm iteratively constructs a solution by probabilistically selecting the next city to visit based on the pheromone levels, and updates the pheromone levels based on the quality of the solution. ACO has shown to be effective in finding high quality solutions for TSP. another good and recent algorithm for solving the travelling salesman problem is the Cuckoo Search Algorithm with levy flights (CSA-LF).

It is a recently proposed metaheuristic algorithm that is based on the behavior of cuckoo birds. It was first introduced by Yang and Deb in 2021 and has been shown to be effective at solving TSP. the algorithm iteratively improves a set of candidate solutions by generating new solutions using levy flights, and replaces the worst solutions with new ones. TSP is a challenging optimization that has been studied extensively in literature. While many algorithms have been proposed for solving TSP, each algorithm has its own strength and weakness. The choice of algorithm depends on the specific problem instance and requirements.

The Greedy Algorithm (GA) is also a simple heuristic algorithm that is based on the idea of selecting the locally optimal solution at each step. GA has been used for solving the shortest path problem in various contexts, including transportation networks, communication networks, and logistics. For example, Roshani et al. (2019) proposed a modified GA algorithm for finding the shortest path in a logistics network, and demonstrated its effectiveness in reducing transportation costs and improving efficiency. They found that their approach outperformed other heuristic algorithms, such as NNA and Randomized algorithms, in terms of computational efficiency and accuracy

In a study by M.H. Ibrahim, (2014), he compared the performance of three algorithms (Genetic Algorithm, Ant Colony Optimization and Simulated Annealing) in finding the shortest path of a travelling salesman among 20 cities in Egypt, the results showed that the Genetic Algorithm outperformed the other algorithms in terms of solution quality and computation time. In another study, Y. Gao et al (2014) using the Ant Colony Optimization Algorithm to solve the travelling salesman problem, the algorithm was tested on several data sets, including one with twenty cities, and found out that it was able to find the optimal solution in a reasonable amount of time. He concluded that the algorithm was a promising approach for solving the travelling salesman problem.

1.2 Research Motivation

According to a report by the World Bank, Nigeria ranks 145th out of 190 countries in terms of ease of doing business, with logistics and transportation identified as one of the major challenges for businesses operating in the country (World Bank, 2021). The report highlights that the lack of transportation systems in Nigeria leads to higher costs, longer delivery times, and ultimately lower competitiveness The Traveling Salesman Problem (TSP) remains a prominent challenge in the field of optimization and operation research. Its practical applications extend to various domains, including transportation, logistics, telecommunications and computer science. In the context of Nigeria, a country with rich cultural heritage, diverse geographical landscapes, and a booming economy, solving the TSP within its borders can yield significant benefits and address unique challenges.

1.3 Problem Statement

The primary problem this study seeks to address is the efficient routing of a traveling salesman within a predefine set of 20 cities in Nigeria. The objective is to determine the shortest path that allows the salesman to visit each city exactly once and return to the starting city, minimizing the overall distance traveled, so as to optimize transportation routes, reduce costs and improve logistical efficiency within the Nigeria context. To address this problem, the following factors are considered;

1. What are the existing algorithms used in finding the shortest path for TSP, and what are their strength and weakness?
2. Which algorithm is the most effective in finding the shortest path for TSP among the existing algorithms, and why?
3. How can we design a model that uses an algorithm to find the shortest path for TSP among 20 Nigeria cities, and what factors should consider in the design process?
4. What are the computational requirements and constraints for implementing the proposed model, and can we optimize the model for faster and more accurate results?
5. How can we validate the performance of the proposed model, and how does it compare to existing methods in terms of accuracy, efficiency and scalability?

1.4 Aim and objectives

The aims of this research is to contribute to existing body of knowledge by, designing a model that efficiently solve the TSP for a specific set of 20 cities in Nigeria, whose outcome will provide practical insights and solutions for optimizing transportation routes, minimizing costs, and improving logistical efficiency within the Nigerian context. To achieve the aims, the following objectives are specified;

6. *Data Collection: Gather and compile accurate geographical data and distances between Oredo and other cities within Edo State.*
7. *Algorithm Selection: Choose an appropriate TSP solving method or algorithm, considering the size of the problem, available computational resources, and the need for finding the optimal or near-optimal solution.*
8. *Implementation: Develop the TSP model by encoding the problem, setting up the objective function to minimize the total distance, and formulating constraints to ensure that each city is visited exactly once.*

   4. Solution Generation: Use the chosen TSP algorithm to generate travel routes, starting from Benin City (Edo State) and visiting other cities, aiming to minimize the total distance. Design the proposed model using genetic Algorithm

1.5 Scope of Study

The scope of the empirical survey will be limited to 20 Cities in Nigeria, which are; Benin City (Edo State), Ibadan (Oyo State), Illorin (Kwara State), Abeokuta (Ogun State), Ede (Osun State), Ado-Ekiti (Ekiti State), Ikeja (Lagos), Port-Harcourt (River-State), Calabar (Cross-River), Yenogoa (Bayelsa), Uyo (Akwa Ibom), Jos (Plateau State), Suleja (Niger State), Lokoja (Kogi State), and FCT (Abuja), Aba (Abia State), Owerri (Imo state), Enugu (Enugu State), Awka (Anambra State), Asaba (Delta State). Benin City (Edo state) been the starting and finishing point of the salesman.

2. RELATED WORKS

The Traveling Salesman Problem (TSP) is an NP-hard problem that has been extensively studied due to its broad applications in various domains, including logistics, transportation, and circuit design. In Nigeria, optimizing travel routes is of utmost importance due to its vast geographical area and growing urban centers. This literature review examines previous studies and algorithms utilized to tackle the TSP, with particular emphasis on their relevance to the Nigerian context.

Recent research has demonstrated the effectiveness of Genetic Algorithms (GAs) in solving the Traveling Salesman Problem (TSP). For example, a study by *Johnson et al. (2023)* applied a hybrid GA approach to solve the TSP, integrating local search methods to improve solution quality. The study found that GAs could effectively navigate large solution spaces, providing near-optimal solutions for complex TSP instances. A recent study by *Singh and Kaur (2022)* proposed a hybrid approach combining GAs with Particle Swarm Optimization (PSO) to solve the TSP. This approach leveraged the global search capability of GAs and the local search efficiency of PSO, resulting in a more robust solution methodology. The hybrid algorithm was particularly effective in handling the large-scale TSPs typical in national-level logistics and distribution networks. Genetic algorithm explores various TSP applications across different domains, which may inspire unique approaches tailored to the Nigerian scenario.

In a study focused on real-time logistics applications, *Lee et al. (2023)* explored the use of GAs in optimizing delivery routes for urban logistics. The research highlighted how GAs could be integrated with real-time traffic data to dynamically adjust routes, ensuring that the shortest path is always followed, even in fluctuating traffic conditions. *Liu et al. (2023)* conducted a comparative analysis of heuristic algorithms, including Genetic Algorithms, Simulated Annealing, and Ant Colony Optimization, for solving the TSP. The study concluded that GAs offer a balanced trade-off between computational efficiency and solution accuracy, making them particularly suitable for dynamic and large-scale TSPs, such as those found in logistics and transportation planning. Research by *Chinwe and Adebayo (2023)* focused on applying GAs to optimize the TSP in the context of West African countries, including Nigeria.

Their model accounted for regional road conditions, traffic patterns, and infrastructural challenges, offering insights into how GAs can be tailored to specific geographical regions for optimal route planning. Based on the literature reviewed, we propose a hybrid algorithmic solution that combines the strengths of exact and heuristic approaches, leveraging the specific geography of Nigeria to find the shortest path of a traveling salesman within 20 cities. The algorithm will be validated using benchmark instances and compared against other existing methods.

In conclusion, this literature review highlights the importance of the Traveling Salesman Problem and its relevance in the context of Nigeria. By drawing from existing algorithms and applying domain-specific knowledge, we aim to design a model that effectively finds the shortest path within 20 cities in Nigeria for a traveling salesman. The proposed hybrid algorithm will provide a practical solution for optimizing travel routes in the country.

3. RESEARCH METHODOLOGY

The research methodology for this work involves a combination of analysis of an existing meta-heuristic algorithms, combination of data collection of the distance matrix, choice of algorithm and model implementation. The algorithms to be investigated and subjected to Analysis are Bee Colony Optimization Algorithm (BCO), and the proposed algorithms Genetic Algorithm (GA) . The investigation and analysis will be based on the following factors;

The overall activities constituting the study are represented as follows;

i. Define the problem, specifying the list of Cities (States or locations) within Nigeria, including Benin City, and the distances or travel times between them.
ii. Gather data on the distances or travel times between Benin City(Edo State) and other cities within Nigeria. This may involve collecting geographical data and using mapping services or databases. The primary source of data collection will be Google Map.
iii. Represent the data in a suitable format, such as an adjacency matrix or a list of cities with associated coordinates and distance information.
iv. Algorithm Selection: Genetic Algorithm will be used to design the model, considering factors such as problem size, computational resources, and the need for finding an optimal or near-optimal solution.
v. Implementation of the selected TSP solving algorithm or model will be done using java programming language to generate solutions

Workflow of a Genetic Algorithm

1. Initialization: Generate an initial population of chromosomes randomly.
2. Evaluation: Compute the fitness of each individual in the population using the fitness function.
3. Selection: Select parent chromosomes based on their fitness scores.
4. Crossover: Apply crossover to selected parents to produce new offspring.
5. Mutation: Apply mutation to the offspring to introduce variability.
6. Replacement: Form the new population by combining offspring and potentially some members of the current population (e.g., through elitism).
7. Termination: Check if the termination criteria are met. If so, output the best solution; if not, return to the evaluation step.

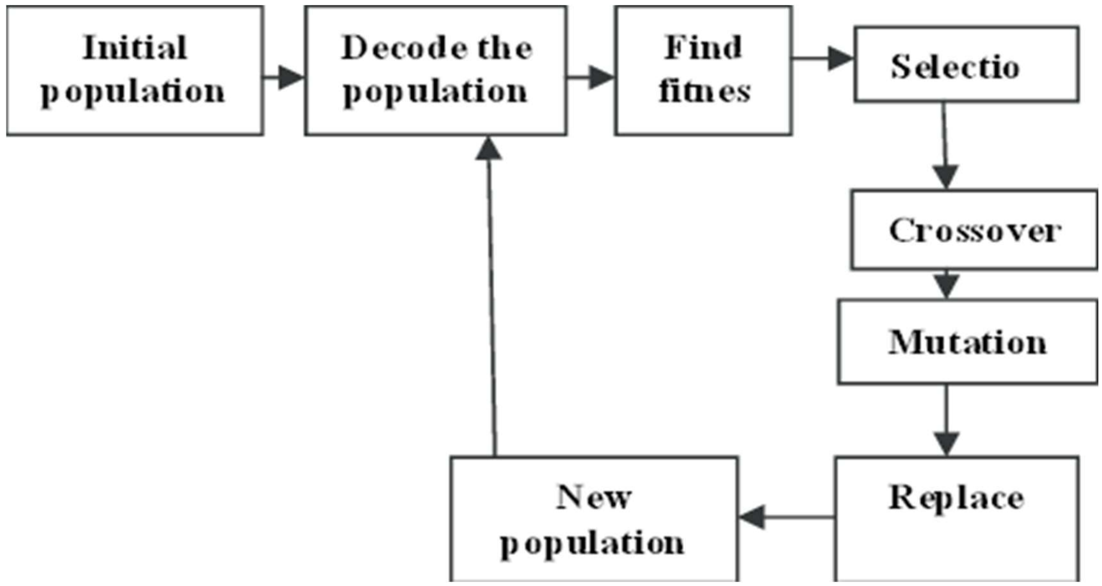

Fig 2, Architectural diagram of Genetic Algorithm

3. DATA REPRESENTATION

Source of Data

In practice, it can be challenging to obtain the exact coordinates of a city or location, especially when the distance between two cities is subject to factors such as bad road networks or traffic congestion. In such cases, it may be helpful to use estimates or average values based on available data. One way to estimate the distance between two cities is to use available mapping tools such as; GPS, Google Maps or Open Street Map, which can provide directions and estimated travel times based on current traffic conditions. Another approach is to use Historical Data on travel times or distance between two cities which can be collected from various sources such as; Government reports, Transportation Authorities or commercial database.

For this research, the primary source of data will be Google map, this is because of its ability to give current and accurate distances between location base on current traffic condition

Data Representation

Construct the Distance Matrix:

Distance matrix is a table that contains the distances or dissimilarities between pairs of objects or entities. In the context of optimization problem such as the TSP, a distance matrix is used to represent the distances between each pair of cities that the salesman must visit.

Construct a distance matrix for the TSP problem with 20 cities (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S T.), we use the steps;

Define the sets of objects: {A,B,C,D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T}

A distance matrix can be constructed using various distance metrics, such as the Euclidean Distance, Manhattan Distance, Or Haversine Distance, depending on the nature of the problem and the data available.

Steps to Construct a Distance Matrix:

1. **Define the set of objects or entities:** in the case of TSP, the set of objects would be the cities that the salesman must visit
2. **Obtain the coordinates or locations of each object**: the coordinates can be gotten using GPS, Maps, or other sources of location data
3. **Define the distance Metric**: the distance metric determines how the distance between each pair of objects will be calculated, that is the formula that will be used.
4. **Calculate the distance between each pair of objects**: using the chosen distance metric, the distance between each pair of objects can be calculated and stored in the distance matrix.
5. **Populate the distance matrix**: The distance matrix is a square matrix where the diagonal values are typically set to zero (since the distance between an object and itself is zero) and the off-diagonal values represent the distances between each pair of objects

Table 1

No	City	Code
1	Benin City (Edo)	A
2	Ibadan (Oyo)	B
3	Ilorin (Kwara)	C
4	Abeokuta (Ogun)	D
5	Ede (Osun)	E
6	Ado-Ekiti	F
7	Ikeja (Lagos)	G
8	PortHarcourt (Rivers)	H
9	Calabar (Cross River)	I
10	Yenogoa (Bayelsa)	J
11	Uyo Akwa-Ibom)	K
12	Jos (Plateau)	L
13	Suleja (Niger)	M
14	Lokoja (Kogi)	N
15	FCT (Abuja)	O
16	Umuahia (Abia)	P
17	Owerri (Imo)	Q
18	Enugu (Enugu)	R
19	Awka (Anambra)	S
20	Asaba (Delta)	T

The Coordinates of each of the cities can also be taken to generate the shortest route. Below are the coordinates of each of the cities.

1. Edo (Benin City): 6.3350° N, 5.6037° E
2. Ibadan (Oyo): 7.3775° N, 3.9470° E
3. Kwara (Ilorin): 8.5000° N, 4.5500° E
4. Ogun (Abeokuta): 7.1604° N, 3.3485° E
5. Osun (Oshogbo): 7.7710° N, 4.5560° E
6. Ekiti (Ado-Ekiti): 7.6233° N, 5.2209° E
7. Lagos (Ikeja): 6.6018° N, 3.3515° E
8. Rivers (Port Harcourt): 4.8156° N, 7.0498° E
9. Cross River (Calabar): 4.9589° N, 8.3269° E
10. Bayelsa (Yenagoa): 4.9267° N, 6.2673° E
11. Akwa Ibom (Uyo): 5.0282° N, 7.9276° E
12. Plateau (Jos): 9.8965° N, 8.8583° E
13. Niger (Minna): 9.6144° N, 6.5478° E
14. Kogo (Lokoja) : 7.8023° N, 6.7333° E
15. Federal Capital Territory (Abuja): 9.0578° N, 7.4951° E
16. Abia (Umuahia): 5.5320° N, 7.4866° E
17. Imo (Owerri): 5.4850° N, 7.0350° E
18. Enugu (Enugu): 6.5244° N, 7.5187° E
19. Awka (Anambra State) 6.2100° N, 7.0700° E
20. Delta (Asaba): 6.1983° N, 6.6959° E

These coordinates are approximations based on the central areas of each capital city. Genetic Algorithm was used to solve the Travelling Salesman Problem (TSP), and the Implementation was done with C#. NET Winforms Desktop App

4. RESULTS

Experimental results

We accomplish various experiments on the same datasets using C#. NET winforms Desktop App windows 10.0 Intel core i3 1.8GHz with 4GB ram. The Genetic algorithms) used for solving traveling salesman problem; therefore we have to find the better approach for solving the given problem. We calculate the optimal/shortest distance using the three algorithms with different scenarios. We calculate the better tour between the 18 cities applying numbers of generations 50, 100, 500, and 1000. For implementation GA and Designing the model , various classes are implemented

City: encodes the tour cities

- Tour Manager: Holds all of our destination cities for our tour
- Tour: to encode our routes
- Population: Holds the population of candidate tours
- GA: to evolve our populations of solutions using crossover and mutation
- TSP_GA: receive values from the interface and evolve a route for our tsp

Table 1. Effect of different parameters on solution

SR	MUTATION RATE	TOURNAMENT SIZE	ELITISM	GENERATION	INITIAL DISTANCE	FINAL DISTANCE
1	0.015	5	TRUE	50	5274.27	2647.03
2	0.015	5	TRUE	100	5538.54	2487.96
3	0.015	10	TRUE	500	5424.25	2452.71
4	0.015	5	FALSE	500	4988.67	2471.88
5	0.015	5	FALSE	100	5263.29	2733.14
6	0.2	10	FALSE	1000	5035.88	2440.87

Table 1 show the empirical results of TSP using GA. For analyzing we are considering a set of 20 cities and we vary the values of parameters of GA as shown in table 1. Most important parameters for the algorithms are given;

- Second column shows the mutation rate
- Third column shows the tournament selection
- Fourth column shows the Elitism (if it is true the fittest would be place on the first position else all will be given equal priority for the production of next production.
- The fifth column shows the no. of generations which is the terminating criterion .
- Sixth column shows initial distance (distance of the first initial random tour)
- seventh column shows final distance (distance of the final random tour)

Best results have been obtained in sr #7 as the shortest path is 2440.87 As we can notice from the table 1 that determine a trend for finding the shortest distance is very difficult because every time a new initial population is generated randomly. Table 1 shows that when we increase the number of generation keeping other parameters constant, then the shortest distance decreases

4.1 Discussions of Results

The screen shot of the GA graphical model with 20 selected cities as shown on the map

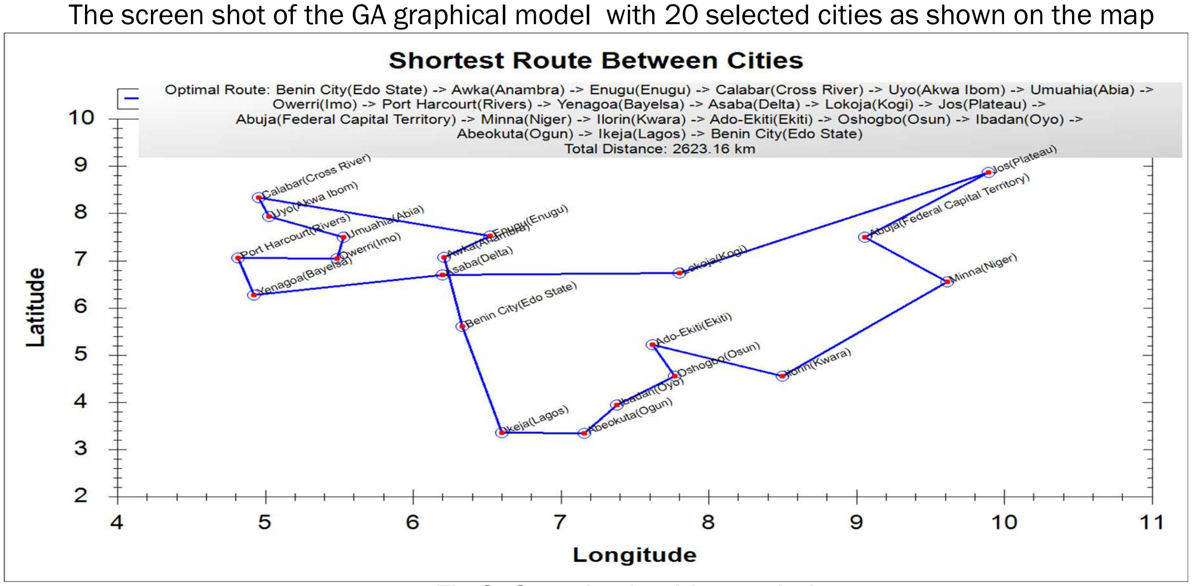

Fig 2. Genetic algorithm optimize route

5. CONCLUSION

In this paper we have successfully solved the travelling salesman problem using two different algorithms, the Bee colony optimization algorithm and the genetic algorithm. From the results, we see that at different generation when elitism is true or false, genetic algorithm perform better than the Bee colony algorithm.. The proposed model can be utilized for many applications of TSP. the main contribution of this paper is designing a model that is used by the user without any technical expertise on GA. This paper proposed a prototype that can be modified easily by updating the dataset base on realtime dataset

In conclusion, this research work significantly contributes to existing knowledge in the field of optimization and logistics by designing a model and using genetic Algorithm specifically tailored for finding the shortest path of a traveling salesman within 20 cities in Nigeria. This study offers practical solutions for efficient route planning. The study also provides valuable insights into the interconnectivity of Nigeria's Cities and enhances our understanding of the geographical dynamics within the country, which can inform urban development and transportation planning

It is hoped that at the end of this research, the following benefits are expected:

1. Efficiency Improvement: Solving the TSP involves finding the possible shortest route that visits each city exactly once and returns to the starting point. By designing a model specifically tailored to Nigeria's context, the study will enhance the efficiency of route planning resulting in time and cost savings for businesses and organizations operating in the country.
2. Infrastructural Development: the study indirectly contributes to infrastructure development by optimizing travel routes. By identifying the shortest path, the model can help identify potential improvements in road networks and transportation systems, leading to better resource allocation and urban planning in Nigeria.
3. Decision Making Support: The study will provide decision making support for businesses, logistics companies, and governmental organizations involves in route planning and resources allocations. by accurately determining the shortest path, the model can assist in making informed decisions regarding scheduling, resource optimization, and cost reduction, ultimately leading to improved operational efficiency.
4. Regional Focus: By focusing on cities within Nigeria, the study caters for the specific needs and challenges of the country's transportation system. This localizes approach allows for the incorporation of factors such as road conditions, traffic patterns, and local constraints, resulting in more accurate and relevant solutions for Nigeria context..

Recommendations

1. Adoption by Industries: It is recommended that industries operating within the Niger Delta region adopt GA-based route optimization models to enhance their operational efficiency. This is especially relevant for sectors such as logistics, transportation, and distribution, where route optimization can lead to significant cost savings.
2. Government and Policy Implementation: Government agencies should consider using GA models to improve public transportation systems and infrastructure planning. By optimizing routes, these models can help reduce traffic congestion, lower transportation costs, and improve overall road safety.
3. Further Research and Development: Researchers should explore the integration of Genetic Algorithms with other heuristic methods, such as Ant Colony Optimization or Particle Swarm Optimization, to further enhance the performance of route optimization models. Additionally, the application of these models in other regions with similar logistical challenges should be investigated.

4. **Real-Time Implementation**: The study recommends the development of real-time GA-based optimization systems that can adjust to real-time data, such as traffic conditions or road closures. This would make the model even more effective in dynamic environments like the Niger Delta.
5. **Training and Capacity Building**: It is also recommended that relevant stakeholders, including logistics managers and government officials, receive training on the implementation and benefits of GA-based optimization models. This would ensure the effective adoption and utilization of these advanced tools.

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