INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

***Corresponding author**.

appiah.mk@yahoo.com

Using genetic algorithm to solve multiple traveling salesman problem and considering Carbon emissions

Chris Jojo Obi[1]*, **Xiong Qiang**[1], **Appiah Martinson Yeboah**[1]

1 School of Management, Jiangsu University, 301, Xuefu Road, Zhenjiang, 212013, China

Abstract

Objectives: The Multiple Travelling Salesman problem is a complex combinatorial optimization problem which is a variance of the Traveling Salesman Problem, where a lot of salesmen are utilized in the solution. In this work a cold chain logistics and route optimization model with minimum transport cost, carbon cost and Refrigeration cost are constructed. **Methods**: A genetic algorithm is then proposed to solve for the Multiple Travelling Salesman Problem with time windows while transport cost, carbon emission cost and refrigeration cost is minimized. **Findings**: It was observed that the algorithm evolved towards the direction of the optimal value of the fitness function. **Novelty**: There are a number of studies that considered tournament selection strategy but just a few have applied genetic algorithm considering insertion method to solve a Multiple Travelling salesman Problem. This study uses insertion method to obtain optimal solution. Also, the researcher considered time windows, transport cost, carbon emission cost and refrigeration cost.

Keywords: Genetic algorithm method; cold-logistics; multiple travelling salesman problem

1 Introduction

As the standard of living of people increase continuously, demand for fresh food also increases the development of the cold chain logistics. This development comes along with cost associated with them, therefore to decrease the cost associated with cold chain logistics, researchers have taken upon themselves to research on optimization of distribution networks which doesn't only consider general cost but also cost associated with refrigeration and carbon emissions[1].

The main objective of logistics is to get materials which are needed at the right place and at the right time. In doing this, the total operating cost and constraints attached must be satisfied. This work considers a Travelling Salesman Problem with time windows and minimizes transport cost, carbon emission cost and refrigeration cost. It gives an overview of a set of courses with overall minimum route cost which serves all the demands. In literature, there are many variations of TSP which discusses the types of restrictions or constraints such as the number of cities, number of salesman or time windows.[2]. Multiple Travelling Salesman happens to be an example of these variations. In this Salesman problem, routes and cities of the salesman are found.

The routes cover all cities while every salesman visit at least a city starting from a particular point and returns to the exact point.[3]. For example, n represents the number of cities while m represents the salesmen, where m salesmen have to visit n cities to deliver goods. The main objective is to identify the distance for all salesman such that the total travelling cost is minimized. The cost metric may stand for distance, time etc.

Multiple Travelling salesman Problem can be applied in real life situation because it covers more than one salesman. Example of real-life application is shown in[4] and[5]. Therefore, this paper aims to solve Multiple Travelling Salesman Problem with time windows and minimize transport cost, carbon emission cost and refrigeration cost with the application of Genetic Algorithm.

A new crossover operator was proposed for traveling salesman problem to minimize the total distance. This approach has been linked with path representation, which is the most natural way to represent a legal tour. Computational results are also reported with some traditional path representation methods like partially mapped and order crossovers along with new cycle crossover operator for some benchmark TSPLIB instances and found improvements.[6]

A modified Gravitational Emulation Local Search (MGELS) is used by Shokouhi, R. A. (2015) to solve a symmetric m-TSP. In this method, a sweep algorithm is used to generate feasible solutions to help improve the modified Gravitational Emulation Local Search. After experiment, the results uncovered that the said strategy is superior over other optimization algorithms used to solve the m-TSP.[7]

A meta-heuristic method was proposed to optimize the solution +local subsections for a peculiar problem. This heuristic can be used as part of many neighborhood search methods. Result showed that the method is quite efficient and produces higher quality solutions.[8]

A novel multi-objective hybrid quantum immune algorithm was proposed based on cloud model to improve the delivery efficiency and reduce the cost of distribution requirements. Results showed that C-HQIA is an efficient algorithm for the GVROP. Authors also identified that the parameter optimization of the C-HQIA is related to the types of artificial intelligence algorithms.[9]

Two metaheuristic methods for the m-TSP was proposed by P. Venkatesh, A. S. (2015). The first approach was based on artificial bee colony algorithm while the second was based on an algorithm for invasive weed optimization. To strengthen the approach the more, a local search was implemented.[10]

Ziqi & Peihan, (2020) proposed an adaptive genetic algorithm approach to find an optimal solution of a non-deterministic polynomial hard problem. Results showed that customer satisfaction is a critical influence for companies to plan multi-echelon vehicle routing strategy. Also, current modest carbon price and trading quota setting in china have only a minimal effect on emissions control.[11]

Bektas, T. (2006) introduced Genetic to solve m-TSP with the goal of minimizing both the overall distance and the gap between the distances each salesman has travelled.[12]

Aditi, K. M. (2016) proposed several TSP's with imprecise data as Linear programs. In his work a hybrid heuristic algorithm which combined Ant colony and Genetic Algorithm to minimize cost and time was proposed. The authors created an algorithm capable of solving single and multi-objective restricted large TSP's with smooth, fuzzy and raw data. The researchers say that their algorithm outperforms other conventional non-hybrid algorithms and it accommodates many different real-life scenarios. Presents Vehicle Route Problem (VRP) that considers characteristics of customers. In their work a fuzzy clustering algorithm based on Axiomatic Fuzzy was proposed to group customers into clusters. A numerical case study was applied to demonstrate the relevance of the method. Results show that the approach performs very well to identify similar customer groups and incorporate individual customer's service priority into VRP. Results appears that the approach performs exceptionally well to recognize customer groups and connects individual customer's benefits in VRP.[13]

Youssef Harrath, A. F. (2019) proposed a two-part chromosome crossover to solve Multiple Travelling Salesman Problem. In their work a genetic algorithm was used to find the best solution. Observing some limitations with the GA, they included TCX to overcome the limitations and improve solution quality. Results show that TCX can help improve the solution quality of the GA.[14]

Liao, T.Y. (2017) considered routing optimization under a cap and trade mechanism based on the travelling Salesman Problem. In their work they used tabu search algorithm to obtain solutions within an appropriate time of computation. They looked at the effect of carbon trading, carbon cap and carbon routing decision and carbon emission. The outcome appeared that the model beneath trade mechanism is more effective in reducing carbon emissions.[15]

Li jiang, H. C. (2019) proposed an iterated local search algorithm four local search operators to solve a travelling salesman problem which considered the reduction of carbon emission in a last mile delivery. Her goal was to reduce total cost and carbon emission by assigning parcel locker while routes are been scheduled. The proposed method was tested on a set of scattered and clustered instances. Results showed how superior competitive the algorithm was.[16]

Xiao-Hong, L., Shan, M.-Y., Zhang, R.-L et al. (2018) focused on multi-objective green logistics optimization. The optimal criteria of environmental costs: as far as possible to reduce the noise, pollution and fuel cost of external cost paid amount, and try to reduce the noise, pollution and fuel consumption itself. A few blended numbers programming details of multi-criteria vehicle Routing problem was taken in account. Some integer programming details if multicriteria vehicle routing problems was considered. The precise strategies are applied to obtained optimal solutions. [17]

Leng, et al., (2020) proposed a cost-saving, energy-saving, and emission reducing bi-objective model for the cold chain-based low-carbon location-routing problem. In the proposed model, a strategy is developed to meet the requirements of clients as to the demands on the types of cargos, that is, general cargos, refrigerated cargos, and frozen cargos. In the experiment the authors assessed the effectiveness of a proposed framework. This they did by examining the utility of seven multiobjective evolutionary algorithms. Extensive experiments were carried out to investigate the effects of the proposed strategy and variants on depot capacity, hard time windows, and fleet composition on the performance indicators of Pareto fronts and cold chain logistics networks, such as fuel consumption, carbon emission, travel distance, travel time, and the total waiting time of vehicles. [8]

In order to attain efficiency in the transportation of agro products and customer fulfillment, a linear programming strategy of operations research was used to minimize the route of logistics transportation

Xiao-Hong, L., Shan, M.-Y., Zhang, et al. (2018) paper provides a low-carbon and environmental protection point of view in his work a hybrid genetic algorithm with heuristic rules is outlined to solve the model, and a case is utilized to confirm how effective the algorithm is. Through a practical example of the simulation outcomes shows the use of the model. At last, he introduced a carbon tax policy, analyzed the carbon tax's influence on the total cost and carbon emissions, proves that the carbon tax policy effectively minimizes carbon dioxide emissions in the cold-chain logistics network. [17]

Hussain, A., Muhammad, Y. S., Sajid, M. N., Hussain, et.al. (2017) proposed a Vehicle Routing Optimization with Soft time windows model. In his work he adopted a developed genetic algorithm which is the seeker genetic algorithm. Uncertainty reasoning and the nearest neighbor strategy was combined to help improve the mutation operator. So finally, cold chain logistics is solved with conventional genetic algorithm and seeker genetic algorithm. Results showed that seeker genetic algorithm obtains a path with the lowest cost. [18]

Liao, T.-Y. (2017) proposed details and a crossover meta-heuristic algorithm to address on-line vehicle routing problem, for reducing costs which surrounds financial matters and emissions. A crossover meta-heuristic was outlined to solve the on-line VRP and arrangement system utilizing DynaTAIWAN simulation is actualized. The numerical outcome showed that carbon dioxide can be decreased by combining the emission components into the function. [11]

The researcher categorized the literature stated above in three sections: Multiple Traveling Salesman Problem with other Algorithms, logistics VRP which considers carbon emission and Cold Chain logistics VRP without considering Carbon Emission. However, as far as the researcher knows, there are relatively few researches on cold chain logistics which considers factors of carbon emissions such as energy consumption from refrigeration, fuel consumption from vehicles, carbon emission cost, refrigeration cost as well as time windows.

Also, from the literature stated above, few studies have applied genetic algorithm which considers tournament selection strategy and insertion method to solve Multiple Travelling salesman Problem. In the paper, a genetic algorithm which uses insertion method to obtain optimal solution is proposed to solve the model. This method has the capacity to avoid being caught in local optimal solution like conventional strategies searching from a single point.this method also uses probabilistic selection rules. In the work it uses fitness score which is obtained from objective functions.

Hence, this article seeks to solve Multiple Travelling Salesman Problem with time windows and minimize transport cost, carbon emission cost and refrigeration cost with the use of Genetic Algorithm.

This article is organized in the following manner; section 2 looks at other literature which talks about the problem and the techniques applied to solve the MTSP. The next Section exposes the technique and model applied to solve the MTSP. Section 4 displays results which is the distances sorted and optimal path. This is presented on a graph and the operational results is shown in Table 4. Lastly, this research concludes that the optimal distances found will in reduce costs associated with transportation.

2 Research methodology

2.1 Conceptual framework

Vehicle routing problem is a basic problem in logistics field because of its wide application and high economic value. The study considers an optimal design of cold chain logistics network which takes into account transport products from distribution centers and then transfer products to each terminal demand point (locations) under constraints of limited time, reduce the related transportation costs, carbon emission as well as refrigerated cost. In essence, the study seeks to solve the objectives below. Also, a simplified diagram of the cold chain logistics network is shown below the research objectives in Figure 1.

RO 1: To identify the shortest tour travelled by the vehicle?
RO 2: To identify the cost associated with transportation and carbon emissions along the vehicle?
RO 3: Lastly to identify the Refrigeration cost associated with the transportation of products?
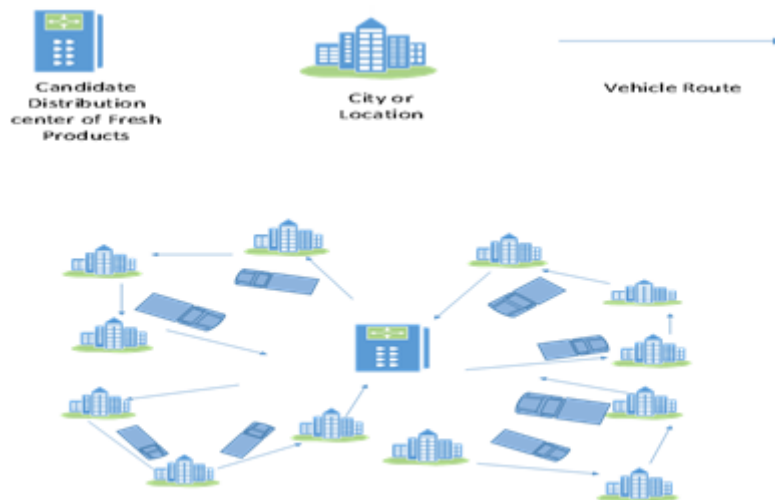Legend:

Fig 1. A simplified Diagram of the cold chain logistics

A simplified diagram of the cold chain logistics network is shown above in Figure 1. The goal of the optimization is to route all 4 vehicles so that all 12 delivery points (customers) can be accessed by one of them. The researcher has scheduled distances of four vehicle to decrease the full distance travelled by vehicles. It gives a possible scenario for routing four (4) vehicles starting and ending in the warehouse.

2.2 Model description/assumptions

The Model routes a single depot with four (4) vehicles and twelve (12) cities by following procedure below: The model considers the path selection of 4 cars and a single yard in 12 cities. The steps are as follows:

1. The model looks at a single depot with four (4) vehicles which has a load capacity constraint to serve some cities.
2. The demand of the goods is known ahead of time, and the travel distance between cities and the depot is also known in advance.
3. The maximum demand of goods along the routes must not be more than the vehicle capacity.
4. Goods sent to various customers are delivered by a single vehicle.
5. Four (4) Vehicles and Four (4) routes have been scheduled to reach the cities from the depot. After serving customers within the cluster, the vehicles return to the depot. Clustering of customer were done based on the level of goods required and the nearest in route from the depot.

2.3 Mathematical model

In this article, a transportation objective (cost) and carbon emission cost functions are established. This usually assures that the cost found in both variables are reduced.

a. This objective is to minimize transport cost

The goal is to minimize transport cost. This objective function guarantees that the cost involved in transport is minimized. It also has a proportional relation to the distance travelled by vehicles. The researcher modified mathematical formula from [19] and can be shown as:

$$\frac{\sum_{ij=1}^{L} X_{ij} \left((d_{ij}) - (n+1) \right)^2}{v} \quad, \quad N = 0, 1, 2, 3 \tag{2}$$

b. Carbon emission cost function

A carbon emission cost function is established from a regression analysis per distance from this function ensures that carbon related costs are minimized. This cost includes fuel and energy consumption. This model is proportional to the distance travelled by vehicles.

$$MinCe = \sum_{ij=0} X_{ij} \sum d_{ij} \ (r0S(p_{ij}) + \omega p_{ij}] \tag{3}$$

c. Refrigeration costs

In cold chain logistics, goods must be kept under low-temperature to ensure quality. This system helps maintain and control temperature of goods along the routes [23]. Therefore, the researcher considered refrigeration cost under Multiple Traveling Salesman Problem while considering time window. Refrigeration cost during transportation and unloading of cargoes is considered as well. They are all factored into a cost function to minimize cost associated with refrigeration. The mathematical model is as follows:

$$C_q = \sum_{i\&j=0}^{N} \sum_{k=1} X_{ijk} \left[C_e(t_j - t_i) + C_e' \right]$$

d. Constraints

$$\sum_{i,j \in V} d_{ij} = n \tag{4}$$

$$\sum_{i \in N} d_{ij} = 4 , \ where \ i \in N \tag{5}$$

$$\sum q_i d_{ij} \leq Q_k, \ i \in N \tag{6}$$

$$\sum q_i d_{ij} \leq Q_g, \quad i \in N \tag{7}$$

The objective function as shown in equation 1,2 and 3 is to minimize cost.

The 5th Constraint shows that 4 refrigerated vehicles will deliver goods to each customer along the distances scheduled. Constraints (6) ensures that goods assigned to a vehicle should not exceed the capacity of the vehicle. Finally, constraint (7) ensures that demand from the cities is not more than the total storage capacity of the depot g. Table 1, shows the meaning of the notations in the formula stated above.

2.4 Parameters and Variables

To build this model, this article shows the meaning of notations used in the formula in Table 1.

Table 1. Meaning of notations in the formula.

Parameters	Meaning
g	Distribution Centre
Q_g	Total storage of Depot
X_{ij}	Transportation
d_{ij}	Distance
N	Cities
k	Number of Tracks
q_i	City Demand
Q_o	Capacity of Trucks
ρ	The fuel consumption per unit distance by traveling salesman
ρ^*	Fuel consumption per unit distance by travelling salesman vehicle is loaded
r_o	It represents the coefficient values of C_o2 emission
p_{ij}	The carrying capacity of travelling salesman refrigerated truck when moving between cities

Continued on next page

Table 1 continued

s	The fuel consumption per unit distance by traveling salesman
w	Carbon emissions generated from distributing unit weight cargoes during driving unit
X_{ijk}	0-1 variable,$X_{ijk} = 1$ if the vehicle k visits customer j and I, otherwise $X_{ijk} = 0$
t_j	Arrival time to customer j
t_i	Arrival time to customer i
C_q	Transportation process of unit time

2.5 Methodology

The truck dispatching system (TDS) method for determining the optimal vehicle routing is the genetic algorithm.

Genetic algorithm is used to provide better solutions iteratively from a set of attainable population solutions. These operators are random, and genetic algorithms enable search areas to be analyzed in many ways. Once the operators are applied, they use a fitness function to evaluate the population. Select the most suitable individuals to breed in order to realize better possible solutions. Transversal and mutation operators are used repeatedly in breeding until they are stopped. The different components used to develop genetic algorithms are described in detail in the next section. The preparation process of GA is introduced below;

a. Encoding

The genotype of an individual (chromosome) is represented by a sequence of integers with n different values. This path representation is simple to implement and provides a direct interpretation of the TSP solution (Tours) chromosome. A chromosome $C_r = (g_1, g_2, \ldots, g_n)$ where $g_i \in V$, $1 \leq i \leq n$ represents a gene (node) in the chromosome.

b. Initial Population

In genetic algorithm, the generation of initial population is a very important step. Usually, the initial populace is randomly generated. To achieve an optimal solution, the first population is constructed carefully. The method adopted is as follows; One chromosome is produced at random and is retained if the traveling salesman's constraints are met, otherwise another chromosome is produced until n chromosomes are formed.

c. Evaluation

In this case, the value of fitness is allotted to each chromosome, but in the travelling Salesman problem, the fitness value is inversely proportional to the travel sales man problems final travel length. It can be seen that the higher the fitness value, the better the chromosome. The fitness function $Cr = (g_1, g_2, \ldots, g_n)$ is stated below:

$$f(C_r) = \frac{1}{C_{g_n g_1} + \sum_{i=1}^{n-1} C_{g_i g_{i+1}}}$$

d. Selection

The process is to select the best individual from the existing population to form an unused population. Tournament selection strategy is adopted in the selection process. this ensures that the better individuals have the higher percentage of been selected and the worse ones are eliminated. In so doing, the algorithm converges quickly. Nonetheless, it is imperative that the fitness values of individuals do not converge earlier in order to maintain the difference in population. The principle behind this selection process is based on the size of the fitness value of the individual, that is, a random individual is selected from the population, and then the individual with the highest fitness value is selected to enter the offspring population.

e. Crossover

Crossover operation is to select individuals in a population with a certain probability of crossover, and then replace and recombine some genes of the parents to produce new individuals. In this article, an ordered crossover operator and a sequential crossover operator are used to construct the crossover operator.

f. Mutation

Mutation operators mimic the process of biological change. The algorithm avoids local search and maintains the diversity of population. There are few common mutation operators, including reverse mutation, insertion mutation, exchange mutation, etc., but the insertion method is adopted in this article. In this way, the best chromosomes from the old population are inserted into the new generation, as described in the Figure 2 below.

g. Terminating Condition

The termination condition is the condition that determines whether to stop the operation. In the work, the greatest of iterations for the algorithm is set as R. Should the level of iterations exceed the total number of iterations R, the iteration is stopped and the optimal population is obtained.

2.6 The schematic diagram below shows the algorithm design of the genetic algorithm
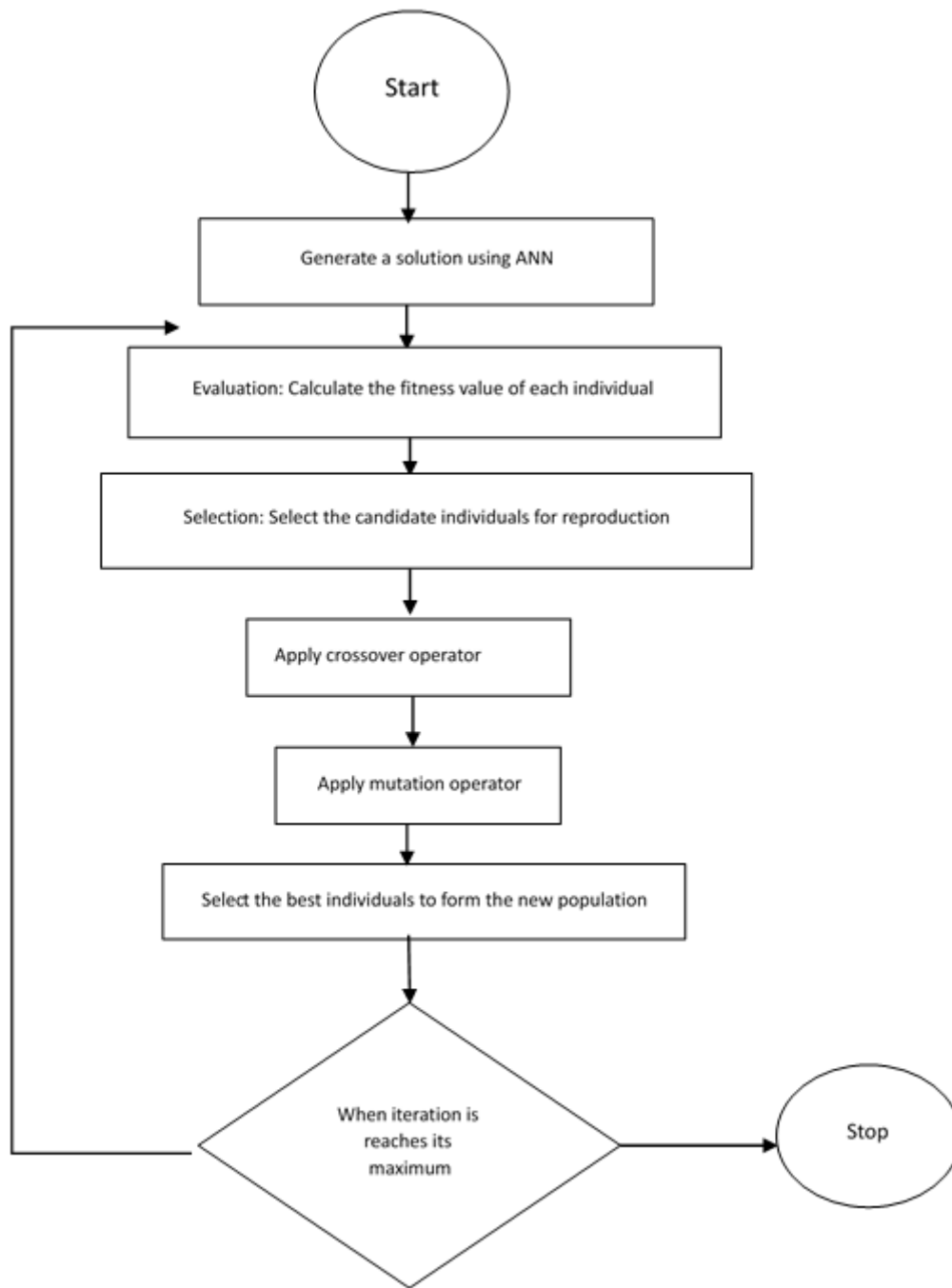
Fig 2. Genetic algorithm flowchart diagram

2.7 Experimental data and parameter setting

The researcher used primary data from Shedharv Agroe wholesale center with an average of 12 locations in Zhenjiang China. Table 2 shows the parameter settings and objectives of the model while Table 3 shows the service time allocated to each customer. The number of products carried by the travelling salesman is constant and the transport cost is $4 per kilometer.

Table 2. Objective-related parameter settings

Parameter	Value
r^o	3.74kg/L
Q_{ij}	2.50t
ω	0.0077/kg.km
p_o	0.256L/km
p^*	0.377L/km
ρ	300$/t
C_e	15 $/hour
$C'e$	20$/hour

3 Results and Discussion

Genetic Algorithm was coded into MATLAB R2014a and all experiments in the Paper were evaluated on PC's with intel˚. In this work MATLAB was used to implement the genetic algorithm. After 462 times of iteration conducted, the solution was stable. Insertion mutation in the algorithm helped to find the best value. This shows that the Genetic algorithm has a stronger function extreme value optimization ability. Finally, after computing for the optimal distance, a summary of the results of the costs involved are shown in Table 4. Table 3 shows customers information and Figure 3 shows the optimal distance that is the tour length.

Table 3. Customer information

Number	1	2	3	4	5	6	7	8	9	10	11	12
Service time (min)	0	20	10	20	20	25	25	25	22	15	15	15

Table 4. shows a summary of experimental results of all costs using GA

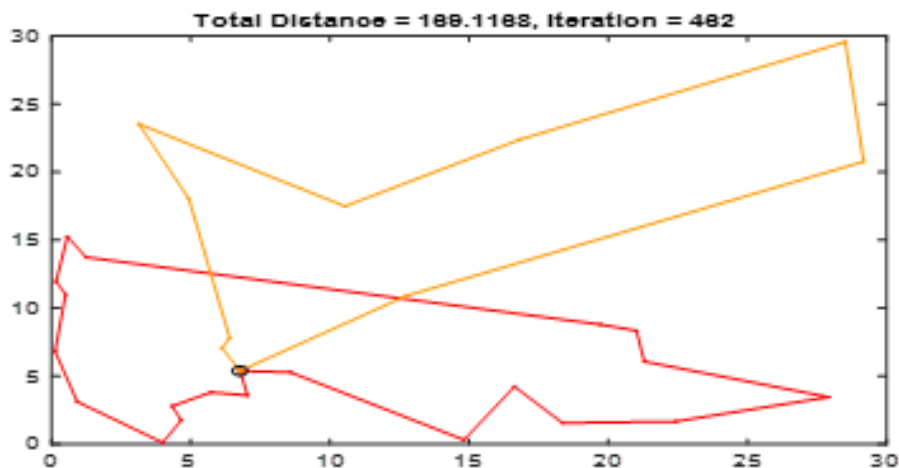| COST	VALUE ($)
Carbon Emission Cost	474,373.9
Transport Cost	114,401.9682
Carbon Emissions(kg)	1,125
Refrigeration cost	3050

Fig 3. Results of the optimization by MATLAB component for 12 locations (cities) with at most 4 salesmen and at most 169 km tour length per salesman.

In summary, the length of the route is 169km.

4 Conclusion

VRP is the key to reduce total cost associated with cold chain logistics. VRP and its variants have been studied and solved in many previous works. However, fewer studies have taken into account path optimization which considered the effect of carbon emissions on transportation. In the study cold chain logistics and route optimization model which considered minimum transport cost and carbon cost was constructed. In the study, a genetic algorithm method was suggested to solve for the optimal distance. The tournament selection method was designed to attain the optimal solution. In essence, the algorithm evolves towards the course of the optimal value of the fitness function. In the experiments, parameters such as the population size of the algorithm and number of iterations had effect on the optimization result. The results revealed the optimal distance to be 169km. Also, after calculating the transportation cost function and carbon emission functions, the results were $114,401.9682 and $474,373.9 respectively. Results from refrigeration cost was $3050.

For future research, real geographical situations can be considered in the planning of the distribution path. Also, the introduction of a road congestion index could be factored in to the model to reflect the actual feasible solution; time window may be taken into account route planning, factoring loading and unloading time and real-time constraints.

Acknowledgements

Disclosure Statement: There is no potential conflict of interest reported by the authors.

References

1) Aditi KM. A hybrid heuristic algorithm for single and multi-objective imprecise traveling salesman problems. *Journal of Intelligent and Fuzzy Systems*. 2001. Available from: https://doi.org/10.3233/IFS-151913.

2) Ala MN. Particle Swarm Optimization: Algorithm and its Codes in MATLAB. 2016. Available from: https://doi.org/10.13140/RG.2.1.4985.3206.

3) Ali O, Vanoudheusden D. Logistics Planning for Agricultural Vehicles. In: and others, editor. Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management. 2009;p. 8–11. Available from: https://doi.org/10.1109/IEEM.2009.5373351.

4) Bektas T. The multiple traveling salesman problem: an overview of formulations and solution procedures. *Omega*. 2006;34(3):209–219. Available from: https://dx.doi.org/10.1016/j.omega.2004.10.004.

5) Gutin G, A P. The Traveling Salesman Problem and Its Variations Combinatorial Optimization. and others, editor;Kluwer Academic Publishers. 2002.

6) Hussain A, Muhammad YS, Sajid MN, Hussain I, Shoukry AM, Gani S. Genetic Algorithm for Traveling Salesman Problem with Modified Cycle Crossover Operator. *Computational Intelligence and Neuroscience*. 2017;2017:1–7. Available from: https://dx.doi.org/10.1155/2017/7430125.

7) Krishna HR. Self-Adaptive Trust Model for Secure Geographic Routing in Wireless Sensor Networks Computer Engineering and Intelligent Systems. 2015. Available from: https://doi.org/10.5815/ijisa.2015.03.03.

8) Leng L, Zhang J, Zhang C, Zhao Y, Wang W, Li G. A novel bi-objective model of cold chain logistics considering location-routing decision and environmental effects. *PLOS ONE*. 2020;29.

9) Liao TY. On-Line Vehicle Routing Problems for Carbon Emissions Reduction. . *Computer-Aided Civil and Infrastructure Engineering*. 2017;17. Available from: https://doi.org/10.1111/mice.12308.

10) Jiang HCL. A Travelling Salesman Problem with Carbon Emission Reduction in the Last Mile Delivery. *IEEE Access*. 2019;8. Available from: https://doi.org/10.1080/00207543.2019.1656842.

11) Zhang Y, Guo W, Cheng T, Zhang J. Cold chain distribution: How to deal with node and arc time windows. *Annals of Operation Research*. 2020. Available from: https://doi.org/10.1007/s10479-018-3071-0.

12) Meneghetti A, Monti L. Greening the food supply chain: an optimisation model for sustainable design of refrigerated automated warehouses. *International Journal of Production Research*. 2015;53(21):6567–6587. Available from: https://dx.doi.org/10.1080/00207543.2014.985449.

13) Leng LO, Zhang J, Zhang C, Zhao Y, Wang W, Li G. A novel bi-objective model of cold chain logistics considering location-routing decision and environmental effects. *PLOS*. 2020;29.

14) Venkatesh P, S A. Two metaheuristic approaches for the multiple traveling salesperson problem. *Applied Soft Computing*. 2015;p. 74–89. Available from: https://doi.org/10.1016/j.asoc.2014.09.029.

15) Shokouhi RA. Solving multiple traveling salesman problem using the gravitational emulation local search algorithm. *Applied Maths*. 2015;11. Available from: https://doi.org/10.12785/amis/090218.

16) Wang S, Tao F, Shi Y. Optimization of Location–Routing Problem for Cold Chain Logistics Considering Carbon Footprint. *International Journal of Environmental Research and Public Health*. 2018;15(1). Available from: https://dx.doi.org/10.3390/ijerph15010086.

17) Xiao-Hong L, Shan MY, Zhang RL, Zhang LH. Green Vehicle Routing Optimization Based on Carbon Emission and Multiobjective Hybrid Quantum Immune Algorithm. *Hindawi Mathematical Problems in Engineering*. 2018;1.

18) Harrath Y, F A. A novel hybrid approach for solving the multiple traveling salesmen problem. *Arab Journal of Basic and applied sciences*. 2019;11. Available from: https://doi.org/10.1080/25765299.2019.1565193.

19) Ziqi W, Peihan W. Optimization of a Low-Carbon Two-Echelon Heterogeneous-Fleet Vehicle Routing for Cold Chain. *Sustainability*. 2020;22.