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A Hybrid Meta-Heuristic Approach for Design and Solving a Location Routing Problem Considering the Time Window

Mohammad Amin Rahmani[a,*], Ahamd Mirzaei[b], Milad Hamzehzadeh Aghbelagh[c]

[a]*School of Industrial Engineering, University of Tehran, Tehran, Iran.*
[b]*School of Computer Faculty, Islamic Azad University, electronic campus, Tehran, Iran.*
[c]*School of Faculty of Information Technology Engineering, Shiraz University of Technology, Shiraz.*

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Abstract

The supply chain requires a distribution network between customers and suppliers. This distribution network can be multifaceted. Combining these two problems into a single problem increases the efficiency of the distribution network and ultimately increases the efficiency of the supply chain. Establishing a window of time to deliver goods to customers also increases their satisfaction and, as a result, more profitability in the long run. Therefore, in this research, an attempt has been made to present a routing-location problem in the multimodal transportation network. A time window is also included in this model. To solve such a model, especially in large dimensions, exact solution methods cannot be used. Based on this, a combined meta-heuristic algorithm (genetic optimization algorithm and neural network) has been proposed to solve the model, and the result has been compared with two gray wolf optimization algorithms and grasshopper optimization algorithms. The presented results indicate the effectiveness of the proposed algorithm.

Keywords: The Problem of Routing - Locating, Time Window, Meta-Heuristic Algorithm of Gray Wolf Optimization, Meta-Heuristic Algorithm of Locust Optimization , Hybrid Meta-Heuristic Algorithm.

1-Introduction

The design of logistics systems requires the adoption of diverse strategies. [1] In many logistics environments, managers must make decisions such as determining the location of distribution centers, assigning customers to each region to provide services, and transportation plans that connect customers. [2] Therefore, the Location Routing Problem (LRP[1]) is defined to determine the number and optimal locations, simultaneously with the schedule of vehicles and distribution routes, in order to minimize the total costs of the system. [3] It is commonly recognized that logistics costs consume a large portion of companies' budgets. By carefully designing the supply chain, these costs can be significantly reduced [4]. In the supply chain, identifying the route that causes the least time and cost in the transportation system has always been the concern of manufacturers and researchers in this field. What method and type of vehicle this route should be transported and how much capacity it has for movement is also one of the key points in the field of LRP. Also, the problem of timing in solving perishable and strategic goods has always been the concern of governments [5].

Transportation can be by road, rail, sea, and air, but due to the low capacity of this fleet and the high cost of this method, air transportation is less important in business and is often used in the movement of special and sensitive goods. Each of the other three methods can be used alone, but two or all three types of fleet are usually used in international trade. A model that can use all three types of fleet and is designed in such a way to consider the first goal of the system, which is to minimize the collection costs, can make the problem model more efficient. Distributors' warehouses should usually be located at the shortest distance from customers so that the cost of local distribution is as low as possible. Identifying the location of these warehouses for establishment or rent is in the field of location research [6]. In most routing/locating problems, a number of devices are responsible for serving the customers. The distance between the customers and the producer has been determined by specific routes that the model should take the shortest route. For local distribution, a warehouse is often established near a group of customers for local distribution, which distributes the local tour of goods from the warehouse to customers.

* Corresponding Author. Email: amin.rahmani72@ut.ac.ir

1 - Location-Routing Problem

Depending on the type of model, different structures can be implemented in this area [7].

Creating a time window in logistics is creating a time frame for delivering goods or services to the target customers. Determining the manner and amount of this period of time is in the hands of the managers and based on the agreement made with the customers. The time window governing this research has the following characteristics: 1-The goods must be delivered to the customers at the appointed time, and if it arrives later than the predetermined time, you will be fined for this. 2- Arriving earlier than the desired time also has disadvantages. Among the most important disadvantages is the imposition of warehousing costs on the system and ultimately increasing the total cost. Based on this, the routing problem of this research should make at least three important decisions: 1- The distance between the customer and the producer based on the distance and transportation costs should be determined in such a way that the cost of the whole project is minimized. 2- Among the candidate points for building a warehouse, a place should be selected and built that has the closest possible distance to the customers. 3- The goods must reach their destinations within a certain time. Therefore, all kinds of perishable and strategic goods can be among the candidate options in this issue.

2-Literature Review

The issue of routing-location is considered a part of distribution management, which is in the field of location studies. They pay special attention to the issues related to the routing of vehicles so that the mentioned warehouses should be covered by the vehicle route [8]. From a practical point of view, the LRP problem is considered a part of distribution management, while from a mathematical point of view, it is usually modeled as a combined optimization problem. The location problem alone is one of the NP-hard problems. The routing problem is also among NP-hard problems in terms of time complexity and problem dimensions. Combining these two and becoming a single problem called routing location is a second-order NP-hard problem in terms of complexity level. Therefore, it is difficult and almost impossible to solve the LRP problem in a large size using exact methods [9]. The articles worked on LRP problems can be classified into the following two categories:1- Classification based on the solution method 2- Classification based on the type of problem. Classification based on solution method: 1. Detailed methods 2. Innovative methods 3. Heuristic methods .Classification based on the type of problem:1. LRP with vehicles without capacity 2. LRP with warehouses without capacity 3. Capacitive LRP 4. Multi-period LRP 5. LRP and inventory management 6. LRP with unknown data 7. Two-level LRP 8. LRP with multiple objective functions or special functions 9. Truck and trailer routing problem 10. Characteristics of vehicle nodes [10].

LRP covers a wide range of application fields in about 10 areas of issues, including distribution of goods, retail, waste collection, relief, transportation industry, design of communication networks, health and blood banks, refueling of vehicles, military equipment, and optical network infrastructures [11]. The logistics location-inventory-routing problem (LIRP) is an integrated optimization of the three problems—a comprehensive optimization problem for the whole logistics system [12]. To assess the literature of relief logistics, no doubt that location and routing decisions are among the problems that have been well-studied in the disaster context [13].

The LRP is a mathematical optimization problem that combines the facility location problem (FLP) and the vehicle routing problem (VRP). The goal is to determine the optimal locations of facilities (such as warehouses, depots, plants, etc.) and the optimal routes of vehicles that serve a set of customers from these facilities. The LRP is NP-hard and has many practical applications in various fields, such as waste management, disaster relief, food supply chains, and logistics [14,15]. Waste management: The LRP can be used to minimize the cost and risk of collecting and transporting hazardous or industrial waste from generation nodes to storage or treatment facilities [16]. Disaster relief: The LRP can be used to design a relief network and determine efficient routes to deliver relief supplies or evacuate injured people or people at risk after a disaster [17]. Food supply chains: The LRP can be used to minimize the total cost and environmental impact of distributing perishable products from suppliers to customers using low-temperature transportation [18].

The LRP is a NP-hard problem that is difficult to solve optimally, especially for large-scale instances. Therefore, many heuristic and metaheuristic algorithms have been proposed to find good solutions in reasonable time. Some of the most common methods are: Tabu search (TS): This is a local search method that uses a memory structure to avoid revisiting previously explored solutions and escape from local optima. Simulated annealing (SA): This is a probabilistic method that mimics the physical process of annealing, where a material is heated and then slowly cooled to reach a minimum energy state. The method accepts worse solutions with some probability that decreases over time. Genetic algorithm (GA): This is a population-based method that simulates the natural process of evolution, where solutions are encoded as chromosomes and undergo crossover, mutation, and selection operators to generate new solutions. Multi-objective optimization (MOO): This is a branch of optimization that deals with problems that have more than one objective function to be minimized or maximized. The goal is to find a set of Pareto-optimal solutions that represent the trade-offs between the conflicting objectives [19].

3-Problem Description and Mathematical Formulation

3-1-Modeling Framework

The proposed model divides the distance between the producer and customers into three levels:

• Level 1 represents potential points for changing the type of transportation if needed. This is considered the terminal rental price if the transportation situation changes.

• Level 2 like level 1, are potential points that are candidates for passing the transportation route. If needed, changing the transportation mode from one mode to another can be done in this terminal. In this case, the terminal rent is considered.

• Level 3 represents points that are likely to create the main warehouse for unloading and delivery to the local distribution network. From these points, one point should be selected and built for the construction of the warehouse. The cost of this construction will be included in the problem model.

• Level 4 represents the coordinates of customers' points. It is established among the customers of the transportation tour that the type of distribution in this local distribution network is only possible through road mode. The distribution fleet should pass each customer only once so that all customers are covered and at the end, the vehicle should return to the warehouse.

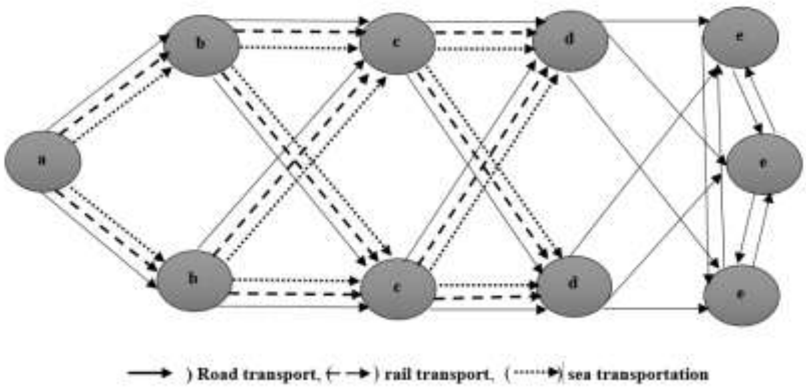

Fig.1.Schematic of the Problem Model

In the suggested model, the gap between the manufacturer and the consumers is categorized into three tiers. Accordingly, the suggested mathematical model is formulated as follows.

- **Index:**

A Producer

B Collection of middle terminals of the first level

C Collection of middle terminals of the second level

D A set of appropriate locations for the establishment of the main storage facility

E, E' A set of consumer locations

F, F' A set of methods for transporting goods in three ways: road (R1) = 1, railway (R2) = 2, sea (R3) = 3

- **Parameters:**

$GF1_{(A, B, F)}$ = The gap between the manufacturer and the first-level terminals

$GF2_{(B, C, F)}$ = The gap between the first-level terminals and the second -level terminals

$GF3_{(C, D, F)}$ = The gap between the second -level terminals and Suitable locations for constructing the main storage facility

$GF4_{(D, E, M)}$ = The gap from main warehouse to customers

$GF5_{(E, E')}$ = The gap between the consumers

D1, D2 = Q1, Q2 Customer demand according to fuzzy logic for transportation

$ER_{(E)}$ = The soonest time to transport the commodities to the consumer

$LA_{(E)}$ = The latest time to transport the commodities to the consumer

$RA_{(E)}$ = Random numbers to generate delivery ranges for unexpected circumstances

FE = FTE Fixed values for time window parameter (early delivery)

FL = FTL Fixed values for time window parameter (late delivery)

PE = PTE Penalty for the premature arrival of commodities

PL= PTL Penalty for the late arrival of commodities

B = B Allocable budget

- **Decision variables:**

$V1_{(a, b, f)}$ = Binary variable to choose a path the terminal from the manufacturer to the first-level terminals

$V2_{(b, c, f)}$ = Binary variable to choose a path the terminal from the first-level terminals to the second -level terminals

$V3_{(c, d, f)}$ = Binary variable to choose a path the terminal from the second -level terminals to the main storage facility

$V4_{(d, e)}$ = Binary variable to choose a path the main storage facility to the first customer

V5 (e) = Binary variable to choose order of customers

$W1_{(a, b, f)}$= The amount of cargo transported from the manufacturer to the first-level terminals

$W2_{(b, c, f)}$ = The amount of cargo transported from the first-level terminals to the second-level terminals

$W3_{(c, d, f) =}$ The amount of cargo transported from the second-level terminals to the main storage facility

$W4_{(d, e)}$ =The amount of cargo transported from the main storage facility to the first customer

$ET_{(E)}$= The duration of time early delivery of the goods to the customer

$LT_{(E)}$= The duration of time late delivery of the goods to the customer

$EP_{(E)}$= Penalty for early delivery of the goods to the customer

$LP_{(E)}$= Penalty for late delivery of the goods to the customer

- **Mathematical Model**

The problem model is described as follows:

$$\begin{aligned} MINz = \sum_{a\in A}\sum_{b\in B}\sum_{f\in F}(V1_{(a.b.f)} \times W1_{(a.b.f)} \times GF1_{(a.b.f)} \times CF_f) + \sum_{b\in B}\sum_{c\in C}\sum_{f\in F}(v2_{(b.c.f)} \times W2_{(b.c.f)} \\ \times GF2_{(b.c.f)} \times CF_f) \\ + \sum_{c\in C}\sum_{d\in D}\sum_{f\in F}\left(V3_{(c.d.f)} \times W3_{(c.d.f)} \times GF3_{(c.d.f)} \times CF_f\right) \\ + \sum_{d\in D}\sum_{e\in E}\sum_{f\in F}\left(V4_{(d.e.f)} \times W4_{(d.e.f)} GF4_{(d.e.f)} \times CF_f\right) \\ + \sum_{e\in(\mathrm{E.E'})}\sum_{f\in F}(V5_{(e)} \times GF5_{(\mathrm{E.E'})} \times CF_f) + \sum_{e\in(\mathrm{E.E'})} LP + \sum_{e\in(\mathrm{E.E'})} EP) + CT + CC \end{aligned} \quad (1)$$

M St.

$$\sum_{a\in A}\sum_{b\in B}\sum_{f\in F} V1_{(a.b.f)} = 1 \quad (2)$$

$$\sum_{b\in B}\sum_{c\in C}\sum_{f\in F} F2_{(b.c.f)} = 1 \quad (3)$$

$$\sum_{c\in C}\sum_{d\in D}\sum_{f\in F} F3_{(c.d.f)} = 1 \quad (4)$$

$$\sum_{d\in D}\sum_{e\in E} F4_{(d.e)} = 1 \quad (5)$$

$$\sum_{e\in E}\sum_{e'\in E} F5_{(e.e')} = 1 \quad (6)$$

$$F5_e \times F5_{e'} = 0 \qquad \forall_{(e.e')\in E} \quad (7)$$

$$\sum_{a\in A}\sum_{f\in F}\left[W1_{(a.b.f)}\times V1_{(a.b.f)}\right]-\sum_{c\in C}\sum_{f\in F}\left[W2_{(b.c.f)}\times F2_{(b.c.f)}\right]=0 \qquad \forall_{b\in B} \tag{8}$$

$$\sum_{b\in B}\sum_{f\in F}\left[W2_{(b.c.f)}\times V2_{(b.c.f)}\right]-\sum_{d\in D}\sum_{f\in F}\left[W3_{(c.d.f)}\times F3_{(c.d.f)}\right]=0 \qquad \forall_{c\in C} \tag{9}$$

$$\sum_{c\in C}\sum_{f\in F}\left[W3_{(c.d.f)}\times F3_{(c.d.f)}\right]-\sum_{e\in E}\sum_{f\in F}\left[W4_{(d.e)}\times F4_{(d.e)}\right] \qquad \forall_{d\in d} \tag{10}$$

$$\sum_{d\in D}\left[w4_{(d.e)}\times F4_{(d.e)}\right]-\sum_{e\prime\in E}\left[W5_{(e.e')}\times F5_{(e.e')}\right]=0 \qquad \forall_{e\in E} \tag{11}$$

$$\sum_{a\in A}\sum_{b\in B}\sum_{f\in F}\left[W1_{(a.b.f)}\times F1_{(a.b.f)}\right]\geq D1 \tag{12}$$

$$\sum_{a\in A}\sum_{b\in B}\sum_{f\in F}\left[W1_{(a.b.f)}\times F1_{(a.b.f)}\right]\leq D2 \tag{13}$$

$$\mathrm{ET_e}=\mathrm{ER_e}-\mathrm{RA_e} \qquad \forall_{\mathrm{e}} \tag{14}$$

$$\mathrm{ET_e}\times\mathrm{FE}\times\mathrm{PE}=\mathrm{EP_e} \qquad \forall_{\mathrm{e}} \tag{15}$$

$$\mathrm{LT_e}=\mathrm{LA_e}-\mathrm{RA_e} \qquad \forall_{\mathrm{e}} \tag{16}$$

$$\mathrm{LT_e}\times\mathrm{FL}\times\mathrm{PL}=\mathrm{LP_e} \qquad \forall_{\mathrm{e}} \tag{17}$$

$$\mathrm{Z}\leq\mathrm{B} \tag{18}$$

$$\left\{\mathrm{V1_{(a.b.f)}}.\mathrm{V2_{(b.c.f)}}.\mathrm{V3_{(c.d.f)}}.\mathrm{V4_{(d.e)}}.\mathrm{V5_{(e.e')}}\right\}\in\{0.1\} \tag{19}$$

$$\left\{\mathrm{W1_{(a.b.f)}}.\mathrm{W2_{(b.c.f)}}.\mathrm{W3_{(c.d.f)}}.\mathrm{W4_{(d.e)}}.\mathrm{W5_{(e.e')}}.\mathrm{TE_{(e)}}.\mathrm{TL_{(e)}}.\mathrm{EP_{(e)}}.\mathrm{LP_{(e)}}\right\}\geq 0 \tag{20}$$

The optimization problem involves binary decision variables that are integers. Their task is to identify and transfer the most optimal states for the path and locations of the desired problem. Constraints (2), (3), and (4) ensure that the binary variables defined in each section choose at least one and at most one path from the producer to the main warehouse. Constraint number (5) is responsible for identifying the closest point among candidate points to the customers for the construction of the warehouse. Constraint (6) selects the closest customer with a warehouse. Constraints (7), (8), (9), (10), and (11) are binary variables for creating a tour among customers such that all customers are covered, and no customer's vehicle is used more than once before returning to the warehouse. Restrictions number (12) and (13) create demand based on fuzzy logic for customers. Restrictions number (14) and (15) are for when goods reach customers earlier than intended, and subsequently, some penalty is considered for the system. Restrictions number (16) and (17) ensure that when goods arrive at the destination later than the specified time, the system will be penalized based on the amount of delay time. Limitation (18) has determined project implementation costs based on budget constraints. It expresses the limits of all variables (19) and (20) used in the problem.

Based on fuzzy logic approach and the following mathematical model (21), which is a fuzzy mathematical model that has parameters with fuzzy triangular numbers, constraints 12 and 13 are expressed as constraints 22 and 23:

$$Min\ z=C^{t}\ X \tag{21}$$

St.

$$a_e x=b_e \quad e=1.2.3\ldots\ldots n$$

$$a_e x\leq b_e \quad e=1.2.3\ldots\ldots n$$

$$X\geq 0$$

$$\sum_{a\in A}\sum_{b\in B}\sum_{f\in F}\left[W1_{(a.b.f)}\times V1_{(a.b.f)}\right]-\sum_{e\in E}[(1-\tfrac{N}{2})\times\frac{D_e^o+D_e^m}{2}+(\tfrac{N}{2})\times\frac{D_e^p+D_e^m}{2}]\geq 0 \tag{22}$$

$$\sum_{a\in\in A}\sum_{b\in B}\sum_{f\in F}\left[W1_{(a.b.f)}\times V1_{(a.b.f)}\right]-\sum_{e\in E}[(N)\times\frac{D_e^o+D_e^m}{2}+(1-N)\times\frac{D_e^o+D_e^m}{2}\leq 0 \tag{23}$$

3-2- Algorithm Test

Due to the fact that the problem is NP-HARD, the exact solution of the model cannot be provided by GAMS software in a reasonable time, and due to the exponential increase in the dimensions of the problem, the exact solution is not possible. Therefore, after examining the meta-heuristic algorithms and the cases used in each of them in past articles and researches, the problem model was solved with a hybrid genetic algorithm and neural network (GA-NA), and the results were compared with two gray wolf optimization algorithms (GWO) and grasshopper optimization algorithms (GOA).

The results of the settings of the grasshopper optimization algorithm using the Taguchi method in the Minitab software are shown in Figures 2 and 3.

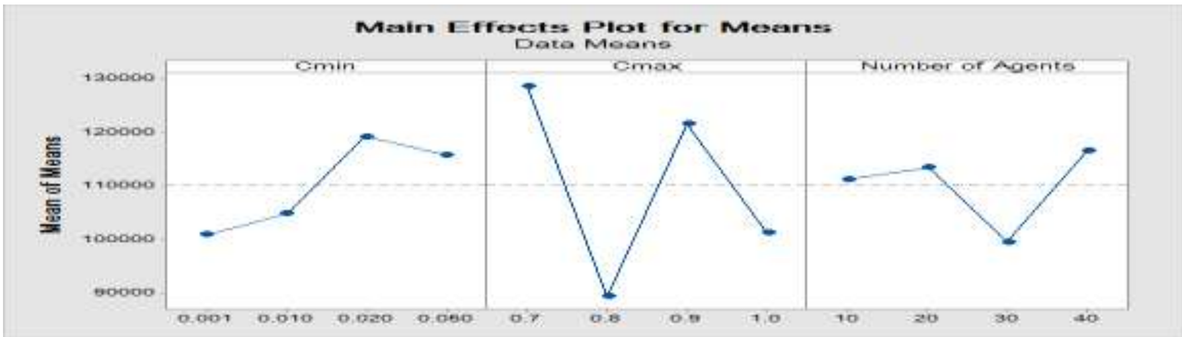

Fig.2.Main effects plot for means

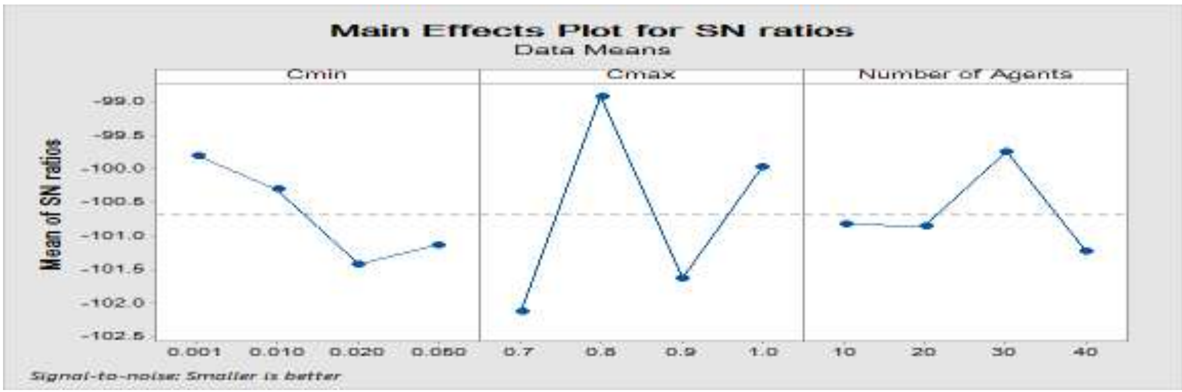

Fig.3.Main effects plot for SN ratios (GOA)

The results of the settings of the gray wolf optimization algorithm with the Taguchi method in Minitab software are shown in Figures 4 and 5.

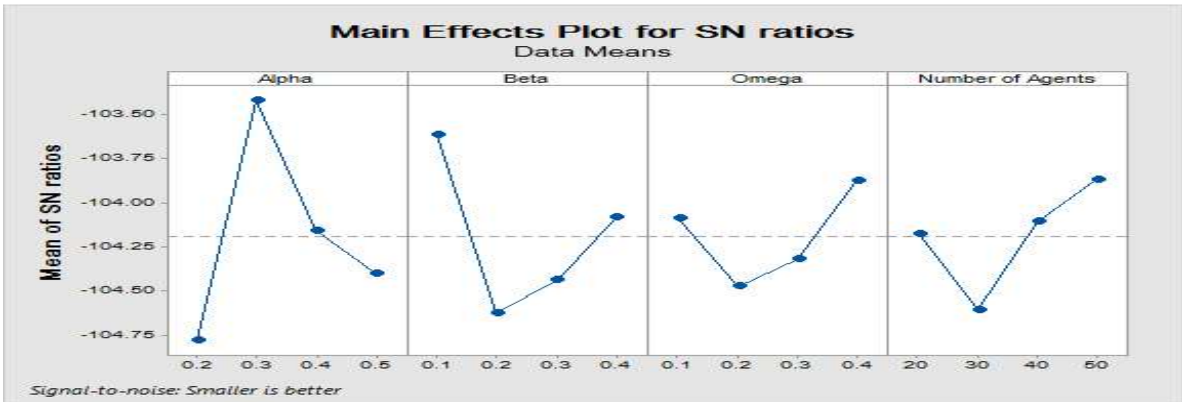

Fig.4.Main effects plot for SN ratios (GWO)

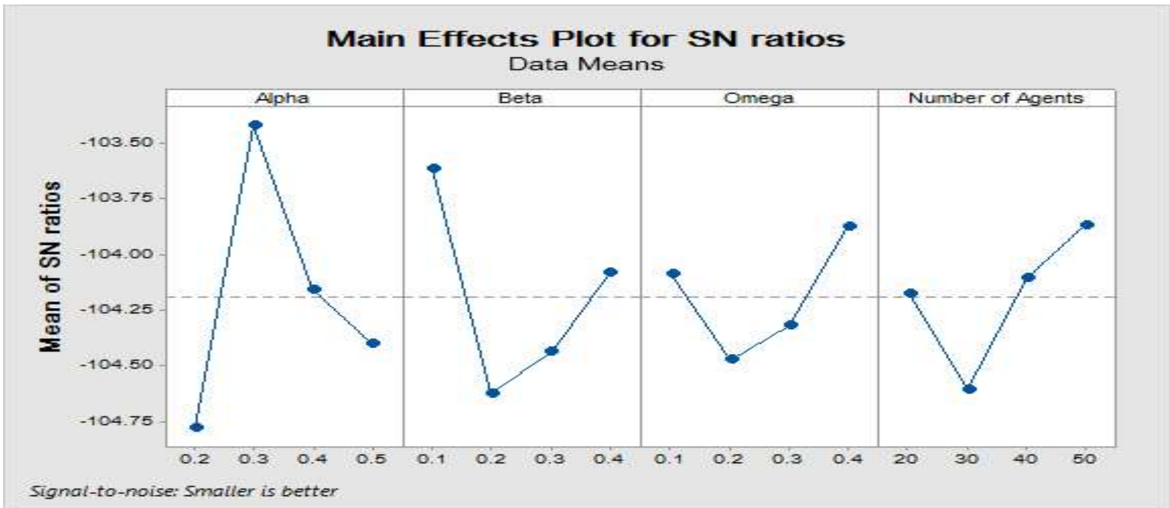

Fig.5.Main effects plot for SN ratios(GWO)

The results of genetic algorithm and neural network settings with Taguchi method in Minitab software are shown in Figure 6.

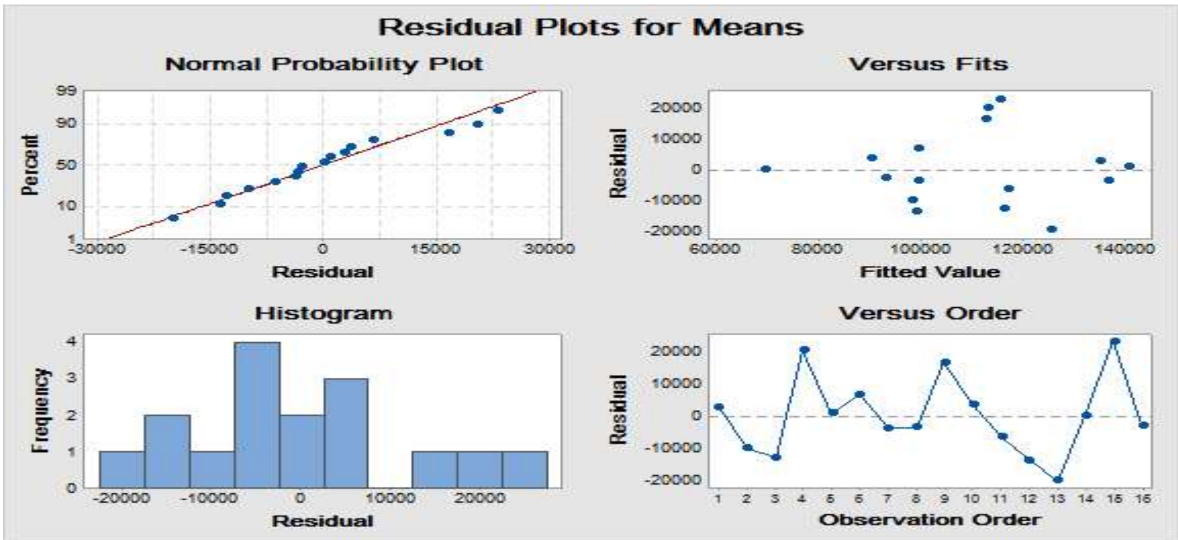

Fig.6.Main Effects Plot Means

The quantification of the initial values of this algorithm is based on the basic article of the provider (Mirjalili et al., 2017) and is done as random numbers at each level.

4-Sensitivity Analysis to the Number of Warehouses (m)

In order to validate the problem model, the parameters of the problem were evaluated and the values were presented in tables 1 to 4.

Table1:
Coordinates of producers, terminals, warehouses and customers

Uniform INT [0,20]	X & Y (a)
Uniform INT [21,70]	X&Y (b)
Uniform INT [71,120]	X&Y (c)
Uniform INT [121,170]	X & Y (d)
Uniform INT [171,200]	X & Y (e)

Table2:
Time window parameters

FTL	FTE	PTL	PTE	R (i)	L (i)	E (i)
~ uniform (3 , 5)	~ Uniform INT [0,1]	3	2	~ uniform (3 , 5)	20	12

Table3:
Fuzzy parameters

α-level	Demand^{O}	Demand^{m}	Demand^{p}
0/5	70	80	90

Table4:
Dimensions of the problem

e	d	c	b	a	scenario	
15	5	3	6	1	1	Small dimensions
10	10	6	10	1	2	
20	20	30	20	1	3	
45	40	30	40	1	4	Medium size
50	80	70	50	1	5	
65	60	70	70	1	6	
200	100	100	120	1	7	large scale
180	120	130	140	1	8	
190	120	130	140	1	9	

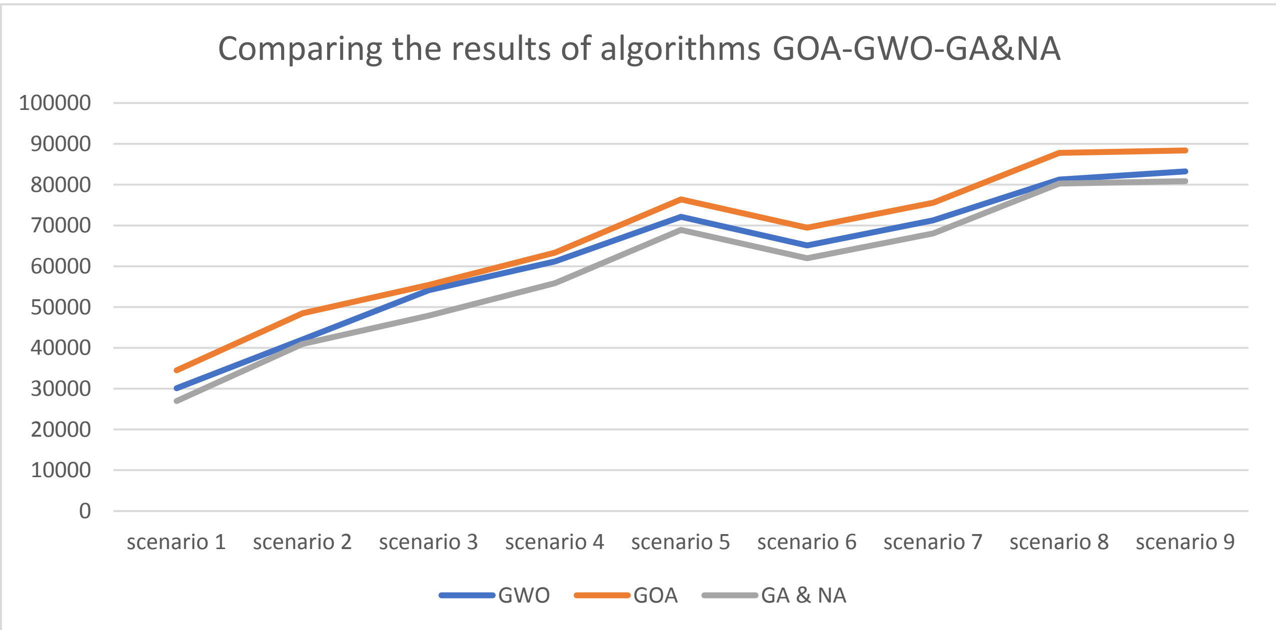

Fig.7.Comparing the Result of Algorithms

As shown in Figure 1, the results indicate that hybrid genetic algorithm and neural network has a more optimal output than the grasshopper meta-heuristic algorithm and the gray wolf meta-heuristic algorithm.

5-Conclusion

To create a supply chain, a wide distribution network is needed in the desired area. In this distribution network, first the desired routes and locations should be determined and finally the main route should be selected. The purpose of this research was to design a location routing network by considering different parameters in a combined manner. The model presented in this research is a location routing problem in a multimodal transportation network considering time windows, fuzzy logic, and the capacity of the transportation fleet. In the presented model, the customer's demand was first expressed in triangular fuzzy form and then defuzzified by presenting different methods. To solve the problem model of this research, two new meta-heuristic algorithms (gray wolf optimization algorithm and grasshopper optimization algorithm) have been proposed separately, and finally a combined meta-heuristic algorithm (genetic optimization algorithm and neural network optimization algorithm) was presented. The results indicate that the proposed hybrid algorithm has provided far more optimal solutions and hence this algorithm can be used to solve location routing problems.

Also, due to the consideration of the time window, the proposed model can be used to solve the problems of relief routing, routing and location of prone points to provide special services during disasters such as floods and earthquakes, and moving and transporting perishable materials. As a suggestion to improve and expand the research done, it is possible to use information technology parameters and their effectiveness in solving location routing problems in future research.

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