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A routing and scheduling problem in offshore logistics management with time windows and different ships

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Abstract

Nowadays, the economic impacts of offshore logistics are highly joined with optimization models and algorithms. The role of maritime transport with optimized routes and a valid scheduling for ships in ports can improve the performance of offshore logistics in real setting. This paper provides a new application and extension to the Vehicle Routing Problem with Time Windows (VRPTW) for offshore logistics. This study considers an applicable case in container terminals for different ships. The proposed model as a mixed integer non-linear programming approach provides some merits in the literature with simultaneous consideration of the routes for different ships with different properties and the time windows in order to minimize costs. The proposed model is solved by an exact solver by using LINGO software and because of inherent complexity of problem proposed in the real-world cases, the Genetic Algorithm is used to find an optimal/global solution in a reasonable time. Finally, an in-depth analysis and discussion is provided to conclude the main findings and practical implications of the results. The outputs confirm the applicability and efficiency of GA as it can achieve the near-optimal solutions in comparison with the exact solver and encourage further development of the proposed model in real-world applications.

Keywords

Offshore logistics, Vehicle routing problem with time windows; Routing of ships; Genetic algorithm;

1. Introduction

The offshore logistics specially focus on the designed ships transport goods, tools, equipment and personnel to and from offshore installations, and keep the installations provisioned and supplied for

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smooth and continuous production. In this regard, the Maritime transport has a broader history than other types of transportation, such as trains, cars, and planes. However, from the perspective of operations research/management science, limited research has been conducted on the ship routing problem, compared with much research done in the area of vehicle routing problem. However, attention to maritime transport has increased in recent decades and gained more importance. The high impact of the maritime transport on the economic growth of developing countries like Iran, creates a grand challenge for this study to develop a routing and scheduling problem for offshore logistics as an extension to the Vehicle Routing Problem with Time Windows (VRPTW).

As the Vehicle Routing Problem (VRP) is one of the most essential and famous combinational optimization problems that has been studied extensively. This problem was first raised by Dantzig and Ramser as a critical issue in the field of transport distribution and logistics. It was shown that applying management methods and optimization issues in transportation have significant effect on reducing commodity costs (Dantzig & Ramser, 1959). A few years later, Clarke and Wright improved the Dantzig and Ramser in 1959 results by presenting a greedy heuristic approach (Toth & Vigo, 2002). A clear trend found in the vehicle routing studies of recent decades' hovers around the transportation by trucks. In this regard, we mention some of them in this paper (Alhamad, Alrashidi, & Alkharashi, 2019; Karbassi Yazdi, Kaviani, Emrouznejad, & Sahebi, 2020). Coelho et al. investigated the routing problem of a heterogeneous fleet that allowed to travel multiple times (Coelho et al., 2016). Most notably, Lokukaluge et al. examined the impact of weather forecasts on the ship safety and found out that ship safety could affect ship's route speed. Also, taking the optimal route results in reduced fuel consumption and consequently lower air pollution(Perera & Soares, 2017) .

As an extension to the VRP, the VRPTW is being popular in different real-world fields. For example, Li et al. investigated the VRPTW with heterogeneous fleet and open routes (Feiyue Li, Golden, & Wasil, 2007). In this problem, the customers' demand is supplied by a fleet that possesses a certain number of vehicles with different capacities and related costs depending on the types of vehicle. With increased freight, cost-effective management of fuel costs, and daily operating costs for heterogeneous ships have become important (Daganzo, 1989). This increase in sea freight between ports, besides fuel costs issue, has other consequences such as the emission of CO2 and NOx gases. This environmental issue has recently drawn the attention of many media due to the negative impacts of climate change and air pollution. On the other hand, the cost of fuel and CO2 production is strongly dependent on the speed of the ships. Therefore, this study considers the types of the ships and the routing decisions based on the time windows intended to decrease costs as an application for the offshore logistics.

The offshore logistics academically creates a link between ships routing and scheduling of quay crane problems. From our literature search, the scheduling of ships and quay crane problems is firstly reviewed. Then, the routing optimization of ships is studied accordingly. For example, Zhihong and Na (Zhihong & Na, 2011) presented a nonlinear mathematical programming model to reduce the time of servicing to ships arrived at the terminal at horizon times, taking into account the non-crossing constraint of the quay cranes. Chen et al.(Chen, Lee, & Cao, 2011) presented a mixed integer programming model which addressed the unique features in scheduling problem of allocating cranes in the indented berths. Legato et al. (Legato, Trunfio, & Meisel, 2012) have proposed an improved model for the scheduling of quay cranes, taking into account factors, such as the performance rate of each crane, safety requirements, precedence of containers, ready time, due date of each crane, while the cranes can move in one direction (unidirectional cranes). Chen et al. (Chen, Lee, & Goh, 2014) focused on a particular strategy for cluster-based quay crane scheduling problem that associated with moving the unidirectional cranes in a timeline. By using this strategy called unidirectional quay crane scheduling problem in the literature, the problem of scheduling the quay cranes is improved. To solve the problem, they also used the state-of-the-art algorithm, which provided a better structure for searching the optimal solution. Imai et al. (Imai, Yamakawa, & Huang, 2014) provided a strategy for berth template problem (BTPS) to select ships from applicants for limited time horizons. Al-Dhaheri and Diabat (Al-Dhaheri & Diabat, 2015) focused on the problem of scheduling the quay cranes to minimize the processing time for each vessel, so their goal was to present a way to reduce the differences between the container loads stacked over a number of bays and create a balance between ship bays in in the loading and unloading operations. They also eliminated the limitation of the unilateral movement of the quay cranes and made it possible for the quay cranes to move on both sides, even when the operation of one bay has not been completed. Al-Dhaheri et al. (Al-Dhaheri, Jebali, & Diabat, 2016) proposed a new model, which considered the constraints of ship stability, crane displacement time, task preemption, and unidirectional movement of cranes. Because of the possibility of unexpected breakdown of cranes and a negative impact of cranes rescheduling on the planned berth, ship owners and crane operations, Liu et al. (C. Liu, Zheng, & Zhang, 2016) studied the rescheduling of the crane with the aim of reducing negative deviations from the initial scheduling. Wu and Ma (Wu & Ma, 2017) focused on the problem of scheduling quay cranes, by considering the draft and trim constraints, with the goal of minimizing loading time. Agra and Oliveira (Agra & Oliveira, 2018) presented an integrated model of berth allocation, quay crane assignment and scheduling problem, which considered a set of heterogeneous cranes with discretion for time and space variables. The efficient operation of the terminal depends on the proper planning of the container movement, called "stowage planning". Azevedo (Azevedo, de Salles Neto, Chaves, & Moretti, 2018) addressed the integrated problem of the 3D stowage planning problem and quay cranes scheduling problem in container vessels. Liang et al. (Liang, Fan, Xu, Ding, & Gen, 2018) presented a coupling model to investigate the relationship between two aspects of the quay scheduling problem: task dispatch and quantity configuration of quay cranes. The first issue determines the loading sequence of cranes and the second issue determines the number of cranes allocated to each vessel. More recently, Safaeian et al.,(Safaeian, Etebari, & Vahdani, 2019) developed an integrated Quay Crane Assignment and Scheduling Problem (QCASP) with Several Contractors. They applied a teaching-learning-based optimization algorithm (TLBO) to solve the problem.

Another part of works related to the offshore logistics, studied the routing optimization of ships rather than its scheduling in ports. For example, Yamashita et al., (Yamashita, da Silva, Morabito, & Ribas, 2019) developed a multi-start heuristic to solve a real-life VRPTW for an oil company in Japan. Their model formulates the ship routing and scheduling to collect crude oil extracted from offshore platforms and to deliver it to terminals. Li et al., (Feng Li, Yang, Wang, & Weng, 2019) studied an integrated routing and scheduling of ships for the application of steel plants alongside a river in China. Pratap et al., (Pratap, Zhang, Shen, & Huang, 2019) introduced a bi-objective routing and scheduling of ships with green emissions. Their goal was to analyze the effect of the environmental pollution on the economic routes of ships. Yazdi et al., (Karbassi Yazdi et al., 2020) developed a metaheuristic so-called the Binary Particle Swarm Optimization (BPSO) algorithm to find an optimal solution for ship routing and scheduling of Liquefied Natural Gas (LNG) logistics. At last but not least, Alhamad et al., (Alhamad et al., 2019) innovated a Tabu Search (Liang et al.) For a ship routing and scheduling problem with time windows. They generated large-scale test studies to show the high-performance of their heuristic in comparison with the exact solver.

Taken together, the routing and scheduling of ships can be formulated with many factors and solved with different algorithms. Although adding more elements make this optimization problem more efficient and practical, it increases its difficulty. These reasons keep this literature active and many optimization models and algorithms have been developed to address the problems of offshore logistics. This study with simultaneous consideration of different types of ships and time windows in addition to the fuel consumption constraints creates a new problem for ships routing and scheduling studies. Since the proposed model as an extension to the VPRTW is much difficult, the Genetic Algorithm with a unique encoding scheme is applied to solve the proposed model optimality.

The remainder of this paper is organized as follows. Section 2 presents problem description, assumptions, notations, and mathematical formulation of the problem. Section 3 discusses the proposed GA. Section 4 provides computational results. Sections 5 includes this paper and future directions.

2. Problem Definition

Maritime transport has a broader history than other types of transportation, such as trains, cars, and planes. However, from the perspective of operations research/management science, limited research has been conducted on the ship routing problem, compared with much research done in the area of vehicle routing problem. However, attention to maritime transport has increased in recent decades and gained more importance.

The ocean-going vessels are divided into three main groups:

1) Industrial ships: These are the most common ocean transportation ships used to transport bulk products. In this case, all loads must be serviced, and the goal is to reduce operating costs.
2) Tramp ships: In tramp ships, the goal is to increase profits by choosing the right cargo for a fleet of ships. Tramp ships carry the shipments from one point to another (much like a taxi). Also, tramp ships serve temporary customers who have requested relocation. In this case, the cargos must be transferred directly from the loading port to the discharge port at a specified time. Usually, tramp ships carry the loads for one customer at one time.
3) Line ferries: Line ferries follow a timetable and itinerary similar to line buses and usually carry loads for a large number of customers.

In this study, a routing problem is presented along with the ship movement scheduling for cargo transfer. Tramp and liners are considered, and the capacity and travel time of each ship varies.

In this problem, the ports are considered in two forms of discharge and loading. A certain amount of one cargo is loaded in one port and unloaded in another.

Each cargo has a specified number, time window, loading, and unloading ports. The scheduling company provides an itinerary for loading and discharge of the ships. Some cargoes may not be considered in the schedule and treated as spot cargoes and so being serviced by tramp vessels. Tamp vessels increase the costs incurred to the company, as the cost of shipping by tramp vessels is much more expensive than the company vessels. Besides, it is difficult to determine the cost of tramp ships in the itinerary, as the delivery schedule is set 45 days before the onset of each part, and the global economy is subject to frequent cost fluctuations. For this reason, planners try to use liners as much as possible and to use the tramp vessels the least. The cargoes can be separated and loaded by more than one ship (if they do not surpass their loading and unloading time window). The cargo can also be loaded from multiple ports and unloaded into multiple ports. Figure 2-3 shows a general view of the routing shipping problem. As can be seen, the departure and destination ports are different from the loading and unloading ports.

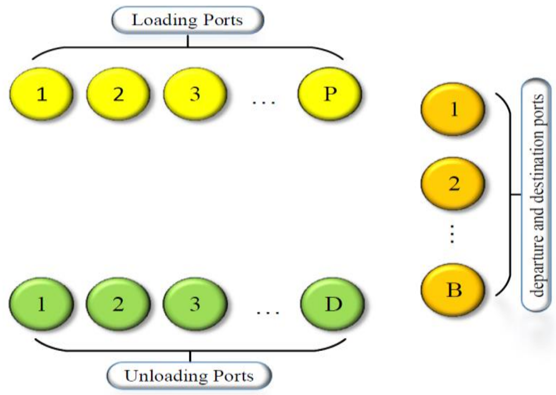

Fig. 1. Graphical display of ship routing problem

2.1. Assumptions

1) Liners and tramps are heterogeneous.
2) Tramp vessels are rented if needed.
3) Tramps can service one cargo (Tramps can only load in one port, while liners can load multiple times during one trip).
4) All loads must be serviced.
5) Each cargo has a specific loading and unloading port.
6) Each loading and unloading port has a time window.
7) Each cargo can be serviced by tramp ships, liners, or both.
8) Each cargo can be serviced by more than one ship.

Table (1): Sets, Parameters and decision variables.

Sets	
Symbol	**Meaning**
P	A set of ports that loading takes place in them. $P=\{1,2,\ldots,n\}$
D	A set of ports that unloading takes place in them. $D=\{n+1,n+2,\ldots,2n\}$
E	A set of departure and destination ports of the ships. $E=\{2n+1,2n+2,\ldots,2n+B\}$
k	A set of ships. $K=\{1,\ldots,k\}$
N	A set of middle ports. $N=P\cup D$
V	A set of all ports. $V=N\cup\{v_1,\ldots,v_n\}\cup\{v_1^{'},\ldots,v_n^{'}\}$ in the graph $G=\{V,A\}$
A	A set of all routes. $A=V\times V$ in the graph $G=\{V,A\}$
Parameters	Meaning
Symbol	-

i	The existing load in i[th] port. Each load has two ports: the loading port (i) and discharge port (n+1)
V_k	Any k ship can move under the graph $G_k = \{V_k, A_k\}$, so that $V_k = N \cup \{v_k\} \cup \{v_k'\}$
A_k	Any k ship can move under the graph $G_k = \{V_k, A_k\}$, so that $V_k = N \cup \{v_k\} \cup \{v_k'\}$
T_{ijk}	Travel time from port i to port j by ship k.
C_{ijk}	The cost of travel from the port i to port j by ship k (including the fixed cost of port j and travel cost).
L_i	The amount of loaded or unloaded cargo in port i if $i \in P$. $L_i = L_{n+i}$ if $i \in P$ and $n+i \in D$. indicating that the amount of loading in port i is equal to the amount of unloading in port $n+i$.
S_i	The time tasks to anchor in port i.
H_k	Maximum capacity of ship k.
E_i	The earliest arrival acceptable time in the time window for the port $i \in V$.
F_i	The latest arrival acceptable time in the time window for the port $i \in V$.
C_{bk}^{w}	The cost of selecting dock b as the departure of the ship k.
$C_{bk}^{w'}$	The cost of selecting dock b as the destination of the ship k.
R_i	Freight cost of tramps for shipment of cargo i which is proportional to the amount of the cargo.

Decision variables	
Symbol	Meaning
x_{ijk}	One, if the ship passes through the arc (i,j), 0 otherwise.
q_{ik}	The amount of cargo in the ship k when it arrives port i.
a_{ik}	Time to reach port I by ship k.
y_{ik}	Indicates a portion of the cargo in port i serviced by the ship (by liners)
Z_i	Indicates a portion of the cargo in port i that is serviced by tramp vessels.
v_k	The departure condition of ship k. $v_k = 2n + k$
v_k'	The destination condition of ship k. $v_k' = 2n + h + k$
w_{bk}	One if dock b is the departure of the ship k, 0 otherwise.
w_{bk}'	One if dock b is the destination of the ship k, 0 otherwise.

2.2. Mathematical model

$$\min \sum_{k\in K}\sum_{(i,j)\in A} C_{ijk}x_{ijk} + \sum_{i\in P} R_i L_i Z_i + \sum_{b\in E}\sum_{k\in K} C_{bk}^{w} W_{bk} + \sum_{b\in E}\sum_{k\in K} C_{bk}^{w'} W_{bk}' \qquad (1)$$

$st:$

$$\sum_{k\in K} Y_{ik} + Z_i = 1 \qquad \forall i \in P \qquad (2)$$

$$\sum_{j\in V} x_{mjk} - \sum_{i\in V} x_{i,n+m,k} = 0 \qquad \forall k \in K, \forall m \in P \qquad (3)$$

$$\sum_{j\in P} x_{bjk} = W_{bk} \qquad \forall k \in K, \forall b \in E \qquad (4)$$

$$\sum_{i\in D} x_{ibk} = W'_{bk} \qquad \forall k \in K, \forall b \in E \tag{5}$$

$$\sum_{b\in E} W_{bk} \le 1 \qquad \forall k \in K \tag{6}$$

$$\sum_{b\in E} W'_{bk} \le 1 \qquad \forall k \in K \tag{7}$$

$$\sum_{i\in V} x_{imk} - \sum_{j\in V} x_{mjk} = 0 \qquad \forall k \in K, \forall m \in P \cup D \tag{8}$$

$$Y_{i,k} + Y_{n+i,k} = 0 \qquad \forall k \in K, \forall i \in P \tag{9}$$

$$Y_{jk} \le \sum_{i\in V} x_{ijk} \qquad \forall k \in K, \forall j \in P \tag{10}$$

$$a_{ik} + S_i + T_{ijk} \le a_{jk} + M(1 - x_{ijk}) \qquad \forall k \in K, \forall i \in V, j \in P \cup D \tag{11}$$

$$E_i \le a_{ik} \le F_i ; \forall k \in K \qquad \forall i \in N \tag{12}$$

$$a_{ik} + T_{i,n+i,k} \le a_{n+i,k} \qquad \forall k \in K, \forall i \in P \tag{13}$$

$$q_{ik} + L_i Y_{ik} \le q_{jk} + M(1 - x_{ijk}) \qquad \forall k \in K, \forall i \in V, j \in P \cup D \tag{14}$$

$$q_{bk} \le H_k (1 - w_{bk}) \qquad \forall k \in K, \forall b \in E \tag{15}$$

$$q_{ik} \le H_k \qquad \forall k \in K, \forall i \in N \tag{16}$$

$$x_{ijk} \in \{0,1\} \qquad \forall k \in K, \forall (i,j) \in A_k \tag{17}$$

$$Z_i \ge 0 \qquad \forall i \in P \tag{18}$$

$$a_{ik} \ge 0 \qquad \forall k \in K, \forall i \in V_k \tag{19}$$

$$q_{ik} \ge 0 \qquad \forall k \in K, \forall i \in V_k \tag{20}$$

$$Y_{ik} \ge 0 \qquad \forall k \in K, \forall i \in P \tag{21}$$

$$Y_{n+i,k} \le 0 \qquad \forall k \in K, \forall i \in P \tag{22}$$

In this model, the objective function (1) minimizes the total costs, including the cost of servicing by tramps and liners, and the cost of selecting the dock as the departure and destination. Constraint (2) indicates that all cargoes are serviced by liners and trampers (every cargo can be serviced by more than one vessel at a time). Constraint (3) relates to the protection of the load from the loading node to the discharge node, which means that if the ship k goes to the port i for loading i, it must meet the discharge port n+1 for unloading cargo i. Constraint (4) implies that if the dock b is the departure of the ship k, then ship k departs from the departure point to one of the loading ports or goes straight to its destination. Constraint (5) indicates that if the dock b is the destination of the ship k, then ship k goes to its destination from one of the discharge ports or goes to the destination directly from its departure. Constraints (6) and (7) ensure that each ship can only have one departure and one destination. Constraint (8) indicates that if the vessel enters one of the middle ports, it must exit from that port, too. Constraint (9) ensures that the amount of cargo loaded in port *i* by the liners is equal to the amount of cargo discharged at the corresponding node. Constraint (10) implies that if the ship *k* has been loaded in port *j*, it must have met port *j*. Constraint (11) presents that when ship *k* arrives port *j* so that if skip *k* has passed arc $(i,j) \in A_k$, time of reaching ship *k* to port *j* is greater than or equal to the arrival time to port *i* plus the time of anchoring in port *i* plus the time of moving from *i* to *j*. Constraint (12) guarantees that the arrival time of the ship does not exceed the window time of port *i*. Constraint (13) indicates that the loading of cargo *i* by the ship *k* occurs before its discharge in its corresponding port.

Constraint (14) expresses the existing cargo in ship k in port i similar to constraint (11). Constraint (15) shows that cargo on board ship does not exceed the ship capacity. Constraints (16) to (22) determine the limits of decision variables.

3. Genetic algorithm

To solve the proposed model as an NP-hard problem, we apply a Genetic Algorithm . Nature-inspired optimization methods differ significantly from conventional optimization methods (Fathollahi-Fard, Ahmadi, Goodarzian, & Cheikhrouhou, 2020; X. Liu, Tian, Fathollahi-Fard, & Mojtahedi, 2020; Whitley, 1994). In conventional methods, each new solution candidate is selected as the new solution if it improves the objective function value, but in the nature-inspired algorithms, all new candidate solutions have the opportunity to be chosen(Fathollahi-Fard, Hajiaghaei-Keshteli, Tian, & Li, 2020; Fathollahi-Fard, Ranjbar-Bourani, Cheikhrouhou, & Hajiaghaei-Keshteli, 2019; Safaeian, Fathollahi-Fard, Tian, Li, & Ke, 2019).

Genetic algorithm introduced by Holland (Whitley, 1994) is one of the most important heuristic algorithms used to optimize different functions. In this algorithm, past information is extracted concerning the hereditary nature of the algorithm and used in the search process.

3.1. Solution structure display

The first and most crucial step in implementing a genetic algorithm is the solution display. The solution structure presented in this problem consists of five rectangular matrices that are described in turn.

The first matrix: This matrix is called T matrix. With this matrix, all possible routes are created according to the problem conditions. The dimension of this matrix is 1 x 2P, and P denotes the number of nodes in which the loading is done, and the numbers 1 through 2P are randomly permutated there. Since each loading node has its corresponding discharge node, in some routes, the problem conditions are not met, so unjustified solutions are eliminated using a heuristic algorithm.

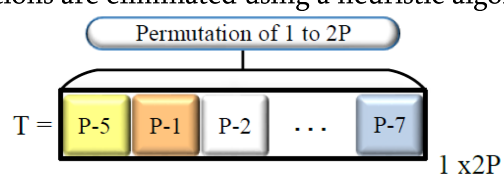

Fig. 2. The first chromosome string for establishing the route

In the heuristic algorithm, each route starts from the initial node, and the modified path is generated in a second matrix. If the examined node is the loading port, it is placed at the beginning of the second matrix. But if the examined node is the discharge node, there will be two states. If its corresponding loading port has been serviced, it is added to the continuation of the second matrix; otherwise it remains in its initial position, and the procedure resumes from the beginning of the initial route again.

For example, if there are 5 loading ports and 5 discharge ports and the random path created by the string chromosome T, then (23) is the heuristic algorithm operates as follows:

$$8 \rightarrow 9 \rightarrow 1 \rightarrow 2 \rightarrow 7 \rightarrow 3 \rightarrow 5 \rightarrow 10 \rightarrow 4 \rightarrow 6 \quad (23)$$

First, nodes 8 and then 9 are checked. Since both nodes are discharge nodes and their prerequisites have not been met, they are not transferred to the second matrix. Then node 1 is transferred to the second matrix since it is a loading node. Each time that a node is moved to the second matrix, the first matrix is checked from the beginning of the route, so after moving port 1 to the modified matrix, ports

8 and 9 are re-examined, and because their prerequisites have not been met, they remain in their positions. In the next step, node 2 is moved to the second matrix, and still prerequisites of nodes 8 and 9 have remained unfulfilled. Node 7 is a discharge port, and its corresponding loading port (port 2) has already been serviced, so it is added to the continuation of the modified matrix. Port 3 has no prerequisite, and then discharge port 8 is added to the modified matrix because its prerequisite (port 3) has been serviced. This process repeats until all ports are transferred to the second matrix. The modified route is as follows:

$$1 \rightarrow 2 \rightarrow 7 \rightarrow 3 \rightarrow 8 \rightarrow 5 \rightarrow 10 \rightarrow 4 \rightarrow 9 \rightarrow 6 \tag{24}$$

The second matrix: This matrix is called Z matrix. This chromosomal string has 1 x P dimensions and determines the ratio of loading in each port by liners and trampers. Numbers from 0 to 1 are assigned to each gene of the chromosome. For example, if the first gene has a value of 0.2, it means that 0.2 of the cargo of the first loading port is serviced by the tramp vessel

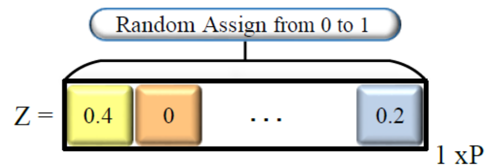

Fig. 3. The second chromosome string to determine the ratio of loading of liner and tramp ships

The third matrix: This chromosomal string has 1 x P dimensions and is called S matrix. The genes in this chromosome are numbered 1 to k that represent which ship is servicing what loading port and its corresponding discharge port. For example, if the problem has 5 loading port, 5 discharge ports, and 2 liners and the first gene is assigned 2, it means that the loading port 5 and discharge port 6 are serviced by ship 2.

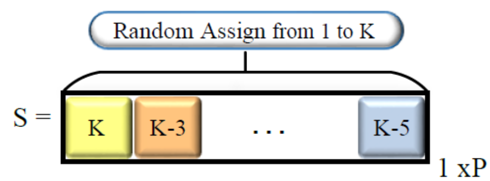

Fig. 4. The third chromosome string to allocate loading and discharge ports to liners

The fourth Matrix: This chromosomal string has 1 x k dimensions and is called O. This chromosome determines the origin of the vessels and assigns numbers 1 to b to each gene. For example, if the problem has 3 ports of departure and destination, each gene is assigned numbers 1 to 3. If the first gene of the chromosome has a value of 2, it means that the departure of the first vessel is port 2.

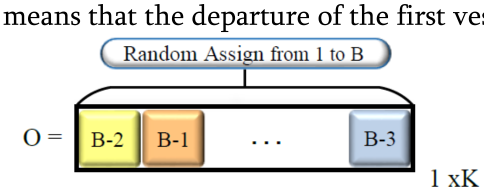

Fig. 5. The fourth chromosome string to determine the departure port of the ship

The fifth matrix: This chromosome is named D and acts exactly like the O chromosome, except it determines the destination of each vessel.

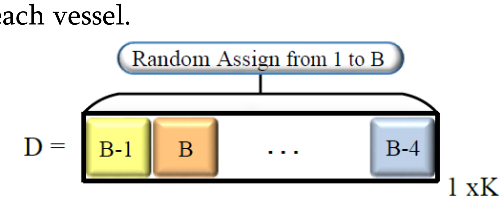

Fig. 6. The fifth chromosome string to specify the destination port of the ship

4. Computational results

In this section, first, the parameters of the GA algorithm are adjusted, then some random test problems are generated and the performance of the presented model is investigated by a using an exact solver and the GA algorithm.

4.1. Parameter setting

The quality of an algorithm is significantly influenced by its parameter values. One of the purposes of the design of the experiments is to change the input variables deliberately to detect and identify the output variations [26-30]. There are several ways to design the experiment. One of these methods is parameter tuning by the Taguchi method that proposes a minimum number of orthogonal experimental designs in which the factors can be independently verified. In this method, the signal to noise ratio (S/N) is used to determine the best combination of experiments. To measure the best N/S ratios, Taguchi has proposed three equations of (5-4), (5-5) and (5-6) in which Yi is the answer value in the ith experimental condition and n is the number of designed experiments. Also, in the equations S and y¯ are the mean and variance of the experiment answers, respectively [26].

$$(S/N)_S=-10log_{10}(\frac{\sum y_i^2}{n}) \quad (5\text{-}4)$$

$$(S/N)_t = -10log_{10}(\frac{1}{n}\sum\frac{1}{y_i^2}) \quad (5\text{-}5)$$

$$(S/N)_T= -10log_{10}(\frac{y^2}{s^2}) \quad (5\text{-}6)$$

To improve the performance of the proposed algorithms, we adjusted their input parameters by the Taguchi method. Because of the designed problems for the model, the parameter setting has been performed on problem 20. Table (2) presents the different levels of the parameters of the genetic algorithm. The experiments are for algorithm L_9 using the Taguchi method. Table (3) presents the orthogonal arrays of the algorithm and its results.

Table (2): Parameter levels of GA algorithm

Parameters	Low (1)	Medium (2)	High (3)
npop	50	100	150
nIt	50	100	150
Pc	0.5	0.7	0.9
Pm	0.3	0.4	0.5

Table (3) : The designed experiments of GA algorithm

npop	nImp	maxit	bata	RPD	SN
1	1	1	1	0.0250673	12.01784
1	2	2	2	0.116317	18.68716
1	3	3	3	0.107701	19.35564
2	1	2	3	0.078352	22.11898
2	2	3	1	0.116317	18.68716
2	3	1	2	0.063274	23.97548
3	1	3	2	0	80
3	2	1	3	0.094238	20.51548

3	3	2	1	0	80

The S/N index obtained for each algorithm parameter in Figure (7) indicates the best level for the algorithm. The optimum values for each parameter are also shown in Table (4).

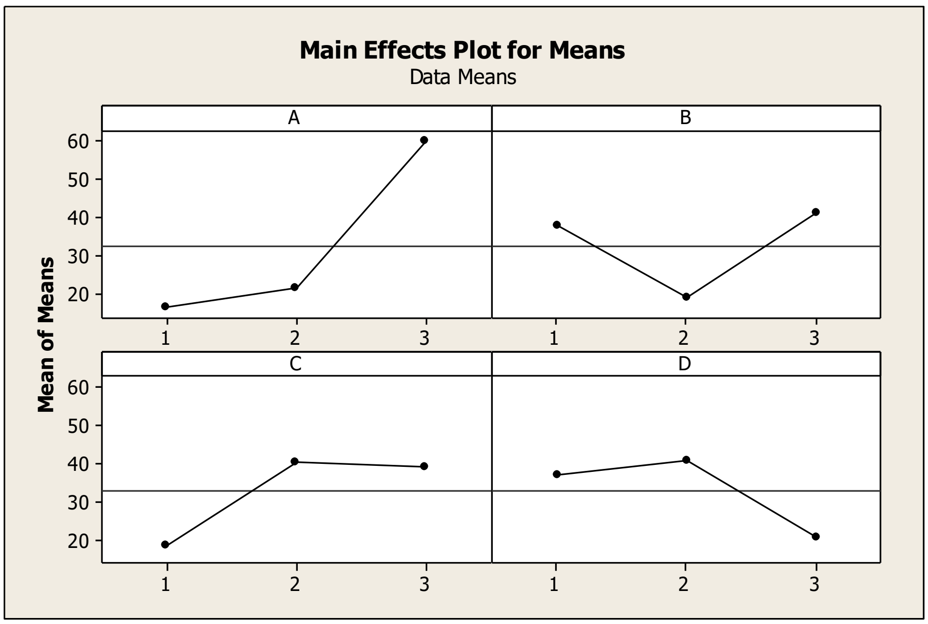

Fig. 7. S/N diagram of GA algorithm

Table (4): The optimal values of parameters of FA and ICA algorithms

Algorithm	**Optimal value**			
	n pop	nIt	PC	PM
ICA	150	150	0.7	0.4

4.2. Random example in small and large scales

In this section, the performance of the presented routing model and the GA algorithm extension is verified through 10 numerical examples in small scale and 10 numerical examples in large scale. Tables 4 and 5 in the supplementary illustrate the parameters of the examples generated in small and large scales. Small-scale examples are optimally solved by exact solver in LINGO 17.0 software using a 3.5 GHz PC and 8 GB RAM. Also, all examples have been solved by the introduced GA algorithm in MATLAB. Then the results were compared in terms of the objective function value (OFV) and CPU time. Each example has been solved 20 times by the GA algorithm and then the average OFV and CPU time values have been reported. Since differences between the exact method and Genetic Algorithm are reasonable, the accuracy of model has been demonstrated.

Also, the routes of liners and tramps can be observed under the Rout column in Table (5).

Table (5): The calculation results of numerical examples in small and large scales

	Exact			GA			Gap
No:	Rout	OFV	CPU Time (s)	Rout	OFV	Mean CPU Time (s)	
1	k1: 11→1→6→4→2→9→3→7→8→5→10→11	47	1123	k1: 11→1→6→4→2→9→3→7→8→5→10→11	47	4.7	0
2	k2: 8→1→4→3→2→6→5→7 k3: 8→3→6→8	55	264	k2: 8→1→4→7 k3: 8→3→6→2→5→8	61	3.5	0.1
3	k3: 8→3→6→2→1→4→5→7	34.1	2	k3: 8→3→6→2→1→4→5→7	34.1	3.5	0
4	k1: 9→2→6→4→8→1→3→5→7→10	47.03	52	k2: 9→4→8→1→2→5→6→10	50.67	3	0.07
5	k1: 9→1→3→5→7→10 Tramp ship: 2,4,6,8	30.98	20	k2: 9→1→5→3→7→10 Tramp ship: 2,4,6,8	36.78	3	0.18
6	k2: 11→4→8→2→6→1→5→9 Tramp ship: 3,7	33.57	16	k2: 9→4→8→2→6→1→5→9 Tramp ship: 3,7	33.57	4	0
7	k1: 9→2→4→8→3→7→6→1→5→10	45.16	267	k1: 9→2→4→8→3→7→6→1→5→10	45.16	4.2	0
8	k1: 11→1→6→3→8→4→9→5→10→2→7→13	38	2521	k2: 11→5→10→3→8→1→6→4→9→2→7→13	39	5	0.02
9	k1: 11→1→6→4→3→9→8→5→10→12 Tramp ship: 2,7	38.36	87	k1: 11→1→6→5→10→12 Tramp ship: 2,3,4,7,8,9	39.96	4	0.04
10	k1: 15→5→11→2→8→15 Tramp ship: 1,3,4,6,7,9,10,12	44.6	414	k1: 15→5→11→2→8→15 Tramp ship: 1,3,4,6,7,9,10,12	44.6	3.6	0
11	-	-	More than one hour	k2: 15→5→11→14 k3: 13→4→10→2→8→14 Tramp ship: 1,3,6,7,9,12	78.66	5	-
12	-	-	More than one hour	k2: 15→1→8→4→11→7→14→5→12→15 Tramp ship: 2,3,6,9,10,13	51.56	4.5	-
13	-	-	More than one hour	k2: 15→2→9→6→13→15 Tramp ship: 1,3,4,5,7,8,10,11,12,14	89.7	4	-

14	-	-	More than one hour	k2: 15→4→11→5→12→7→14→15 Tramp ship: 1,2,3,6,8,9,10,13	94.8	5	-
15	-	-	More than one hour	k2: 17→7→15→8→16→6→14→5→13→1→9→18 Tramp ship: 2,3,4,10,11,12	64.96	6	-

Table (6): Continued

	Exact			GA			Gap
No:	Rout	OFV	CPU Time (s)	Rout	OFV	Mean CPU Time (s)	
16	-	-	more than one hour	k2: 17→5→13→7→15→6→14→2→10→1→9→18 Tramp ship: 3,4,8,11,12,16	70.44	6	-
17	-	-	more than one hour	k1: 18→4→12→5→13→7→15→6→14→18 Tramp ship: 1,2,3,8,9,10,11,16	89.26	5	-
18	-	-	more than one hour	k3: 18→5→13→4→12→7→15→17 k4: 18→1→9→6→14→17 Tramp ship: 2,3,8,10,11,16	70.26	5.5	-
19	-	-	more than one hour	k1: 19→6→15→8→17→1→10→9→18→19 k2: 19→5→14→7→16→4→13→20 Tramp ship: 2,3,11,12	66.46	6.5	-
20	-	-	more than one hour	k3: 14→5→11→13 k4: 14→1→7→4→10→14 k5: 14→6→12→14 Tramp ship: 2,3,8,9,13,14	39.46	5	-

Figure 8 shows the graphical representation of solution problem 18. In this problem, we have considered 8 loading ports (ports 1 to 8), 8 discharge ports corresponding to the loading ports (ports 9 to 16), and 2 ports for the ship's departure and destination (17 and 18). There are also 4 liner ships. The first and second ships had no movements. The third ship has met and been serviced by the yellow port, and the fourth ship has visited and serviced the orange ports. Ports 2, 3, 8, 10, 11, and 16 have been serviced by tramp ships. Besides, ports 17 and 18 are the departure and destination of the ships.

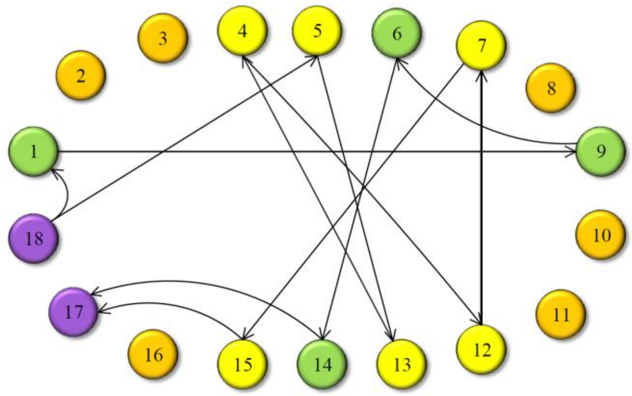

Fig. 8. Graphical display of problem 18

5. Conclusion

Conventionally, the offshore logistics studies are primary formulated as a routing optimization and scheduling of ships. These decisions have a significant role to optimize the traveling cost per distance, total traveling time and the number of vehicles in the supply chain networks most practically for container terminals in the global trade centers. The new contributions of this model were to consider the routes of two types of ships, the time windows and a multi-modal transportation system simultaneously. The proposed was solved by an exact solver as well as a Genetic Algorithm for large-scale tests. The performance of GA was enhanced by a Taguchi experimental design method. Finally, an in-depth analysis and discussion was provided. The results confirm that our solutions from GA are reliable and close to the global solutions.

This research can open several new contributions for the future works. Without a doubt, other heuristics and metaheuristics can solve the proposed problem practically and computationally better than GA. Therefore, more efforts to solve heuristically the proposed problem are needed. The sustainability dimensions and environmental regulations can be ordered to improve the proposed model as a multi-objective optimization model which is the potential continuation of this study.

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