Advances in Industrial Engineering, Winter 2020, 54(1): 41-52
DOI: 10.22059/jieng.2021.318000.1751

RESEARCH PAPER

A Two Stage Recourse Stochastic Mathematical Model for the Tramp Ship Routing with Time Windows Problem

Amin Jamili *

School of Industrial Engineering, College of Engineering, University of Tehran, Iran.

Received: 26 January 2021, Revised: 10 March 2021, Accepted: 14 March 2021

Abstract

Nowadays, the majority of international trade in goods is carried by sea, and especially by ships deployed in the industrial and tramp segments. This paper addresses routing the tramp ships and determining the schedules including the arrival times to the ports, berthing times at the ports, and the departure times at an operational planning level. At the operational planning level, the weather can be almost exactly forecasted, however in some routes some uncertainties may remain. In this paper, the voyaging times between some of the ports are considered to be uncertain. To that end, a two-stage stochastic mathematical model is proposed. In order to find near to optimum solutions in a limited amount of time, a new hybrid heuristic algorithm is proposed to solve large-size examples. Moreover, a case study is defined and tested with the presented model. The computational results show that this mathematical model is promising and can represent acceptable solutions. Specifically, the value of the stochastic solution, VSS, is computed, and the results show that using two-stage stochastic with recourse improves 1.1% the objective value.

Keywords:
Scheduling;
Uncertainty;
Hybrid Heuristic Algorithm

Introduction

Team The Ship Routing Problem (SRP) varies with the carrier's operation type, and is divided into three categories known as 1) Liner shipping, 2) Industrial shipping, and 3) Tramp shipping. The liner shipping is a tactical problem, where the routings, as well as the schedules, are planned some months before transshipments. In Industrial shipping the berthing sequences and schedules are not tactically planned, but yet there are fixed berthing ports. Tramp shipping belongs to the operational planning level, where it acts similar to taxis which follow any possible shipments. This paper addresses the tram shipping under weather uncertainties. It is assumed that in some routes, the weather forecasts are not exact, and the voyaging times are not fixed values.

- A cargo is considered as the set of containers transported to the specified destination.
- Routing is the sequencing of ports for ships transporting the cargoes.
- Scheduling is assigning the times to each ship arriving, berthing, and departing the ports.
- A voyage is considered as one section of a specific route between two ports.

* Corresponding author: (A.Jamili)
Email: a_jamili@ut.ac.ir

Previous Works

The Tramp Ship Routing Problem (TSRP), has many similarities with the open vehicle routing problem, with time windows, pickup, and delivery. The reader's attention is drawn to the excellent reviews on this subject by Toth and Vigo [1] and Berbeglia et al. [2]. Grandinetti et al. [3], Wassan and Nagy [4] recently studied this problem as well. Ronen [5] presented a review of ship routing, and scheduling, and discussed briefly the differences between vehicle and ship routing and scheduling problems. He indicated that SRP is less structural, and its operational environment is more complicated. Christiansen et al. [6] reviewed the recent researches on ship routing and scheduling and related problems and provided four basic models in this domain. The results show that liner shipping, marine inventory routing, and optimal speed have come to the forefront, while complex critical problems remain wide open and provide challenging opportunities. Kjeldsen [7], Cho et al. [8], Fagerholt and Christiansen [9], and Fagerholt [10] studied the liner shipping or industrial shipping routing problem. Cho et al. [8] proposed a modified nonlinear model for bulk cargo ship scheduling, and then reformulate it into a linear mixed-integer programming problem. Fagerholt and Christianson [9], and Fagerholt [10] studied the pickup and delivery SRP with time windows and assumed certain loading ports and discharging ports. Liu and Chen [11] studied TSRP. Since this problem consists of time and space aspects, they used a multi-commodity time-space network to formulate the optimization model. Romero et al. [12] discussed aspects related to data gathering and updating and presented a GRASP algorithm to solve this problem. The proposed solution approach is applied to a salmon feed supplier based in southern Chile. De et al. [13] proposed a mixed integer non-linear programming model for ship routing and scheduling problems and employed particle swarm optimization-composite particle (PSO-CP) to solve the problem. Dithmer et al. [14] studied liner shipping routing and scheduling problem and investigated the impact of emission control areas in the routing and scheduling of liner vessels. Alhamd et al. [21] proposed the Tabu Search heuristic for the ship routing and scheduling to minimize the overall cost of shipping operation without any violations. Fan et al. [15] addressed the tramp ship routing and scheduling with speed optimization considering carbon emissions, and proposed a genetic simulated annealing algorithm based on a variable neighborhood search to solve the problem. Kim et al. [16] considered the problem of ship routing and fleet sizing problem and suggested a simulated annealing algorithm with some analytic methods. Homsi et al. [17] studied industrial and tramp ship routing problems and proposed an exact branch-and-price algorithm and a hybrid genetic base search.

Considering the above literature review, it can be found that the uncertainty in running times affected by the weather condition is not addressed. Meanwhile, among the metaheuristic algorithms, the PSO algorithm is not applied. Table 1, shows the position of this paper amongst the studied literature considering the applied algorithm.

Table 1. The position of the current paper amongs the studied literature considering the proposed solving algorithm

	GRASP	PSO	Tabu Search	Genetic algorithm	Simulated annealing algorithm	Branch-and-price algorithm
Liu and Chen (2013)	×					
De et al. (2016)		×				
Alhamd et al. (2019)			×			
Fan et al. (2019)				×	×	
Kim et al. (2019)					×	
Homsi et al. (2020)				×		×
Current study		×			×	

Contribution of the Paper

The novelty of this paper is listed as follows:

1) Proposing a new mathematical model for the TSRP.
2) Applying a two-stage stochastic model for considering the uncertainty of the weather condition. Moreover, it is concluded that by the applied stochastic model, more applicable solutions are achieved.
3) Proposing a new hybrid algorithm based on the PSO algorithm.

Outline

In the next section, the problem is described in detail. Section 3 represents a new mathematical model. In Section 4, the two-stage stochastic model is proposed. In Section 5, a new hybrid heuristic algorithm is proposed. Section 6 deals with the case study. Finally, the concluding remarks are given at the end to summarize the contribution of this paper.

Problem Description

Tram shipping problem can be considered as a network, where the nodes in the network represent the demand points at ports, and the arcs in the network represent the flow directions of ships. Tram shipping is mainly conceived as a short-term problem. The tramp ship routing and scheduling problem consist of creating routes for a heterogeneous fleet of ships that ensure that all demands between the ports are delivered at the lowest possible cost. Each demand is known by the port pair that stipulates the origin and destination. Splitting demand on different routes is not allowed.

The ports can function as transshipment hubs. A ship is assigned to one route which it sails continuously. It is assumed that the required compatibility between ships and ports exists. In other words, the ports can accommodate the ships calling and required cranes are available either in the ports or on the ships. The fleet consists of several ships that can be divided into different types. Ships of the same type will have similar characteristics such as speed capabilities, and capacity. The major shipping lines have a number of ships of each type, and there seems to be a strong preference for similar ships on a route. The speeds of the ships are previously known and are considered as the input parameters. The tramp shipping business covers cargoes by less-than-shipload. This feature makes the studied problem more complicated because a ship may have several cargoes with various origin or destination ports. A cargo can be carried unless arcs exist in ship sub-networks. For example, if a ship sails from Port 2 to Port 3, then to Port 1, then cargoes can be carried from Port 2 to Port 1 or from Port 3 to Port 1. A ship cannot load cargoes beyond its capacity/deadweight limitations. Each cargo is carried by the meeting its pickup/delivery time windows and loading/discharging operation times. The total transit time for each cargo includes the time to be carried on the ship as well as loaded/discharged at ports. The loading/discharging operation times in the origin and destination of the cargoes should be considered. If several cargoes are being picked up or delivered at the same time, the longest operation time, but not the total time, is taken as the loading or discharging operation time. To maintain service quality and to prevent cargoes from incurring damage, each cargo should not be carried by different ships (non-split load) and should not be transferred to another ship on the way to the destination port (direct transport).

The problem is to maximize the profit considering the gross weight of ships in ports based on the loaded and discharged cargoes in ports which should be always less than the maximum capacity. The arrival times to the ports should be computed so that the ships can service the loaded and unloaded cargoes. For each cargo, a specific time window is considered. The problem is formulated in the following section.

The Proposed Tramp Ship Routing Mathematical Model

This section is to propose the mathematical model for the described problem. The employed notations are shown below:

Table 2. The employed notations

Symbol	Description
A	Set of ports
S	Set of ships
H	Set of cargoes
C_{ijk}	Shipping cost of arc (*i*,*j*) by ship *k*
I_{O_lkl}	Income of shipping cargo l from its origin, i.e. o_l, by ship *k*
x_{ijk}	A binary variable equal 1, if ship *k* move from *i* to *j*
y_{ikl}	A binary variable equal 1, if ship *k* loads cargo *l* in port *i*
z_{ikl}	A binary variable equal 1, if ship *k* discharges cargo *l* in port *i*
q_{ik}	The gross weight of ship k in port *i*
c_k	The maximum capacity of ship *k*
p_{ik}	Arrival time of ship *k* to port *i*
b_{ik}	Berthing time of ship *k* in port *i*
t_{ijk}	Voyaging time of ship *k* between ports *i* and *j*
r_{ik}	Release time of ship *k* from its origin *i*
u_l^l	The earliest time for loading cargo l
u_l^u	The latest time for loading cargo l
v_l^l	The earliest time for unloading cargo l
v_l^u	The latest time for unloading cargo l
f_l	The loading time of cargo l
g_l	The unloading time of cargo l
o_l	Origin of cargo l
d_l	Destination of cargo l

$$Z = max \sum_{k \in S} \sum_{l \in H} I_{O_lkl} \times y_{O_lkl} - \sum_{i \in A} \sum_{j \in A} \sum_{k \in S} c_{ijk} \times x_{ijk} \quad (1)$$

Eq. 1 indicates the objective function which maximizes the profit which equals the incomes minus costs.

$$\sum_i x_{ijk} - \sum_m x_{jmk} = \begin{cases} -1, & \text{if } j \text{ is the origin port of ship } k \\ 1, & \text{if } j \text{ is the last port considered for ship } k \\ 0, & \text{otherwise} \end{cases}, \quad (2)$$
$$\forall j \in A, k \in S$$

Constraints (2) guarantee the continuity of ship movements.

$$q_{ik} + \sum_l y_{jkl} - \sum_l z_{jkl} \le q_{jk} + M \times (1 - x_{ijk}), \qquad \forall i,j \in A, k \in S \quad (3)$$

Constraints (3) indicate the gross weight of ships in ports based on the loaded and discharged cargoes in ports.

$$q_{ik} \leq c_k, \qquad \forall i \in A, k \in S \tag{4}$$

Constraints (4) specify that the gross weight of ships should be less than the maximum capacity.

$$y_{o_l kl} = z_{d_l kl}, \qquad \forall l \in H, k \in S \tag{5}$$

Eq. 5 ensures that if a cargo is loaded by a ship, it should be discharged by the same ship in the destination port.

$$y_{o_l kl} \leq \sum_j x_{o_l jk}, \qquad \forall l \in H, k \in S \tag{6}$$

Constrains (6) guarantee that any cargo can be loaded on those ships which are berthed in the origin ports of the cargoes.

$$z_{d_l kl} \leq \sum_i x_{i d_l k}, \qquad \forall l \in H, k \in S \tag{7}$$

Constrains (7) guarantee that any cargo can be discharged from those ships which are berthed in the destination ports of the cargoes.

$$p_{ik} + t_{ijk} + b_{ik} \leq p_{jk} + M \times (1 - x_{ijk}), \qquad \forall i, j \in A, k \in S \tag{8}$$

Constraints (8) indicates that the arriving time of a ship to a port is more than the summation of arriving time to the previous port, the berthing time in the previous port, and the voyaging time between the ports.

$$p_{i'k} = r_{i'k}, \qquad \forall k \in S \tag{9}$$

Eq. 9 specifies that the arriving time of any ships to their origins equal the release time. Note that i' is the original port of ship k.

$$u_l^l - M \times (1 - y_{o_l kl}) \leq p_{o_l k} \leq u_l^u + M \times (1 - y_{o_l kl}), \qquad \forall l \in H, k \in S \tag{10}$$

Constraints (10) ensure that any cargoes can be loaded on a ship whenever its arriving time to the origin port of the cargoes are between the earliest and latest loading time of the cargoes.

$$v_l^l - M \times (1 - z_{d_l kl}) \leq p_{d_l k} \leq v_l^u + M \times (1 - z_{d_l kl}), \qquad \forall l \in H, k \in S \tag{11}$$

Constraints (11) ensure that any cargoes can be discharged from a ship whenever its arriving time to the destination port of the cargoes are between the earliest and latest discharging time of the cargoes.

$$x_{ijk} \in \{0,1\}, \qquad \forall i, j \in A, k \in S$$
$$y_{ikl} \in \{0,1\}, \qquad \forall i \in A, l \in H, k \in S$$
$$z_{ikl} \in \{0,1\}, \qquad \forall i \in A, l \in H, k \in S$$
$$p_{ik} \geq 0, \qquad \forall i \in A, k \in S$$

Solution methodology

Since the weather condition cannot be forecasted exactly, the voyaging time between ports, i.e. parameter t_{ijk}, should be considered uncertain in real application.

The form of so-called two-stage stochastic programming with recourse is shown in Eq. 12:

$$\begin{aligned} &\min c(x) + E_\omega Q(x,\omega) \\ &s.t.\ \ Ax = b \\ &\qquad x \geq 0 \\ &\qquad Q(x,\omega) = min\{q(y) | Wy = h - Tx,\ \ y \geq 0\} \end{aligned} \tag{12}$$

Where, ω is the vector containing q, h, and T, and $E_\omega$denotes mathematical expectation considering ω. It is supposed that W is constant.

$c(x)$ is a function that indicates the profit in the first stage. The last part of the objective function specifies the expected penalty costs caused by late delivery. The first, and second stage variables are x, and y, respectively.

In this problem, it is supposed that there is only one path (i^*, j^*) that might be faced by bad weather conditions. Therefore, in the stochastic model, the uncertain parameter t_{ijk}, should be replaced by t_{ijks}, where, index s represents the s-th scenario, and $s \in W = \{1,2\}$. By the same reason $p_{ik} \leftarrow p_{iks}$. Therefore, the constraints (8) are replaced by constraints (13).

$$p_{ik} + t_{ijks} + b_{ik} \leq p_{jks} + M \times \left(1 - x_{ijk}\right), \qquad \forall i,j \in A, k \in S, s \in W \tag{13}$$

In addition, by defining the new variable y_{d_lks} which indicates the lateness of ship k in arriving to the destination port of cargo l under scenario s, the constraints (11) is replaced by (14).

$$v_l^l - M \times z_{d_lkl} \leq p_{d_lks} \leq v_l^u + M \times z_{d_lkl} + y_{d_lks}, \qquad \forall l \in H, k \in S, s \in W \tag{14}$$

Moreover, the stochastic objective function is represented by Eq. 15.

$$\begin{aligned} Z = max \sum_{i\in A}\sum_{k\in S}\sum_{l\in H} I_{ikl} \times y_{ikl} - \sum_{i\in A}\sum_{j\in A}\sum_{k\in S} c_{ijk} \times x_{ijk} \\ - \sum_{l\in H}\sum_{k\in S}\sum_{s\in W} p_s \times cc_l \times y_{d_lks} \end{aligned} \tag{15}$$

Where, cc_l is the penalty cost for late delivery of cargo l, and y_{d_lks} is a variable indicates the lateness of ship k in arriving to the destination port of cargo l under scenario s. p_s is the probability of occurring scenario s. Note that p_s has discrete distribution, and therefore, the generated stochastic program is just an ordinary linear program.

It is necessary to note that if two/three of the paths are subject to uncertainty, then four/eight different scenarios should be considered, and the Eq. 15 should be changed accordingly.

The Hybrid Heuristic Algorithm

Kennedy and Eberhart [20] firstly introduced the Particle Swarm Optimization (PSO). This algorithm is known as an evolutionary one which is based on improving a population of random candidate solutions called particles. During following the steps of this algorithm, each particle moves to a better position with a velocity which is dynamically computed based on achieved learning by all particles. Eq. 16 specifies the formula to update the velocity of each particle:

$$v_t = w \times v_t + c_1 \times Random[0,1] \times (P_l^t - s^t) + c_2 \times Random[0,1] \times (P_g - s^t) \tag{16}$$

$$s^t = s^t + v_t \tag{17}$$

Where, v_t is the velocity related to x_t. s^t is the t-th particle. P_l^t shows the current best local solution obtained by the t-th particle. P_g is the best achieved solution. W is the weight of previous velocity. c_1 and c_2, are to define the weight of the stochastic acceleration terms which push each particle to P_l^t and P_g, respectively.

Simulated annealing (SA) is a well-known metaheuristic algorithm that tries to escape the local optimum by considering the chance of accepting moves which even worsen the objective function value. In this algorithm, the chance of accepting a worse solution, called temperature, reduces as the algorithm proceeds. This leads to seeking the bottom of the local optimum at the final iterations of the algorithm. The computational time can be adjusted by slowing down the trend of reducing the temperature. More details about this algorithm are specified by Eglese, R.W [19]. The proposed Simulated Annealing (SA) algorithm is as follows:

Step 1. k←0, k´←$|T|$

Step 2. k←k+1, Tempk= α ×Tempk-1

Step 3. Select k´ of random ships and considering their associated origin, assign a set of random ports to visit.

Step 4. For each set of random ports, considering all required input data defined in previous sections, compute the related travelling sales man problem with time windows.

Step 5. Find the objective function value, i.e. Z(k).

Step 6. If Z(k)≥ Z(k-1), or Pacceptk>Random [0. 1], Consider this solution as the base solution. If Z(k) is the best found solution, save it as the best solution.

Step 7. If the termination criterion is satisfied, terminate the algorithm, otherwise, k´←1, and Go to Step 2.

Step 1 is to assign the initial values to k as the iteration counter. Step 2, is to define the cooling system, where, $Temp_k$ is the temperature in the k-th iteration and α is the cooling factor. Steps 3 and 4 generate a complete solution. Step 5, compute the objective function value in the k-th iteration, Z(k). In Step 6, considering the probability function to accept non-improving solution in the k-th iteration, $Paccept_k$, the solutions with worse Z(k) is accepted. Step 7, indicate the termination criterion.

Dumas et al. [18] proposed an algorithm the Travelling Salesman Problem (TSP) with time windows. Moreover, $Paccept_k$ specified in Step 6 of the proposed algorithm, is calculated based on the Metropolis Function shown as below:

$$\begin{cases} 1 & \text{If } OFV_k \le OFV_{k-1} \\ exp\left(\frac{OFV_k - OFV_{k-1}}{Temp_k}\right) & \text{If } OFV_k > OFV_{k-1} \end{cases} \tag{18}$$

In addition to the SA algorithm proposed in the above section, a new hybrid PSO-SA algorithm is proposed as follows:

On one hand, PSO combines local search through self-experience as well as global search through neighboring experience which results in more efficiency in searching the optimal solutions. On the other hand, SA is an algorithm designed to find a good solution as specified as before which is enriched by a cooling system that escapes the local optimum. As a result, a combination of PSO and SA algorithms can omit the hard and firm velocity updating mechanism that exists in the PSO algorithm.

By the above explanations, the novel hybrid PSO-SA algorithm contains the following two phases:

1) at the first phase some initial solutions are generated in random, and
2) the PSO-SA algorithm is run based on the general outline specified as follows.

Step 1) Generate "pop" initial random solutions, using Steps 3-5 of the SA algorithm. If any of the constructed schedules is infeasible, regenerate them until we reach the pop number of feasible initial solutions. Set $P_l^t \leftarrow s^t$ and update P_g.

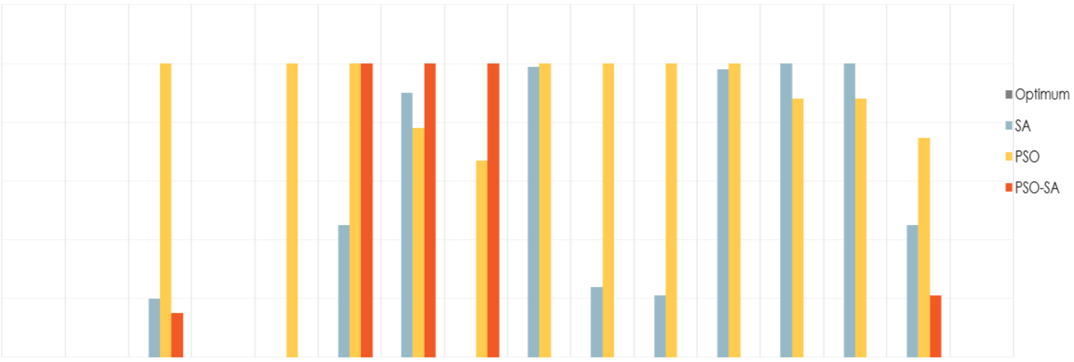
Step 2) Considering each solution, known as particles, the SA algorithm is run. In the case that the new particle is not feasible set $s^t \leftarrow P_l^t$. Update P_l^t and P_g.

Step 3) Considering equations 16 and 17, update the position and velocity of all generated particles in Step 2.

Step 4) In the case that each of the updated particles is not feasible set $s^t \leftarrow P_l^t$.

Step 5) Considering each particle, compute the objective function value, and update P_l^t and P_g. If termination criterion is passed return P_g and stop, otherwise go to Step 2.

11 different $|N| - |T|$ instances are constructed randomly to compare the results of the proposed algorithms, Fig. 1, shows the results.



Algorithms	02-02	03-03	03-04	04-04	05-05	07-07	08-08	09-09	10-10	12-12	14-14	15-15	16-16	18-18	20-20	Average	Trend
Optimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00									
SA	0.00	0.00	0.20	0.00	0.00	0.45	0.90	0.00	0.99	0.24	0.21	0.98	0.79	1.00	1.00	0.45	
PSO	0.00	0.00	1.00	0.00	1.00	1.00	0.78	0.67	1.00	1.00	1.00	1.00	1.00	0.88	0.88	0.75	
PSO-SA	0.00	0.00	0.15	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	

Fig. 1. The comparison of the results

As is shown in Fig. 1, 8 examples are solved by the Lingo software and the optimum solution is achieved. In 5 examples out of these 8 examples the optimum solutions are also achieved by the proposed heuristic algorithms.

Considering the achieved results, the PSO-SA algorithm can outperform the SA, and PSO algorithms. In general, one can say that the results of the PSO-SA algorithm are considerably better than the others as the size of the problems raises.

Case Study

The studied shipping network is depicted in Fig. 2. As can be seen, there exists 9 active ports.

Fig. 2. The case study

The cargoes' data including the weights, the origins and destinations, the pickup time windows, and berthing times are represented in Table 3.

Table 3. The cargoes' data

	1	2	3	4	5	6	7	8	9	10	11	12
O	AN	AN	BA	BA	BA	BA	AK	AQ	AQ	AK	BA	AQ
D	AS	BA	TU	SU	MA	AK	AT	MA	BA	AQ	MA	AT
W	5	12	15	6	12	16	8	1	19	12	10	12
P-T	(4-5)	(3-4)	(3-6)	(1,2)	(1,2)	(1,2)	(1,1)	(1,2)	(1,2)	(2,2)	(3,4)	(4,6)
B-P	1	2	2	1	2	2	1	1	1	1	2	1

The O-D matrix including the voyaging times, and shipping costs is not presented here. By the above explanations, the optimum solution for ship routings and schedules are shown in Fig. 3.

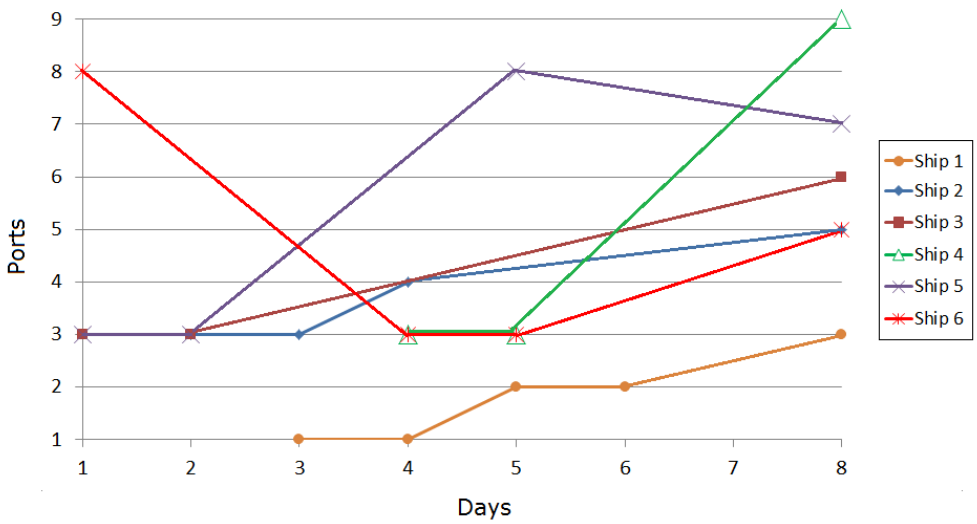


Fig. 3. The optimum solution

In Fig. 3, the ports number are defined as shown in Table 4.

Table 4. Ports' numbers definitions

Ports Abbreviations	AN	AS	BA	SU	MA	AK	AT	AQ	TU
Ports No.	1	2	3	4	5	6	7	8	9

Now suppose that the weather forecasts shows that there might be stormy condition in the area between ports SU to MA, and therefore, the voyaging times for this arc has the following probability function:

$$t_{SU-MA} = \begin{cases} 4, & 25\% \\ 6, & 75\% \end{cases} \tag{19}$$

Considering this uncertainty, and based on the proposed two-stage stochastic model, the optimum solution will be as depicted in Fig. 4.

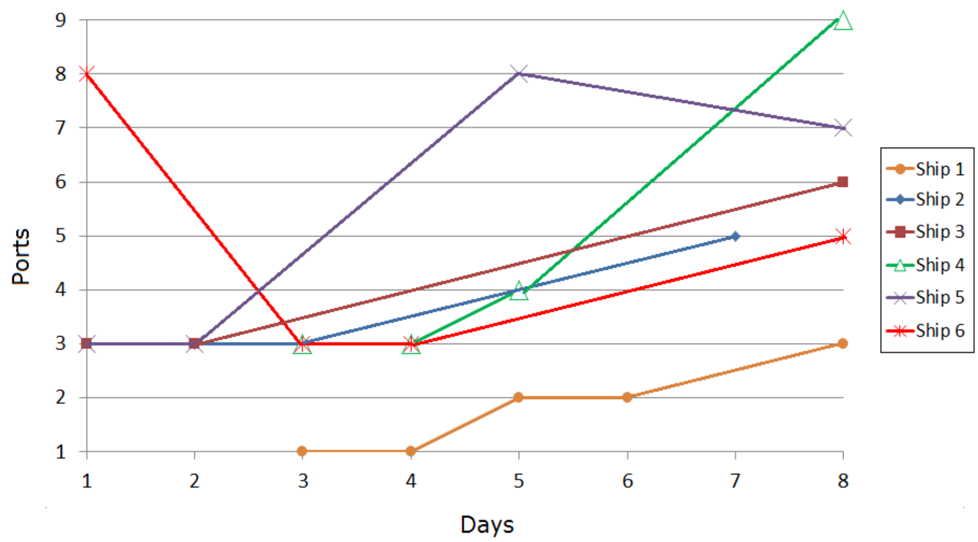


Fig. 4. The optimum solution in uncertainty condition

As is shown in Fig. 4, the optimum solution in uncertain conditions contains no direct connection between ports 4 and 5, and therefore, all the risks related to the bad weather condition are eliminated. Finally, considering the proposed stochastic solution, the expected value of perfect information, EVPI, is computed equal to 7.1% of the objective value, and the value of the stochastic solution, VSS, equals 1.1% of the objective value, which shows the importance of using two-stage stochastic with recourse to consider the uncertainty.

Conclusion

In this paper, the tramp ship routing with time windows was studied. To that extent, a new mathematical model was proposed. In practical conditions, the weather changes may result in violating the constraints. To that end, the two-stage stochastic optimization approach was utilized. The new mathematical models were tested through a case study. In the studied case, it was concluded that the objective function value of the optimum solution of the stochastic model does not differ from the deterministic one, while the affected routes which were located in the bad weather forecasted areas disregarded the optimum solution. In the end in order to solve large-scale examples, a new hybrid heuristic algorithm was proposed. In the studied case study, the optimum solution in uncertain conditions is defined so that no risk threatens the ships by losing less than 0.15% in the objective function. For future works, the author proposes working on more complicated uncertainty structures and studying new heuristic approaches to find good solutions for the studied problem.

References

[1] Toth P. and D. Vigo, “The Vehicle Routing Problem”, Philadelphia: Society for Industrial and Applied Mathematics, 2002.

[2] Berbeglia, G. Cordeau, G.-F., Gribkovskaia I., and Laporte G., “Static Pickup and Delivery Problems: A Classification Scheme and Survey, TOP, 2007; 15: 1-31.

[3] Grandinetti, L., Guerriero, F., Pezzella, F., Pisacane, O., The Multi-Objective Multi-Vehicle Pickup and Delivery Problem with Time Windows, Social and Behavioral Sciences, 2014; 111: 203 – 212.

[4] Wassan N. A., and Nagy, G., Vehicle Routing Problem with Deliveries and Pickups: Modelling Issues and Meta-heuristics Solution Approaches, International Journal of Transportation, 2014; 2 (1) 95-110.

[5] Ronen, D., Cargo ship routing and scheduling: Survey of models and problems, European Journal of Operational Research, 1983; 12: 119-126.

[6] Christiansen, M., Fagerholt, K., Nygreen, B., Ronen, D., Ship routing and scheduling in the new millennium, European Journal of Operational Research, 2013; 228 (3): 467-483.

[7] Kjeldsen K. H., Routing and Scheduling in Liner Shipping, PhD Thesis, Dep. of Economics and Business, AARHUS University, Denmark, 2012.

[8] Cho, S. C., and Perakis, A. N., An Improved Formulation for Bulk Cargo Ship Scheduling with a Single Loading Port. Maritime Policy and Management, 2001; 28 (4): 339-345.

[9] Fagerholt, K., Christiansen, M., A combined ship scheduling and allocation problem. Journal of the Operational Research Society, 2000; 51: 834-842.

[10] Fagerholt, K., Ship Scheduling with Soft Time Windows: An Optimization Based Approach. European Journal of Operational Research, 2001; 131: 559-571.

[11] Liu H.-Y., Chen, C.-Y., An Optimization Model for the Tramp Ship Routing Problem, Storage Management Solutions, 2013; 3: 189-204.

[12] Romero, G., Dur´an, G., Marenco, J., Weintraub, A., An approach for efficient ship routing, International Transactions In Operational Research, 00: 1–28; 2013.

[13] De, A., Krishna Reddy Mamanduru, V., , Gunaskaran, A., Subramanian, N., Kumar Tiwari, M., Composite particle algorithm for sustainable integrated dynamic ship routing and scheduling optimization, Computers & Industrial Engineering, 2016; 96: 201-215

[14] Dithmer P., Reinhardt L., Kontovas C. A., The Liner Shipping Routing and Scheduling Problem Under Environmental Considerations: The Case of Emissions Control Areas, International Conference on Computational Logistics, ICCL 2017; 336-350

[15] Fan, H., Yu, J., and Liu, X., "Tramp Ship Routing and Scheduling with Speed Optimization Considering Carbon Emissions " sustainability, 2019; 11: 1-19.

[16] Kim H-J, Son D-H, Yang W., Kim J-G, Liner Ship Routing with Speed and Fleet Size Optimization: KSCE Journal of Civil Engineering, 2019; 23 (3),1341–1350

[17] Homsi, G., Martinelli, R., Vidal, T., and Fagerholt, K., "Industrial and tramp ship routing problems: Closing the gap for real-scale instances," European Journal of Operational Research, 2020; 283(3), 972-990.

[18] Dumas, Y., Desrosiers, J., E. Gelinas, Solomon, M.-M., An Optimal Algorithm for the Traveling Salesman Problem with Time Windows, Operations Research, 1995; 43(2):367-371.

[19] Eglese, R.W., simulated annealing: A Tool for Operational Research, European Journal of Operational Research, 1990; 46, 271-281.

[20] Kennedy, J., Eberhart, R.C., Particle swarm optimization. In: Proc. of the IEEE International Conference on Neural Networks, IEEE service Center, Piscataway, N.J., 1995; 4, 1942-1948.

[21] Alhamed A., Alkharashi S., Dong J., Metaheuristic algorithm for ship routing and scheduling problems with time window: Cogent Business & Management ; 2019, 6(1), 1-16