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Fleet Optimization in Ro-Ro Transportation: A Case Study from Türkiye

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Abstract

Although maritime transport is the cheapest transportation mode, the management of ships is very costly. Ship management companies try to get the minimum cost and highest profit using ships effectively and efficiently. Therefore, they need to carry out shipment planning at the optimum level. The purpose of this research is to perform the optimum shipment planning of six ships in different sizes and capacities in a Ro-Ro fleet belonging to a ship management company operating in the Black Sea Region. On the basis of data obtained from the company that had problems in operating ships in its fleet effectively and efficiently, a model in A Mathematical Programming Language has been created, and this model has been solved with the GNU Linear Programming Kit, a mixed-integer program solver. Shipment planning has been conducted within the framework of six ships and a 1-year planning horizon, and profit maximization has been determined as the objective function.

Keywords: Fleet planning, Optimization, Maritime, Ro-Ro transportation, Maritime management

1. Introduction

The activities undertaken to accomplish the voyage of vessels within their bodies from one port to another port or from one location to another may be defined as the vessel operation in marine transportation. The criteria for a successful vessel operation are to maintain the idle time of ships in a fleet to a minimum by maximizing the efficiency of the fleet and reducing long-term expenditures regularly. Accordingly, neither fleet planning nor vessel operation should be separated during the planning of fleets. The knowledge of all expenditures is necessary for an effective fleet planning. In the long run, expenditures that are not fully addressed will result in a rise in costs and a decline in profitability [1].

The fleet size of vessel operators may change over time, and a fleet may include vessels of various types, vessels of different sizes, vessels with different cost structures, and diverse vessels with specific features. While the size of a fleet and the variety of transport operators might significantly differ, the shared objective of vessel operators is to optimize their fleet (fixed or variable) [2].

The main field of activity of vessel operation is fleet management. Vessel management activities and fleet management are performed together with the main lines. Fleet management necessitates collaboration with other divisions within the enterprise and the development of various strategies to achieve shared objectives. As a consequence of this necessity, a critical issue known as "fleet planning" appears. The goal of fleet planning is to ensure that the fleet under management gets intended results considering market conditions and revenue levels [3]. Some factors that affect the decision making process in fleet planning are presented as follows [3,4]:

- Large vessels may save money by taking advantage of economies of scale; however, this can pose problems for very large vessels while docking at ports.

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• The operational flexibility of smaller vessels is better than that of bigger vessels. This flexibility provides advantages in docking at ports and finding cargoes.

• The expansion of the container market drives vessels to grow in size and voyage frequency to increase.

• It is also easy to manage vessels that are built in the same class and with the same features.

• Expedition timetables should be organized in line with the capabilities of the managed fleet.

• Fleet requirements should be planned according to high, medium, or low market demands.

In general, vessel operators benefit from their past experience while making decisions. Apart from the fact that making decisions based on experience rather than analytical approaches is simpler for businesses with a limited number of vessels in their fleets, fleet planning exposes far more complex factors as the number of vessels and lines grows. Consequently, more challenging problems arise [5].

Complex operational challenges develop with the assignment of cargoes to a suitable vessel that meets all constraints, particularly in cargo-related activities and cargo operations. The constraints that must be satisfied may be listed, such as the load schedule, load capacity of vessels, and if destination ports are appropriate for the draft and length of vessels. Except for major regular line freight carriers, a small number of medium-sized businesses employ support systems for optimization-based analytical decisions [6].

During demand shrinkage, fleet managers of maritime transport corporations must decide which vessels to maintain in operation and which vessels to retire due to overcapacity [7]. In general, managers gain from their own personal experiences while making decisions. Although enterprises with a limited number of fleets can easily make decisions based on experience without utilizing analytical approaches, as the number of vessels and lines grows, fleet planning gets more complicated, making it more difficult to resolve challenges [5].

Based on the literature review, several researchers have focused on different aspects of fleet planning-related problems. Xinlian et al. [8] employed a dynamic programming model to deploy eight kinds of vessels on six transport lines in search for an optimal fleet plan and for decision making in maritime businesses. The annual load capacity of vessels for each line, annual operating expenditures, lay-up costs, purchase costs of vessels intended to join the fleet, and scrap values of vessels that will leave the fleet if required were the variables and parameters utilized in the cost minimization model. Karaoğlan [9] employed optimization techniques to examine the vessels of a maritime corporation in an application study on tanker scheduling. The study shows that how vessels might be scheduled and profit could be maximized under an optimal fleet plan. Fagerholt et al. [10] intended to distribute the most appropriate voyages to existing vessels in the fleet and to set vessel routes and timetables in a manner that minimizes costs or maximizes revenues in their research on the fleet distribution problem. Meng and Wang [11] addressed a short-term Liner Ship Fleet Planning problem with cargo shipment demand uncertainty for a single-liner container shipping company in their study related to the programming model with chance constraints for the short-term Liner Ship Fleet Planning problems. Gelareh and Meng [12] produced a mixed-integer non-linear programming model for scheduled shipping operations under the short-term fleet planning in marine transportation and solved it by transforming it into an integer linear programming model via the CPLEX solver. Meng et al. [13] sought optimum solutions to a short-term fleet planning problem through the stochastic integer linear programming method. Branchini [14] addressed the tactical planning problem that many liner shipping corporations suffer when they attempt to introduce optional spot voyages in the medium term to generate income. The optimization problem that has been developed for profit maximization was formulated as a mixed-integer programming model that was defined on a directed graph node, which represented the contract and spot voyages. Çakalöz [15] analyzed Ro-Ro transportation in Türkiye and determined how optimum fleet planning could be accomplished. All Ro-Ro lines were analyzed in the context of fleet optimization of vessels, which were the subject of Turkish international trade. Fancello et al. [16] studied the fleet vessel scheduling problem in a Ro-Ro ship fleet. They indicated that this issue is frequently being addressed among existing marine businesses. They identified the problem as a response to the need to improve basic transport services for the development of the island and surrounding areas by re-planning existing connections to improve the overall performance of the Tyrrhenian maritime network. In their study, Ma et al. [17] developed a ship routing and speed optimization model that can minimize transportation costs and emissions while taking Emission Control Area regulations into account. Compared to a real-life scenario, the model can reduce the total costs and emissions of a ship and limit the effect of the increase in the total cost caused by fuel prices. The model can also provide different optimal routes and speeds for different emission levels. In the study aimed at profit maximization, Pasha et al. [18] proposed an optimization model in which tactical liner shipping decisions are handled and emission values are considered. In their study, a heterogeneous fleet of ships created for each route was deployed. They presented a decomposition-based heuristic algorithm to solve the proposed model, which can efficiently handle large-sized problem instances. Numerical experiments have been presented on real-life scenarios that show the effectiveness of the proposed methodology. Škurić et al. [19] investigated the organization of transportation policies, which provides regular passenger ferry fleet services between a given set of routes and predetermined passenger preferences within a defined planning horizon. The proposed mixed-integer linear programming formulation was deployed for a deterministic optimization problem related to maximizing the ferry operator's profit. As a result of the three different mathematical models they employed, equal or better high-quality solutions have been obtained in less computation time compared to the current situation.

In the present study, we present a maritime business that operates in the Samsun Province of the Black Sea Region and specializes in Ro-Ro marine transportation. The objective is to provide an efficient fleet utilization plan/scheme for this maritime business to allow them to boost its profitability by operating its fleet efficiently and effectively. The study intends to ascertain the fact that vessels are not operated efficiently and effectively, to offer a good fleet planning under certain assumptions, and to investigate and plan what the optimum fleet size might be.

2. Context and Problem Formulation

With the dissolution of the Union of Soviet Socialist Republics, Ro-Ro transportation in the Black Sea Region began to rise. This has been facilitated by the mutually growing trade volume and bilateral agreements. Particularly, the substantial export of citrus products from Türkiye resulted in an important Ro-Ro traffic. In this study, a local maritime business that provides Ro-Ro transportation service in the Black Sea was addressed. By their request, the identity of the business is not disclosed, and necessary discretion is respected in this study. The data for the study were obtained through face-to-face interviews with the accounting and leasing departments of the business. The model constructed in this study was developed for the operational plan of six Ro-Ro vessels that operate in Samsun Port in the Black Sea.

The interviews with corporate executives indicate that the fleet was not being operated properly and efficiently, and as a consequence, the business' yearly revenue was lower than it should have been. As corporate data have not been held in a database management system environment, gathering, organizing, and structuring data have been a challenge during the preparation stage before problem formulation. Data tables have been created in the Microsoft Excel© program with the data obtained from the accounting and charter departments of the business. The age of the vessels, fuel consumption, capacity, daily operating expenses, charter rates, yearly charter statistics, depreciation information, port holding charges, and cargo transportation figures for 2018, as well as the gathered revenue data, such as the number of vehicles they transported between 2014 and 2018, were organized and structured within the data tables. With these data tables, examining and analyzing generated income and incurred expenses were enabled.

From Samsun to Russia, the business mostly carries citrus, vegetables, and fruits. As these transports are seasonal, it intensifies at certain times of the year. Citrus transportation is particularly concentrated between mid-October and mid-January. The vessels operate at almost full capacity during this three-month period, whereas some of the vessels are chartered. Those that are not chartered are docked at the port during the other months. According to the data acquired from the business, the vessels in the fleet were largely chartered throughout the Mediterranean and Black Sea regions during the past two years. The majority of vessel charter demands originate from ports in the Arabian Gulf and Mediterranean. Charterers often charter vessels for a limited length of time, and the busy three-month period of the business hinders them from doing so. As a result, the operator encounters challenges in the operation of its vessels in the next nine months and is unable to maximize profit from the vessels. The lack of fleet planning for vessels throughout the year is one of the primary causes of these challenges (Table 1).

Figure 1 indicates the number of vehicles carried from Samsun Port by the vessels of the business that have been studied from 2014 to 2018 and the ratio of total vehicles transported from Samsun Port. While the rate of vehicles transported by the vessels of the business that has been

Table 1. *Number of vehicles carried by ships departing Samsun Port between 2014 and 2018*

Years	i1	i2	i3	i4	i5	i6	Total
2014	483	904	1981	1467	2468	2150	9453
2015	1620	2186	858	2564	1990	910	10128
2016	324	1440	1607	594	379	1013	5357
2017	1490	1831	2800	2083	768	1023	9995
2018	1115	1956	1559	1857	208	651	7346
Total	**5032**	**8317**	**8805**	**8565**	**5813**	**5747**	**42279**

included in the study was over 35% in 2017, this rate dropped to 21% in 2018.

Vessels are chartered for various lengths of time, ranging from one week to five months. The lack of any planning impedes vessels from operating effectively and efficiently. While the average daily operating cost of the container vessel in the fleet is 1700 USD, the average daily operating costs of other Ro-Ro vessels range from 1900 to 2200 USD. Except during the peak months of October and January when the business is occupied, an average operating cost of 1400 USD is incurred per day while the vessels are not operated and are docked. Meanwhile, the daily time-based charter (T/C) charges of vessels range from 4200 USD to 4750 USD (Table 2).

The navigation time of the vessels was computed based on the speed data received, and the navigation times were found to be 21 h for the i1 and i2 vessels and 19 h for the other vessels. As the assignment plans of the vessels are reviewed on a weekly basis, periods other than the cruise time were estimated, such as port times, waiting, and congestion. Port times vary depending on the capacities of the vessels. These times were determined as 35 h for i1 and i2 vessels, 32 h for i3 and i4 vessels, and 30 h for i5 and i6 vessels. Furthermore, once the vessels have finished loading or unloading, they are assumed to begin sailing immediately.

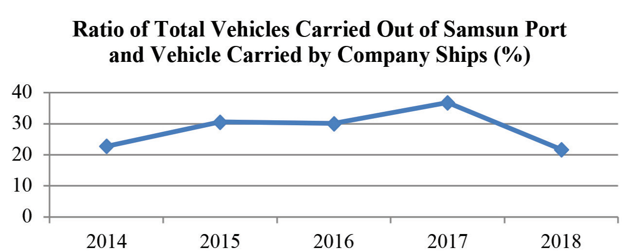

Figure 1. *Vehicle transportation rate of company ships and all ships leaving Samsun Port [20]*

The weekly fuel costs of the vessels were calculated based on this data.

2.1. Mathematical Modeling

In addition to reviewing past studies from various sources, the corporate personnel and expert perspectives in the industry were examined. The mathematical model that was constructed in this study is a mixed-integer linear programming model, which aims profit maximization. The dataset included information on the operating and voyage costs of the vessels and some information derived from their technical features, the revenues generated by their voyages in 2018, and 2018 fuel prices.

After carefully examining this maritime business operation model, we conclude that the business faces the major challenge of not being able to operate its fleet efficiently, rather than a network optimization problem, such as routing. Adopting effective fleet planning to ensure that the business can allocate vessels in its fleet to its own operations or to the charter market through chartering seems to be the only solution for the business to utilize its resources most effectively and optimize its operational profit.

Given the condition of the business, three distinct categories of decision variables have appeared to be basically eligible for the mathematical model to be constructed for fleet planning. The first is whether the relevant vessel would be deployed in its own operations in the corresponding week. The second is whether the relevant vessel would be chartered in the corresponding week. The third is if the relevant vessel would be dispatched to the shipyard. Due to the nature of the decision variables, the constructed model appears as a binary mathematical program. The constructed maximization model intends to maximize the overall operational profit by adding the profit generated by the business from its operations and the profit from the charter market.

Table 2. *Features of ships and operating costs (USD)*

Features of ships and operating costs	i1	i2	i3	i4	i5	i6
Truck/semi-trailer/trailer capacity	81	81	66	66	54	54
Insurance ($/year)	40.000	40.000	35.000	35.000	30.000	30.000
Stores ($/year)	71.000	71.000	70.000	70.000	70.000	70.000
Depreciation ($/year)	177.600	177.600	133.200	133.200	111.000	111.000
Personnel ($/year)	379.400	379.400	361.800	361.800	357.500	357.500
Repair-maintenance-attitude ($/year)	135.000	135.000	130.000	130.000	125.000	125.000
Running cost ($/daily)	2.200	2.200	2.000	2.000	1.900	1.900
Speed (knot/hour)	10	10	11	11	11	11
Cruising fuel consumption (ton/hour)	0.45	0.45	0.45	0.45	0.4	0.4
Fuel consumption in the port (ton/hour)	0.04	0.04	0.03	0.03	0.03	0.03
Financial value of ships $	3.200.000	3.200.000	2.400.000	2.400.000	2.000.000	2.000.000

The model to be constructed is based on the following assumptions:

1) The planning horizon is one year and is on a weekly basis. It is assumed to work for 52 weeks in a year. Therefore, a discrete optimization model will emerge.

2) The business only has one port from which to operate. To put it another way, there are no other problems, such as routing.

3) A vessel is either allocated by the business for its operations, on charter, or dispatched to the shipyard for other activities, such as maintenance and repair, in a given week.

4) When a vessel is allocated by the business for its operations, it is ready to be assigned to the operation again for the following week, chartered, or dispatched to the shipyard for maintenance and repair, among others.

5) When a vessel is intended to be chartered in the charter market, it can be chartered immediately.

6) Once a vessel is chartered, it remains on the charter for at least four consecutive weeks.

7) Vessels operate at full capacity when assigned to the operations of the business.

8) In cases where vessels are dispatched to a shipyard for other operations, such as maintenance and repair, they need two weeks every year for these operations, which must be set sequentially.

9) Although the periodic maintenance-epair operations of the vessels are carried out at certain periods because the established model covers a period of one year without continuity, it is sent for maintenance in any week in the relevant year, covering a period of two weeks in a row.

10) It is obligatory for a vessel to be assigned to its own operations with the capacity to satisfy at least the weekly load demand of the business.

The following would be the information that will be achieved after the model is solved under the above assumptions:

1) In which weeks may the business deploy which vessel for its own operations,

2) In which weeks may the business charter which vessel,

3) In which weeks will the business dispatch its vessels for other operations, such as maintenance and repair,

4) The maximum profit to be generated from the fleet optimization.

The following is the notation for the constructed mathematical model and the associated variable and parameter definitions:

- $i \in I$: set of ships
- $t \in T$: set of weeks
- $x_{it} \in \{0, 1\}$ binary decision variable representing the decision whether the ship "i" should be utilized by the company at week "t" for its own operations
- $y_{it} \in \{0, 1\}$ binary decision variable representing the decision whether the ship "i" should be charter at week "t"
- $z_{it} \in \{0, 1\}$ binary decision variable representing the decision whether the ship "i" should be send to shipyard week "t"

The parameters of the model are given below:

- $Ꝃ_i$: capacity of ship "i"
- λ_t: load of the company at week "t"
- r^o_{it}: operational revenue of ship "i" being deployed at the company's own operations at week "t"
- c^o_{it}: operational cost of ship "i" being deployed at the company's own operations at week "t"
- c^L_{it}: maintenance–repair cost of ship "i" for sending it to the shipyard week "t"
- r^R_{it}: charter revenue of ship "i" for charter at week "t"
- c^R_{it}: charter cost of ship "i" for charter at week "t"
- s_t: total idle capacity in week "t"
- μ: penalty coefficient for unit idle capacity.

Finally, the mixed-integer model can be written as follows:

$$Z\,max = \sum_{i=1}^{m} \sum_{t=1}^{n} \left(x_{it}\left(r^o_{it} - c^o_{it}\right) + y_{it}\left(r^R_{it} - c^R_{it}\right) - z_{it} c^L_{it} \right) - \mu \sum_{t=1}^{n} s_t$$

$$s.t$$

$$\sum_{i=1}^{m} x_{it} Ꝃ_i - \lambda_t - s_t = 0 \; ; \forall t \in T \qquad (1)$$

$$x_{it} + y_{it} + z_{it} = 1; i = 1,\ldots,m; t = 1,\ldots,n \qquad (2)$$

$$\left(1 - y_{i(t-1)}\right) + y_{it} + \left(1 - y_{i(t+1)}\right) \le 2; i = 1,\ldots,m; t = 2,\ldots,n-1 \qquad (3)$$

$$\left(1 - y_{i(t-1)}\right) + y_{it} + y_{i(t+1)} + \left(1 - y_{i(t+2)}\right) \le 3; i = 1,\ldots,m; t = 2,\ldots,n-2 \qquad (4)$$

$$\left(1 - y_{i(t-1)}\right) + y_{it} + y_{i(t+1)} + y_{i(t+2)} + \left(1 - y_{i(t+3)}\right) \le 4; i = 1,\ldots,m; t = 2,\ldots,n-3 \qquad (5)$$

$$\sum_{i=1}^{n} z_{it} = 2 \; ; \forall i \in I \qquad (6)$$

$$\left(1 - z_{i(t-1)}\right) + z_{it} + \left(1 - z_{i(t+1)}\right) \le 2; i = 1,\ldots,m; t = 2,\ldots,n-1 \qquad (7)$$

$$x_{it} \in \{0,1\}; y_{it} \in \{0,1\}; z_{it} \in \{0,1\}; s_t \ge 0; \forall i \in I; \forall t \in T$$

The objective function of this model is to maximize the profit of the this maritime business by assigning its fleet between their own operations and chartering while respecting the necessity of maintenance by sending to the shipyard. At the same time, another part of this multi-objective model comes from minimizing the idle capacity assigned to operations.

The following are the constraints that will be imposed on the model:

The first constraint stipulates that the total capacities of the vessels allocated by the business for its own operations during the planning week must be greater than or equal to the volume of cargoes that the business must transport. Here the constraint is written as equality with a surplus variable (1).

The second constraint stipulates that a vessel is either allocated by the business for its operations, on charter, or dispatched to the shipyard for other activities, such as maintenance and repair, in a given week (2).

The third, fourth, and fifth constraints provide that certain patterns are imposed on the model by preventing such patterns in order for a vessel to be chartered for at least four consecutive weeks (3), (4), (5).

The sixth constraint stipulates that a vessel should be dispatched to the shipyard for maintenance-repair operations for a total of two weeks per year during the planning year (6).

Similar to constraints (3), (4), and (5), the seventh constraint is the prohibition of a certain pattern in order for the two-week time period allocated to the shipyard in constraint (6) to remain consecutive (7).

To construct a computer model of the above algebraic model, one of the several algebraic modeling systems available today should be employed. Hence, we have preferred the GNU MathProg language (GMPL), which is an open-source/free implementation of A Mathematical Programming Language (AMPL), which comes with the GNU Linear Programming Kit (GLPK) solver.

The AMPL modeling system allows us to express constrained optimization problems in an algebraic representation that is close to that utilized in conventional mathematics. The AMPL's solve command causes the AMPL to instantiate the current problem, send it to a solver, and attempt to read a solution computed by the solver [21].

The GLPK comes with its own modeling language, the GMPL, a subset of the AMPL. It contains structures that allow modelers to easily express a wide range of mathematical programming conditions. Furthermore, the GLPK includes several examples that offer a solid overview of how to formulate optimization problems in GNU MathProg. The GLPK may be used as a library or GLPSOL, a standalone solvent. This solver is capable of reading widely accepted file formats, such as mps and cplex-lp. In addition, by constructing the model in GNU MathProg and delivering the model and data files with the mod and dat extensions directly to the GLPK solver, the modeling and solving processes may be accomplished sequentially. While the GLPK solver can be run from the command line in all common operating systems, there is also GUSEK, also known as an integrated development environment with a graphical user interface that was developed for Windows [22].

3. Findings

3.1. Solution of the Mathematical Model

The model was constructed using GMPL (GNU Mathprog), an open-source/free version implementation of the AMPL, and solved with a laptop with a GLPK integer optimizer v4.65 linear and integer program solver, having an AMD® Ryzen 5 3500u processor, 8GB memory capacity, Ubuntu GNU/Linux 20.04 64-bit operating system. AMPL's solve command causes it to instantiate the current problem, send it to a solver, and attempt to read a solution computed by the solver [21].

3.2. Outputs of the Model

The GLPK solver produces a global integer optimal solution for the computer model developed in the GMPL (GNU MathProg), an open-source/free version implementation of the AMPL algebraic modeling language. The outputs of the computer model in the GMPL were compiled.

Vessels were dispatched to the shipyard for maintenance and repair in the most appropriate 2-week period during the year, with the other weeks either allocated by the business for its operations or chartered in a way to maximize profits. The penalty term was utilized in the modeling. The penalty term is based on hypothetical values given to the algorithm of the objective function so that it can attain the global optimal solution in a reasonable amount of time and in a practical manner. Removing this term from the objective function provides the present condition of the business. The yearly profit of the business is estimated to reach a maximum of 13,749,450 USD once all the assignments have been completed and modeled.

Based on the analysis of the data from the model solution in Table 3, in which weeks the vessels will be allocated by the business for its operations (x), in which weeks they can be chartered (y), or in which weeks they can be dispatched to the shipyard for maintenance and repair (z) are indicated. Although several weeks in Table 3 have similarities in terms of the present condition and modeling output, there are disparities in the assignment in general. While the corporation presently deploys primarily i2, i3, and i4 vessels for its own operations, a homogeneous distribution

Table 3. *Current state and post-modeling situation*

Weeks	Current situation in 2018						Post-modeling situation in 2018					
	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6
1. Week		X	Y	X	Y		X	Y	X	Y	Y	Y
2. Week	X		Y		Y		X	Y	Y	Y	Y	Y
3. Week	Y	X	Y	X	Y	X	X	Y	Y	X	X	Y
4. Week	Y	X	Y	X	Y	X	X	X	Y	Z	Y	Y
5. Week	Y	X		X	Y		X	Y	Y	Z	Y	X
6. Week	Y	X		X	Y		Y	Y	X	X	Y	Y
7. Week	Y	X		X	Y		Y	Y	X	X	Y	Y
8. Week	Y	X		X	Y		Y	Y	X	Y	X	Y
9. Week	Y	X		X			Y	Y	X	Y	X	Y
10. Week	Y	X		X			Y	Y	X	Y	X	Y
11. Week		X	X	X			Y	Y	X	Y	X	X
12. Week			X	X	X	Y	Y	Y	X	Y	X	X
13. Week	X	X	X			Y	Y	Y	X	X	X	Z
14. Week	X	X	X	X		Y	X	X	X	Y	Y	Z
15. Week	X	X	X			Y	X	X	Z	Y	Y	X
16. Week		X		X		Y	Y	X	Z	Y	Y	X
17. Week		X	X	X		Y	Y	X	X	Y	Y	X
18. Week	X		X	X			Y	X	X	Y	X	Y
19. Week			X	X			Y	X	Y	Y	X	Y
20. Week				X			Y	Z	Y	Y	X	Y
21. Week			X				Y	Z	Y	Y	X	Y
22. Week		X	X	X	X		X	X	Y	Y	Y	Y
23. Week	X	X	X				X	X	Y	Y	Y	X
24. Week	X	X	X	X			X	X	Y	X	Y	X
25. Week	X	Y		X			X	Y	Y	X	Y	Y
26. Week	Y	Y	X	Y			Y	Y	Y	Y	X	Y
27. Week	Y	Y		Y			Y	Y	Y	Y	Y	Y
28. Week	Y	Y	X	Y			Y	Y	X	Y	Y	Y
29. Week	Y	Y	X	Y			Y	Y	Y	Y	Y	X
30. Week	Y	Y	Y	Y			Y	Y	Y	Y	Y	Y
31. Week	Y	Y	Y	X			Y	Y	Y	X	Y	Y
32. Week	Y	Y	Y				Y	Y	Y	Y	Y	Y
33. Week	Y	Y	Y	X			Y	Y	Y	Y	X	Y
34. Week	Y	Y	Y				Y	Y	Y	Y	Y	Y
35. Week	Y	Y		X			Y	Y	Y	Y	Y	X
36. Week	Y	Y	X				Y	Y	Y	Y	Y	X
37. Week	Y	Y					Y	Y	Y	Y	Y	Y
38. Week	Y	Y	X	X			Y	Y	X	Y	X	Y
39. Week	Y	Y	X	X			X	Y	Y	Y	Y	Y
40. Week			X	X			X	Y	Y	Y	Y	Y
41. Week	X					X	X	Y	Y	Y	Y	Y
42. Week			X	X		X	X	Y	Y	X	Y	X

Table 3. *Current state and post-modeling situation (Cont')*

Weeks	Current situation in 2018						Post-modeling situation in 2018					
	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6
43. Week		X	X	X		X	Z	Y	X	X	Y	X
44. Week		X	X			X	Z	Y	X	X	Y	X
45. Week		X		X	X	X	X	Y	X	X	Y	X
46. Week		X	X	X	X	X	X	Y	X	X	X	X
47. Week	X	X	X	X	X	X	X	X	X	X	X	X
48. Week	X	X	X	X		X	X	X	X	X	Z	X
49. Week	X	X	X			X	X	X	X	X	Z	Y
50. Week	X	X	X	X		X	X	X	X	X	X	Y
51. Week	X	X	X	X		X	X	X	X	X	X	Y
52. Week	X	X	X	X		X	X	X	X	X	X	Y

of ship assignments has appeared in general, despite the fact that i1 and i3 vessels are the most often utilized in the model output. All available vessels were currently allocated by the business for its operations during the period from mid-October until the end of the year, when the voyage density surged, although this condition slightly differed in the model output. The i6 vessel was chartered in particular during the last four weeks of the year, whereas the i5 vessel was chartered during the 48th and 49th weeks. The present condition and model output of the i2 vessel, one of the vessels most frequently deployed by the business for its own operations, was produced in a fundamentally different way. Currently, the business operations were assigned 28 weeks, compared to 16 weeks in the model output. In the model output, the i3 vessel, which the business presently deploys extensively in its own operations, was also evaluated differently. The i3 vessel was chartered for a total of 9 weeks during the year, whereas the model output was chartered for a total of 26 weeks. The business has now assigned the i3 vessel 29 weeks for its operations, but the model has only assigned 24 weeks, with 10 weeks accomplished in the last quarter of the year. In the model output, the i4 vessel was assigned to the charter for 32 weeks, making it one of the most assigned ships to the charter market. The model assigned the i4 vessel by the business for its operations for a total of 18 weeks and 11 uninterrupted weeks during the peak voyages.

To test the model and compare yearly net incomes, Table 4 provides the income-expenditure balance of the current operation, charter, and idle waiting circumstances through a calculation of the collected data. According to the data from 2018, the annual net profit was 9,415,087 USD, which was 13,749,450 USD once the penalty term was removed from the model output. Therefore, the business profit increased by 46%.

Table 4. *Annual net profit for the current situation in 2018*

	Revenue	Cost
Operation	14,773.941	5,334.984
Charter	2,111.930	952.000
Lay-up cost	---	1,185.800
Total	16,887.871	8,333.775
Net profit	**9.415.087 USD**	

3.3. Scenario-Based Solutions of the Model

The profit maximization model based on marine transportation and fleet planning optimization was tested, and its reliability was verified. In the next step, the model was run again with the changes in the parameters. “Cargo demands” and “vessel numbers” were among the parameters defined in the mathematical model that was changed again based on scenarios, and the model was run again. The scenarios considered for the cargo demand and fleet reduction were optimistic and pessimistic. The goal of producing different scenarios is to identify what kind of demand changes may happen and what kind of measures that the business might take.

The first scenario produced for the model was based on data supplied by the port authorities and was deemed an optimistic circumstance. The model was defined and solved based on the weekly vehicle transportation scenario in 2015 when transportation was at its peak between 2014 and 2018. Table 5 depicts the present position and the outcome of the optimistic scenario. A total profit of 16,784,977 USD was achieved as a consequence of the solution. Based on the review of the vessel assignments, the i1 and i4 vessels were the two most assigned by the business for its operations in the modeling output as a consequence of the optimistic scenario.

Table 5. *Optimistic and pessimistic scenarios based the solution results of the model*

Weeks	Current situation in 2018						Optimistic scenario result						Pessimistic scenario result					
	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6
1. Week		X	Y	X	Y		Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y
2. Week	X		Y		Y		Y	Y	Y	X	X	Y	Y	Y	Y	Y	Y	Y
3. Week	Y	X	Y	X	Y	X	X	Y	Y	X	X	Y	Y	Y	Y	X	Y	Y
4. Week	Y	X	Y	X	Y	X	X	Y	Y	Y	X	X	Y	Y	Y	X	Y	Y
5. Week	Y	X		X	Y		X	Z	X	Y	X	X	Y	Y	Y	Y	Y	Y
6. Week	Y	X		X	Y		X	Z	X	Y	X	X	X	Y	X	Y	Y	Y
7. Week	Y	X		X	Y		X	X	X	Y	Z	Y	X	Y	X	Y	Y	Y
8. Week	Y	X		X	Y		X	X	Z	X	Z	Y	X	Y	X	Y	X	Y
9. Week	Y	X		X			X	X	Z	Y	X	Y	Y	X	Y	Y	X	Y
10. Week	Y	X		X			X	X	X	Y	Y	Y	Y	Z	Y	X	X	Y
11. Week		X	X	X			X	X	X	Y	Y	Y	Y	Z	Y	Y	X	Y
12. Week			X	X	X	Y	X	X	X	Y	Y	Y	Y	Y	Y	Y	X	Y
13. Week	X	X	X			Y	X	Y	X	Y	Y	Y	X	Y	Y	Y	X	Y
14. Week	X	X	X	X		Y	X	Y	X	Y	Y	Y	Y	Y	Y	Y	X	Y
15. Week	X	X	X			Y	Y	Y	X	X	X	Y	Y	Y	X	Y	Y	Y
16. Week		X		X		Y	Y	Y	X	Y	X	Y	Y	Y	X	Y	Y	Y
17. Week		X	X	X		Y	Y	Y	X	Y	X	X	Y	X	X	Y	Y	X
18. Week	X		X	X			Y	X	X	Y	X	Y	Y	Y	X	X	Y	Y
19. Week			X	X			X	X	Y	Y	X	Y	Y	Y	Y	Z	X	Y
20. Week				X			X	X	Y	X	Y	Y	X	Y	Y	Z	Z	Y
21. Week			X				X	X	Y	X	Y	Y	Z	Y	Y	X	Z	Y
22. Week		X	X	X	X		X	X	Y	X	Y	Y	Z	Y	Y	Y	X	X
23. Week	X	X	X				X	X	Y	X	Y	Y	X	Y	Y	Y	X	Y
24. Week	X	X	X	X			X	X	Y	X	Y	Y	Y	Y	Y	Y	X	Y
25. Week	X	Y		X			X	X	Y	X	Y	Y	Y	Y	Y	Y	X	Y
26. Week	Y	Y	X	Y			X	X	Y	X	Y	Y	Y	Y	Y	Y	X	Y
27. Week	Y	Y		Y			X	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
28. Week	Y	Y	X	Y			Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	Y
29. Week	Y	Y	X	Y			Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	Y
30. Week	Y	Y	Y	Y			Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	Y
31. Week	Y	Y	Y	X			Y	Y	Y	Y	X	Y	Y	Y	Y	Y	Y	Y
32. Week	Y	Y	Y				Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y
33. Week	Y	Y	Y	X			Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y
34. Week	Y	Y	Y				Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y
35. Week	Y	Y		X			Y	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y
36. Week	Y	Y	X				Z	Y	Y	X	Y	X	Y	Y	Y	Y	Y	Y
37. Week	Y	Y					Z	Y	Y	Z	X	X	Y	Y	Y	Y	Y	Y
38. Week	Y	Y	X	X			Y	Y	X	Z	X	Z	X	Y	Y	Y	Y	Y
39. Week	Y	Y	X	X			Y	Y	X	X	Y	Z	Y	Y	Y	Y	X	X
40. Week			X	X			Y	Y	Y	X	Y	X	Y	X	Y	Y	Y	Z
41. Week	X					X	Y	Y	Y	X	Y	X	Y	X	Y	Y	Y	Z
42. Week			X	X		X	X	X	Y	X	Y	X	Y	Y	Z	X	Y	X

Table 5. Optimistic and pessimistic scenarios based the solution results of the model (Cont')

Weeks	Current situation in 2018						Optimistic scenario result						Pessimistic scenario result					
	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i5	i6
43. Week		X	X	X		X	X	X	Y	X	Y	X	X	Y	Z	X	Y	X
44. Week		X	X			X	X	X	Y	X	Y	X	X	Y	X	X	X	X
45. Week		X		X	X	X	X	X	Y	X	Y	X	X	Y	X	X	X	X
46. Week		X	X	X	X	X	X	X	X	X	X	X	X	Y	X	X	X	X
47. Week	X	X	X	X	X	X	X	X	X	X	X	X	X	Y	X	X	Y	X
48. Week	X	X	X	X		X	X	X	X	X	X	X	X	Y	X	X	Y	X
49. Week	X	X	X			X	X	X	X	X	X	X	X	X	X	X	Y	X
50. Week	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Y	X
51. Week	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Y	X
52. Week	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	Y	X

The i2 and i3 vessels were assigned by the business for its operations for a total of 26 and 21 weeks, respectively, whereas the i5 and i6 vessels were assigned by the business for its operations for a total of 23 and 21 weeks, respectively. During the last seven weeks of the year, when transportation was particularly heavy, all vessels were assigned by the business for its operations. When the present condition in 2018 and the total profits of the optimistic scenario were compared, a profit rise of 78.27% emerged.

The second scenario produced in the study was defined as the pessimistic scenario in the model. The pessimistic scenario is also based on the data in 2016 when the business transported the fewest vehicles from 2014 to 2018. The aircraft crash in 2016 interrupted Türkiye-Russia ties, and the political crisis had a significant impact on trade between the two states. Table 5 shows the vessel assignments that appeared after the pessimistic scenario was run. After the pessimistic scenario modeling, the total profit was 11,451,743 USD. In the table that was created as a result of the pessimistic scenario, the model i2 vessel was assigned for only 8 weeks for its own operations and chartered the remaining weeks. The i1 vessel, the second-largest vessel of the fleet, and the i5 vessel, one of the smallest vessels of the fleet, were both assigned by the business for its operations for a total of 17 weeks. The model assigned the i3 and i4 vessels of the fleet with the same capacity to the businesses own operations for 16 weeks. The i6 vessel, one of the smallest vessels in the fleet, was assigned to the company's own operations for a total of 14 weeks and saved for the two weeks when the vessel was dispatched to the shipyard. It was deemed appropriate to be chartered by the model for the remaining weeks. Generally, all vessels, with the exception of the i2 vessel, were assigned homogeneously for the business' own operations throughout the year. When the present condition in 2018 and the total profits of the pessimistic scenario were compared, a profit rise of 21.63% was noticed. Despite the pessimistic scenario, the model demonstrated that the present condition might provide a greater profit.

Table 6 shows the output findings for the present condition, pessimistic scenario, and optimistic scenario. For the comparison of the three scenarios, this problem was solved with a laptop with a GLPK integer optimizer v4.65 linear and integer program solver, AMD® Ryzen 5 3500u processor, 8GB memory capacity, and Ubuntu GNU/Linux 20.04 64-bit operating system. The optimistic scenario of 2015, in which the business transported the most vehicles from 2014 to 2018; the pessimistic scenario of 2016, in which the business transported the least vehicles from 2014 to 2018; and the present condition in 2018 were based when determining the scenarios. The GLPK solver was unable to solve the problem without utilizing mixed-integer rounding (MIR) truncation algorithms, and it was not possible to solve the scenarios because the solver was trapped in the memory/time limit. Therefore, enabling the MIR option of the GLPK solver to solve this problem instance makes a significant difference in the computing performance. The resulting objective functions did not develop as expected because the scenarios were based on scenarios, and the optimistic scenario outperformed the present condition, whereas the pessimistic scenario underperformed it.

Another scenario produced was to reduce the number of vessels. Within the framework of the scenario, the i5 and i6 vessels with a capacity of 54 trailers, the least deployed in the business operations, were withdrawn from the fleet in order. Table 7 presents a comparison between the present condition and the outputs of the scenario. The comparison we undertook with MIR made it easier for us to arrive at

Table 6. *Load-based scenario comparison*

		Pessimistic scenario	Current situation	Optimistic scenario
With MIR interruptions	Problem	Pessimistic	Current	Optimistic
	Line	1,553	1,553	1,553
	Column	988 (936 integer, 936 binary)	988 (936 integer, 936 binary)	988 (936 integer, 936 binary)
	Coefficient different from 0	7,016	7,016	7,016
	Problem status at end of run	Integer Optimal	Integer Optimal	Integer Optimal
	Objective function	-187548257 (Max) (11451743 After removing the Slack variable, the max. profit)	-377250550 (Max) (13749450 After removing the Slack variable, the max. profit)	-160215023 (Max) (16784977 After removing the Slack variable, the max. profit)
	Time used	213.3 sec.	17063.2 sec.	67.0 sec.
	Memory used	23.0 Mb	499.1 Mb	11.0 Mb
MIR: Mixed-integer rounding				

Table 7. *Vessel-based scenario comparison*

		Current situation	i5 vessel is sold	i6 vessel is sold
With MIR interruptions	Problem	Current situation	I5 vessel is sold	I6 vessel is sold
	Line	1,553	1,303	1,303
	Column	988 (936 integer, 936 binary)	832 (780 integer, 780 binary)	832 (780 integer, 780 binary)
	Coefficient different from 0	7,016	5,864	5,864
	Problem status at the end of the run	Integer optimal	Integer optimal	Integer optimal
	Objective function	-377250550 (Max) (13749450 Slack After removing the Slack variable, the max. profit)	-530868119 (Max) (13131881 After removing the Slack variable, the max. profit)	-530832567 (Max) (13167433 After removing the Slack variable, the max. profit)
	Time used	17063.2 sec.	864.1 sec.	957.2 sec.
	Memory used	499.1 Mb	66.1 Mb	83.3 Mb
MIR: Mixed-integer rounding				

our conclusion. The model output compared two i5 and i6 vessels, which were operated at least in the business' operations, by removing out of the fleet in order. The aim is to find an answer to the question of which vessels will be least affected by downsizing if the company decides to do so. Although everything is the same, i.e., sister (sister) vessels, the differences in the daily charter prices and monthly average incomes have caused us to attain different objective functions.

The model was run again for the remaining five vessels after being withdrawn from the fleet, and the results are presented in Table 8. As a consequence, in contrast to Table 3, some changes took place in the weekly assignments of the i5 and i6 vessels. In the comparison between the i5 and i6 vessels, a change was noticed only in the weeks when they were dispatched to the shipyard. Furthermore, the weeks when the i4 vessel was dispatched to the shipyard have changed, and the i5 vessel was dispatched to the shipyard between the 22nd and 23rd weeks in the scenario when it was withdrawn from the fleet. Meanwhile, the i6 vessel was dispatched to the shipyard in the 4th and 5th weeks when it was removed from the fleet.

Disparities were observed between the present condition modeling and the scenarios in the weekly assignments of the vessels as a consequence of the last scenarios produced. The weeks in which only vessels have to be dispatched to the shipyard are the same in all three cases for the i1, i2, and i3 vessels. Moreover, there is a disparity in the profit to be generated as a result of the i5 and i6 vessels being withdrawn from the fleet in order. If the i5 vessel was withdrawn from the fleet, the maximum profit was calculated to be 13,131,881 USD, and if the i6 vessel was withdrawn from the fleet, the maximum profit was determined to be 13,167,433 USD. The difference was approximately 34,000 USD. When the

Table 8. *Result of the model's ship reduction scenario-based solution*

Weeks	Post-modeling situation in 2018						Disclaimer of the i5 vessel from the fleet					Disclaimer of the i6 vessel from the fleet				
	i1	i2	i3	i4	i5	i6	i1	i2	i3	i4	i6	i1	i2	i3	i4	i5
1. Week	X	Y	X	Y	Y	Y	X	Y	X	Y	Y	X	Y	X	Y	Y
2. Week	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y
3. Week	X	Y	Y	X	X	Y	X	X	Y	X	Y	X	X	Y	X	Y
4. Week	X	X	Y	Z	Y	Y	X	X	Y	Y	Y	X	X	Y	Z	Y
5. Week	X	Y	Y	Z	Y	X	X	Y	Y	Y	X	X	Y	Y	Z	X
6. Week	Y	Y	X	X	Y	Y	X	Y	Y	Y	X	X	Y	Y	Y	X
7. Week	Y	Y	X	X	Y	Y	X	Y	Y	Y	X	X	Y	Y	Y	X
8. Week	Y	Y	X	Y	X	Y	Y	Y	X	Y	X	Y	Y	X	Y	X
9. Week	Y	Y	X	Y	X	Y	Y	Y	X	Y	X	Y	Y	X	Y	X
10. Week	Y	Y	X	Y	X	Y	Y	Y	X	Y	X	Y	Y	X	Y	X
11. Week	Y	Y	X	Y	X	X	Y	Y	X	X	X	Y	Y	X	X	X
12. Week	Y	Y	X	Y	X	X	Y	Y	X	X	X	Y	Y	X	X	X
13. Week	Y	Y	X	X	X	Z	Y	Y	X	X	X	Y	Y	X	X	X
14. Week	X	X	X	Y	Y	Z	X	Y	X	X	X	X	Y	X	X	X
15. Week	X	X	Z	Y	Y	X	Y	X	Z	X	X	Y	X	Z	X	X
16. Week	Y	X	Z	Y	Y	X	Y	X	Z	Y	X	Y	X	Z	Y	X
17. Week	Y	X	X	Y	Y	X	Y	X	X	Y	X	Y	X	X	Y	X
18. Week	Y	X	X	Y	X	Y	Y	X	X	Y	X	Y	X	X	Y	X
19. Week	Y	X	Y	Y	X	Y	Y	X	Y	Y	X	Y	X	Y	Y	X
20. Week	Y	Z	Y	Y	X	Y	Y	Z	Y	Y	X	Y	Z	Y	Y	X
21. Week	Y	Z	Y	Y	X	Y	Y	Z	Y	Y	Z	Y	Z	Y	Y	X
22. Week	X	X	Y	Y	Y	Y	X	X	Y	Z	Z	X	X	Y	Y	Z
23. Week	X	X	Y	Y	Y	X	X	X	Y	Z	X	X	X	Y	X	Z
24. Week	X	X	Y	X	Y	X	X	X	Y	X	X	X	X	Y	X	X
25. Week	X	Y	Y	X	Y	Y	X	Y	Y	X	Y	X	Y	Y	X	Y
26. Week	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y
27. Week	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
28. Week	Y	Y	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y
29. Week	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y	X
30. Week	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
31. Week	Y	Y	Y	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y
32. Week	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
33. Week	Y	Y	Y	Y	X	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y
34. Week	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
35. Week	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y	X
36. Week	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y	X
37. Week	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
38. Week	Y	Y	X	Y	X	Y	X	Y	X	Y	Y	X	Y	X	Y	Y
39. Week	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y
40. Week	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y
41. Week	X	Y	Y	Y	Y	Y	X	Y	Y	Y	Y	X	Y	Y	Y	Y

Table 8. *Result of the model's ship reduction scenario-based solution (Cont')*

Weeks	Post-modeling situation in 2018						Disclaimer of the i5 vessel from the fleet					Disclaimer of the i6 vessel from the fleet				
42. Week	X	Y	Y	X	Y	X	X	Y	Y	X	X	X	Y	Y	X	X
43. Week	Z	Y	X	X	Y	X	Z	Y	X	X	X	Z	Y	X	X	X
44. Week	Z	Y	X	X	Y	X	Z	Y	X	X	X	Z	Y	X	X	X
45. Week	X	Y	X	X	Y	X	X	Y	X	X	X	X	Y	X	X	X
46. Week	X	Y	X	X	X	X	X	X	X	X	X	X	X	X	X	X
47. Week	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
48. Week	X	X	X	X	Z	X	X	X	X	X	X	X	X	X	X	X
49. Week	X	X	X	X	Z	Y	X	X	X	X	X	X	X	X	X	X
50. Week	X	X	X	X	X	Y	X	X	X	X	X	X	X	X	X	X
51. Week	X	X	X	X	X	Y	X	X	X	X	X	X	X	X	X	X
52. Week	X	X	X	X	X	Y	X	X	X	X	X	X	X	X	X	X

scenarios were compared to the model's baseline output, an average profit reduction of 4.3% was observed.

4. Conclusion

Fleet planning is vitally important for Ro-Ro transportation businesses. It does not merely support the operation, but it also aids businesses in determining the levels at which they should get into the charter market. Fleet planning has many aspects other than operational costs and revenues, considering that non-operational activities, such as maintenance and repairing expenditures that are directly part of the overall costs, should be considered a part of the fleet planning process.

In this study, a ship management firm which operates a Ro-Ro transportation business in the Black Sea Region was examined, and a profit maximization natured idle capacity penalizing multi-objective function was identified as the objective function of the fleet planning problem instance. Considering the revenues generated and expenditures incurred from "in-house" and chartering operations, most of the parameters of the mathematical model that would give the fleet plan were derived from respective sources. Six Ro-Ro vessels that operate on the Samsun-Russia line of this maritime business were included in the scope of the research. Finally, the optimal fleet plan consisting of vessel assignment outcomes were accomplished. When the model was run on real-world data, the optimum plan utilizing the vessels was at an optimum level, thus ensuring that profit maximization under the model's constraints has been achieved. Accordingly, the findings support the expected outcomes concerning assignment timings of the fleet. In other words, except the times of the year when the domestic transportation load is high, the model assures resorting to chartering vessels in the fleet and never allows vessels to stay idle within the planning horizon, thus generating more income for the business. The applicability of the model has also been put forward by evaluating optimistic, pessimistic, and vessel landing scenarios along with the current setting.

Although the model was specifically developed for the fleet of a vessel operating business that engages in Ro-Ro transportation in the Black Sea Region, the model can be practically extended and scaled up for many instances in the maritime sector, such as businesses with different fleet sizes and characteristics, especially in the field of regular line transportation. The geographical and business distinctions would not affect the validity or applicability of the model, even if it might be more suitable for various settings having a diversified portfolio that would encourage enhancing the adaptability. The model may be improved by adding additional parameters and constraints based on a variety of real-life scenarios and data available from vessel operating businesses.

On another note, during the research conducted for this study, we have observed that even basic mathematical planning notion is still missing within the industry. The reason behind this unawareness for utilizing mathematical planning for getting better operational outcomes might have roots in many different places, which have been held out of the scope of this paper and might be considered a local problem. However, we believe that there is a lot of room for improving the operating performances of Turkish maritime businesses by employing mathematical planning techniques at any level within many problem domains starting with fleet planning.

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