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EFFICIENCY OF TRAMP FLEET OPERATING UNDER THE CONTRACTS OF AFFREIGHTMENT

Summary. The paper considers the vessels operating on carriages of bulk cargoes to get the maximum profit for the shipowner as his main goal. The items in search are the long-term contracts of affreightment with some clauses indicated as indeterminate values, that can be described using a range of values. It leads to a range of voyage indicators. The vessels' deployment for getting the maximum profit depends on the market situation that is to say possible changes in vessels' time-charter rates and freight rates. This paper presents the mathematical model, based on the fleet and volumes of carriages under a set of contracts of affreightment during the due time. It includes the necessity for the commitment fulfilment by owned and time-chartered vessels and takes into account possible changes in freight

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rates for cargoes carriages. The presented numerical example demonstrates the opportunity for practical implementation of the model.

Keywords: tramp shipping, contracts of affreightment, vessels' operating, vessels deployment, bulk-carrier vessel

1. INTRODUCTION

Nowadays, up to 90% of world trading deals are served by maritime transport [1] which remains the most efficient, and on some trading routes, the only possible transporting way for adjusting the foreign trading links between countries. The bulk cargoes named grain, ore, coal, fertilizers etc. reach up to 92% of the world’s trade and traditionally, their transportation is supported by tramp shipping. So, the carriage of cargo to fulfill a chartering deal should be concluded between the cargo owner and carrier. From the time duration such contracts can be divided into single deals (voyage charter party) and long-term ones (consecutive voyages and contracts of affreightment). The main difference between them (probably it is one of the points stipulating the duration of the contract) is the amount of cargo. Some important features’ consequence of this point, such as the number of voyages to be fulfilled and the number of vessels to be engaged. For shipowners and vessels' operators (under certain market conjecture), long-term contracts can be rather attractive with the guarantees they provide, that is to say rather large volume of transporting work and strong fleet engagement, respectively. So, in a sense they guarantee the same income for shipowners/operators. The main goal of their business is the efficiency of the fleet operating. Taking in mind this concept regarding the contracts of affreightment the background for reaching this goal is deploying the vessels under the carriages of cargoes stipulated in the named deals. The classical definition of such contract gives such a possibility as far as for voyage fulfillment is concerned, where it is allowed to use vessels of different sizes that have been previously settled with cargo owners.

1. LITERATURE REVIEW AND PROBLEM STATEMENT

The contracts of affreightment are one of the types of contracts in tramp shipping where parties (named shipowner and charterer) make a deal for carriage of a specified amount of cargo (usually rather large and for some reason impossible to be transported by one vessel and one voyage) between loading and discharging ports under one contract during certain voyages by vessels of different sizes. Being widely used in tramp shipping and as a contract of carriage of cargo primarily a lot of publications reveal the general concept with the detailed terms of the deal that show the rights and obligations of the parties [2-6]. Obviously, the contracts of affreightment are long-term deals, since they oblige the shipowner to carry the cargo during several voyages. So, the main point for him is to arrange the vessels' operating on carriages under the contract to fulfill the contract commitments on one side and to get the profit from vessels' operating from other.

Considering the duration of the contract, the mentioned problem can be discussed as long-term vessels work. The point is that the task to be solved unfolds in tramp shipping with its specific differences from liner one where the problem of the planning of the vessels work is to be searched considering its one main particulars. The modelling and optimization of vessels' operation and ensuring efficiency in liner shipping is probably the problem of the creation of a network [7] and a lot of publications solve the relevant problems both in general [8-11] and in particular aspects [12-17]. The planning of tramp vessels' operations presents optimization models and methods. To ensure their commercial viability. [18], for instance, they use a Monte-Carlo simulation for creation the decision support system series of short-term voyages in tramp shipping. The flexibility of the proposed decisions lets us use them for a wide range of strategic planning problems, which are identified by the authors as fleet size and mix problems and the analysis of long-term contracts as such, whether they are accepted or rejected. The tactical planning problem for bulk shipping was searched in [19] and allows us to determine the number of vessels and the respective charter duration. The time period under consideration is from six months to three years, with the dividing time unit being six months. [20] searched the maritime fleet deployment problem with voyage separation requirements from the position of the shipowner who operates the fleet on the given number of voyages under already concluded contracts to fulfill the commitments to carry cargoes at the set trade routes (that is to say, long-term contracts) and also tries to get the profit by chartering out the vessels on short-terms charter-parties. So, the problem is based on the situation where the vessels capabilities in operation are rather enough to carry the cargoes under the long-term contracts and are free to be chartered out for a short-term contract. The model presented in [21] is a mixed-integrated one, which among other results, can be used for the selection of long-term and spot contracts in tramp shipping and probably helps to determine their best combination for a set of contracts. The obtained results ensure the decision of the problems of fleet strategic planning – both buying or selling the vessels, chartering them in or out, and that is why it is in some respect a base to develop the program of fleet renewal. The main task of tramp vessel operating is maximizing profit and considering the market’s strong impact, the problem seems to be a different kind of challenge compared with liner shipping. [22] focuses on tramp shipping as the mode that is influenced by factors of stochastic nature (the uncertainty market in particular) and proposes a model for maximizing the profit of all the voyages considering the period in search with the heuristic method for its processing. According to the mentioned publications, the owned fleet of the shipping company is included in the profit (probably – expenses) calculation. The structure of the fleet in operation may include not only owned but also time-chartered vessels, and just to that fleet structure efficient long-term planning is dedicated this paper.

The objective of this paper is to formalize through the mathematical (optimizing) model the efficient fleet (both owned and time-charter vessels in operating) deployment under the contracts of affreightment considering the existent possibility of their chartering-out for carriages of cargoes at the local freight market under spot charter parties.

2. THE ESSENCE OF THE MATHEMATICAL OPTIMIZATION MODEL

Suppose the fleet of a shipping company includes vessels v, and each size counts the $\mathrm{M}_v, v = \overline{1, V}$ ships. The main vessels' details of a certain size $v = \overline{1, V}$ are:

r_v^n– daily fixed costs for vessels owned by the company (crew, maintenance, repair, machinery P&I insurance etc.);

V_v^e – operating speed;

D_v– loading capacity;

f_v^{TC}– daily time-charter rate for vessels operated by the company as a time-charter operator under a considered period of time;

${f'}_v^{TC}$– daily time charter rate for vessels that need to be chartered for one or more voyages to fulfill the commitment in situations where the own fleet is engaged in the carriage of other goods on the free freight market.

For voyages to be carried out, the most important for shipowner terms of each are the cargo volumes and loading/discharging ports. Generally, they can be presented as indeterminate values, most of which can be described using a range of values. In particular, the cargo volumes indicated in the contract of affreightment (COA) $k = \overline{1,K}$ is a range of figures from min to max $[Q_k^{min}; Q_k^{max}]$ as shown at Figure 1. As ports of loading and discharging can be indicated as those that are on some range, the voyage distance is also a range of figures $[L_k^{min}; L_k^{max}]$ limited by the distances from the most outlying loading port on the range to the most outlying discharging port on the range.

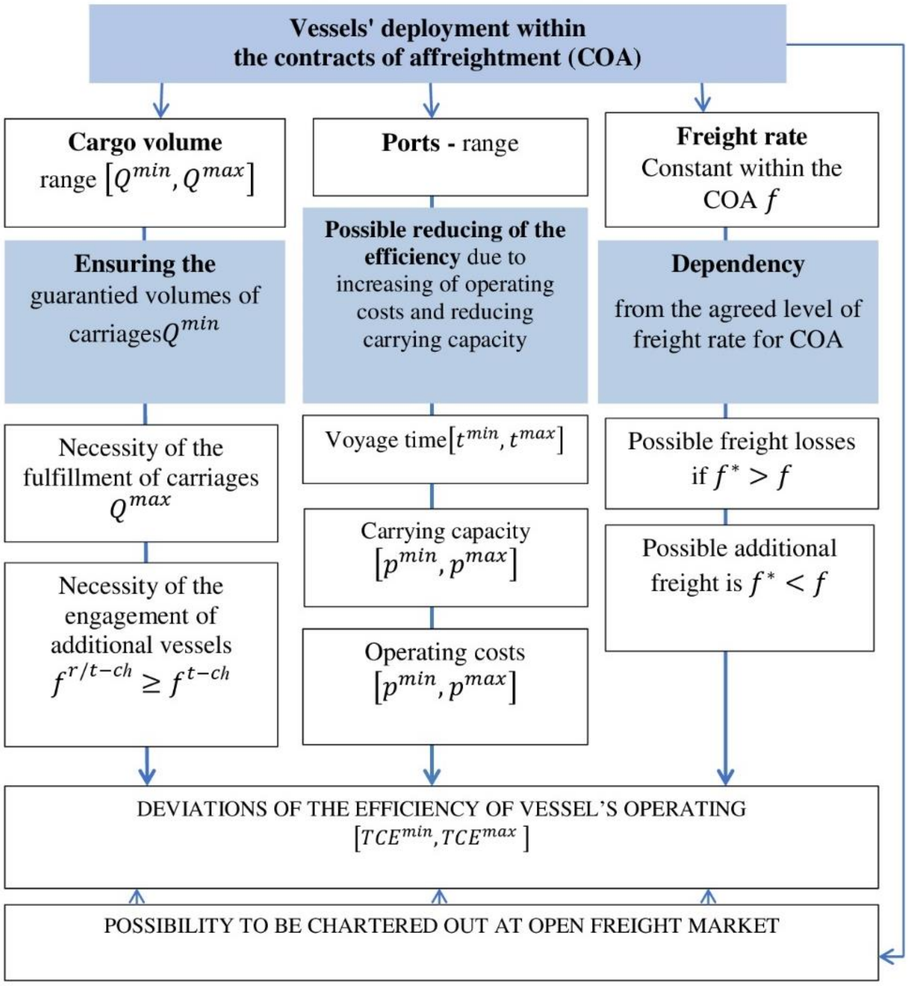

Fig. 1. Features of ship's operation within several delivery systems on a long-term basis

That is to say that the vessels carrying capacity (due to the differences in voyage time) also will vary within a certain range, the limit points of which can be indicated as:

$$p_{vk}^{min} = \frac{T^e}{t_{vk}^{max}} \cdot q_{vk},\ p_{vk}^{max} = \frac{T^e}{t_{vk}^{min}} \cdot q_{vk},\ v = \overline{1,V},\ k = \overline{1,K}, \quad (1)$$

where q_{vk}– vessels loading according to D_v and cargo lot q_k

So, the vessels' $v = \overline{1,V}$ engaged on the long-term freight contract (COA) $k = \overline{1,K}$ is characterized by:

$\left[r_{vk}^{min}; r_{vk}^{max}\right]$ – the range of values of operating costs during the work of the vessel $v$on COA k

$\left[\mathrm{p}_{vk}^{min}; \mathrm{p}_{vk}^{max}\right]$ – the range of the values of vessels v carrying capacity during the work on COA k.

While the vessels in consideration also can be chartered out for carriages of other cargoes at the freight market beyond the concluded COA, let's use the average efficiency of the vessels operating in the region – time-charter equivalent with the range of volumes $\left[\overline{TCE_v^{min}}\ ;\ \overline{TCE_v^{max}}\right]$.

Already concluded COA guarantees to the shipowner a cargo to be carried with a volume of at least Q_k^{min}, $k = \overline{1,K}$. So, the exceeding of this volume $Q_k^{max} - Q_k^{min}$ provides additional work on carriages and some income appropriately.

At the same time, if the shipping company's fleet is involved in other voyages, and the commitment under the COA must be fulfilled, the shipowner must engage the vessels on time-charter for their voyages at the rate ${f'}_v^{TC}$. And mostly:

$$ {f'}_v^{TC} \geq f_v^{TC} \geq r_v^n,\ v = \overline{1,V} \tag{2} $$

i.e., hire payment costs in such a situation, which is a consequence of necessity (urgent replenishment of the company's capabilities for a short time), are significantly higher than fixed costs for own vessels r_v^n or time-charter rates for vessels f_v^{TC}.

Thus, the risk of a possible increase in costs due to the need to urgently increase the carrier's capabilities is defined as:

$$ \Delta R_a \sum_{k=1}^{K} \sum_{v \in \Omega_k} \left(\frac{Q_k^{max} - Q_k^{min}}{\overline{p_{vk}}} \right) \cdot \left({f'}_v^{TC} - f_v^{TC} \right) \tag{3} $$

where $\overline{p_{vk}} = p_{vk}^{min} + \frac{\left(p_{vk}^{max} - p_{vk}^{min}\right)}{2}$ – average carrying capacity of vessels v during their work on COA k;

Ω_k– size of the vessel group under the COA k;

$\frac{Q_k^{max} - Q_k^{min}}{\overline{p_{vk}}}$ in (3) is the additional time for the use of vessels v for each COA k. Respectively, ${f'}_v^{TC} - f_v^{TC}$ is the additional expense, which exceed time-charter rates for the long term.

Obviously, the freight rate f_k is fixed in the contract of affreightment. But the market situation is dynamic and can change rather quickly, so the shipowner risks that the current freight rate f_k' for the carriages on the contract of affreightment can be both higher and lower than the set levelf_k. For sure, for the shipowner it is the potential cost, which can be calculated as:

$$ \Delta R_f = \sum_{k=1}^{K} \left(\overline{f_k} - f_k \right) \cdot \overline{Q_k}, \tag{4} $$

where $\overline{f_k}$ – average freight rate on the direction of carriage under the COA k, and $\overline{f_k}$> f_k.
At the same time, in the case of $\overline{f_k}$ < f_k in (4) can estimate by module the additional freight.
So, the research problem is to organize the vessels operating under the COAS (both owned and time-chartered) operating on the COAs for a long-term period to get the maximum profit.

Let's take that $0 \leq x_{vk} \leq 1,\ v = \overline{1,V},\ k = \overline{1,K}$ - the share of the operating time of the vessels $v$on COA k. Not each vessel in search can carry some voyages, so some x_{vk} are transformed from variables into exogenous parameters and assumed to be equal to 0. This will make it possible to exclude from the further optimization procedure inadmissible options for deploying the vessels under COA.

Let's assume that from the number of vessels of each size operated by the company (they were indicated before as $\mathrm{M}_v, v = \overline{1,V}$), $\mathrm{M}'_v, v = \overline{1,V}$ are the vessels time-chartered by the shipowner for the period under consideration, before the COA concluded. The hire payment for these vessels is f_v^{TC}. At the same time, the company can increase the capabilities by renting the vessels, if the company considers it appropriate and economically justified. Let x_v^{TC} be a number of the vessels v, which should be time-chartered, and $0 \leq x_{vk}^{TC} \leq 1, v = \overline{1,V}, k = \overline{1,K}$ – the part of operating time of the vessel's engagement under the contract $v$on COA k.

Similar to the above considerations, if the vessel x_v^{TC} cannot carry the cargo under the COA k, so x_v^{TC} can be assumed to be equal to 0 and are treated as the exogenous parameters. The time period under consideration – T.

It should be emphasized that most of the indicators used in the model are ranged, or, in other words, are uncertain values of the interval type. The model can take this specificity into account, which means using appropriate optimization methods. Currently, they do not always provide consistent results, and their reliability is largely determined by the specificity of the source data.

Since from the perspective of planning, it is necessary to determine fundamentally the deploying of vessels for voyages under COAs, which can currently be updated and detailed in the future, we will use the average values of the intervals in the model, $Q_k = Q_k^{min} - \frac{Q_k^{max} - Q_k^{min}}{2}$ for instance. At the same time, the spread of such intervals will be taken into account when assessing potential commercial risks associated with the fulfillment of the commitments under the contracts concluded.

The ccriterion of optimality is maximizing profit from operation of the vessels, both owned and time-chartered. To formalize the specified criterion, it is necessary to obtain an expression for the components of profit from vessels operating.

The total freight (income) for all (owned and time-chartered) vessels is defined as:

$$F = \sum_{k=1}^{K} f_k \sum_{v=1}^{V} p_{vk}(x_{vk} + x_{vk}^{TC}) \tag{5}$$

Running costs (for all the vessels) and fixed (for the owned ones):

$$R = \sum_{k=1}^{K} T \sum_{v=1}^{V} r_{vk} \cdot \left(x_{vk} + x_{xk}^{\mathrm{TC}}\right) + \sum_{v=1}^{V} T \cdot r_v^{\text{п}} \cdot (M_v - M'_v), \tag{6}$$

where $\sum_{v=1}^{V} T \cdot r_v^{\text{п}} \cdot (M_v - M'_v)$ – fixed costs only for the company's owned vessels, which are independent of the deployment of the vessels under the COAs;
$\sum_{k=1}^{K} T \sum_{v=1}^{V} r_{vk} \cdot \left(x_{vk} + x_{xk}^{\mathrm{TC}}\right)$ – running costs that depend on the deployment of vessels under the COAs.

Additionally, for running and fixed costs for already time-chartered vessels and vessels that are planned to be time-chartered to fulfill the commitment of the necessary volumes of transportation, the hire payments for time-charter can be presented as:

$$R^{TC} = \sum_{v=1}^{V} T \cdot f_v^{TC} \cdot (x_v^{TC} + M'_v). \tag{7}$$

If, as achieved above, vessels can operate on the open freight market with average daily efficiency $\overline{TCE_v}$during the time free from commitments under COAs, additional profit from operating (taking into account (X) fixed costs on all vessels is calculated) as follows:

$$P_a = \sum_{v=1}^{V} \overline{\mathrm{TCE}_v} \cdot T \cdot (1 - \sum_{k=1}^{K}(x_{vk} + x_{vk}^{TC})), \tag{8}$$

where $(1 - \sum_{k=1}^{K}(x_{vk} + x_{vk}^{TC}))$ – the share of the operating time of vessels v on the freight market.

Thus, the optimization modes can be formulated as follows:

$$[\sum_{k=1}^{K} f_k \sum_{v=1}^{V} p_{vk}\left(x_{vk} + x_{vk}^{\mathrm{TC}}\right) + \sum_{v=1}^{V} \overline{\mathrm{TCE}_v} \cdot T \cdot \left(1 - \sum_{k=1}^{K}\left(x_{vk} + x_{vk}^{\mathrm{TC}}\right)\right) - \sum_{k=1}^{K} T \cdot \sum_{v=1}^{V} r_{vk} \cdot \left(x_{vk} + x_{vk}^{\mathrm{TC}}\right) - \sum_{k=1}^{K} T \cdot \sum_{v=1}^{V} r_{vk} \cdot \left(x_{vk} + x_{vk}^{\mathrm{TC}}\right) - \sum_{v=1}^{V} T \cdot r_v^{\text{п}} \cdot (\mathrm{M}_v - M'_v) - \sum_{v=1}^{V} T \cdot f_v^{\mathrm{TC}}(x_v^{\mathrm{TC}} + M'_v)] \to max \tag{9}$$

subject to constraints:

– by volume of transported cargo under each freight contract:

$$\sum_{v=1}^{V} p_{vk}\left(x_{vk} + x_{vk}^{\mathrm{TC}}\right) \leq Q_k\, ,\, k = \overline{1, K} \tag{10}$$

– by the number of the company's own vessels for each size:

$$\sum_{k=1}^{K} x_{vk} \leq M_v,\, v = \overline{1, V} \tag{11}$$

– by the number of time-chartered vessels, which is mentioned as N_i for each vessel for every group of size:

$$\sum_{k=1}^{K} x_{vk}^{\mathrm{TC}} \leq x_v^{\mathrm{TC}} \leq N_v,\, v = \overline{1, V} \tag{12}$$

– the number of vessels must be an integral and non-negative:

$$x_v^{\mathrm{TC}} \in Z^+ \cup 0,\, v = \overline{1, V} \tag{13}$$

– integer condition and nonnegative variable constraints:

$$x_{vk}, x_{vk}^{\mathrm{TC}} \leq 0,\, v = \overline{1, V}, k = \overline{1, K}. \tag{14}$$

It is also necessary to take into account possible commercial risks in the form of:

$$\Delta R_f = \sum_{k=1}^{K}\left(\overline{f_k} - f_k\right) \cdot \overline{Q_k}, \tag{15}$$

$$\Delta R_a = \sum_{k=1}^{K} \sum_{v \in \Omega_k} \left(\frac{Q_k^{max} - Q_k^{min}}{\overline{p_{vk}}} \right) \cdot \left({f'}_v^{\text{TC}} - f_v^{\text{TC}} \right). \quad (16)$$

For this purpose, based on the results of the deployment of vessels under COAs and the determination of the required number of additional (time-chartered) capabilities - it is proposed to estimate the named values considering the forecasts of the dynamics of freight rates and to adjust the obtained decision.

Since the greatest risk is characterized by possible increase in the freight rate, it is considered appropriate to take such risk into account in (9), for example, as follows:

$$\begin{aligned}
&\left[\sum_{k=1}^{K} f_k \sum_{v=1}^{V} p_{vk} \left(x_{vk} + x_{vk}^{\text{TC}}\right) + \sum_{v=1}^{V} \overline{\text{ТЧЕ}_v} \cdot T \cdot \left(1 - \sum_{k=1}^{K} \left(x_{vk} + x_{vk}^{\text{TC}}\right)\right) - \right. \\
&- \sum_{k=1}^{K} T \cdot \sum_{v=1}^{V} r_{vk} \cdot \left(x_{vk} + x_{vk}^{\text{TC}}\right) - \sum_{v=1}^{V} T \cdot r_v^{\text{п}} \cdot (\text{M}_v - M'_v) - \sum_{v=1}^{V} T \cdot \\
&\left. f_v^{\text{TC}} (x_v^{\text{TC}} + M'_v) - - \sum_{k=1}^{K} \left(\overline{f_k} - f_k\right) \sum_{v=1}^{V} p_{vk} \left(x_{vk} - x_{vk}^{\text{TC}}\right)\right] \to max
\end{aligned} \quad (17)$$

where $\overline{f_k}$ – the possible level of excess of the freight rate on the market at the trading range linked with the one set under the contract f_k with the probability p=0,95 (estimated, for example, according to the forecasts of market development).

3. RESULTS AND DISCUSSION

For a numerical example let us have the vessels with the details indicated in table 1 and COA terms stipulated in table 2.

Tab. 1

Vessels details

Vessels size group	M_v	D_v	f_v^{TC}	r_v^n	$\overline{\text{TCE}_v}$
v =1	2	20000	2500	1800	6500
v =2	3	25000	2600	2000	7000

Note that the initial value of the criterion of optimality - profit from the operating of vessels is 8906 USD (fig. 2), that is, it is the level that corresponds to the profit from chartering the company's tonnage in time charter.

Depending on the ratio of the freight rate $\overline{f_k}$ for a specific COA and the average value of the time charter equivalent $\overline{TCE_v}$, the "priorities" in the deployment of vessels between carriages under the COAs and on the open freight market under the spot charters. Thus, during the experimental research, variation (increase and decrease) of $\overline{TCE_v}$was carried out, which was reflected in the deployment of vessels between COAs.

A formalized description of the objective and constraints in Excel (search for solutions) is presented in Fig. 3.

At the first stage, it was assumed that all COAs should be "covered" by the owned and time-chartered fleet (limitation of 3 units for each standard size of vessels), i.e.:$\sum_{v=1}^{V} p_{vk} \left(x_{vk} + x_{vk}^{TC}\right) = Q_k,\ k = \overline{1, K}$.

Tab. 2

Contract details

COA	Q_k		$\overline{f_k}$	
$k = 1$	180		20	
$k = 2$	200		22	
$k = 3$	280		26	
$k = 4$	350		28	
COA	$v = 1$	$v = 2$	$v = 1$	$v = 2$
	r_{vk}		$\overline{p_{vk}}$	
$k = 1$	1000	1200	80	100
$k = 2$	1200	1300	100	130
$k = 3$	1300	1400	150	190
$k = 4$	900	1000	180	220

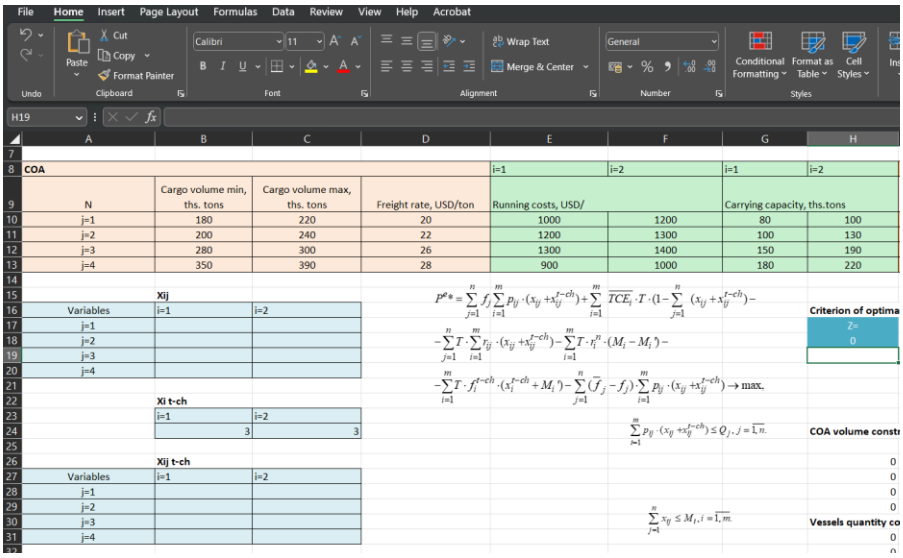

Fig. 2. Input data

Fig. 4 illustrates the solution for such a case. According to the results, it is necessary to time-charter the maximum possible number of vessels (two size groups, consisting of 3 units), of which only a part (3 units) will be used for transportation under the COAs commitments. It is expedient to use other time-chartered vessels, although as owned ones of the first size group for cargo carriages in the region, considering the assigned time-charter equivalent. The value of the objective function Z = 23818 USD.

If the necessity of the full cargo amount (volumes) to be transported changes to $\sum_{v=1}^{V} p_{vk} \left(x_{vk} + x_{vk}^{TC}\right) \le Q_k$.

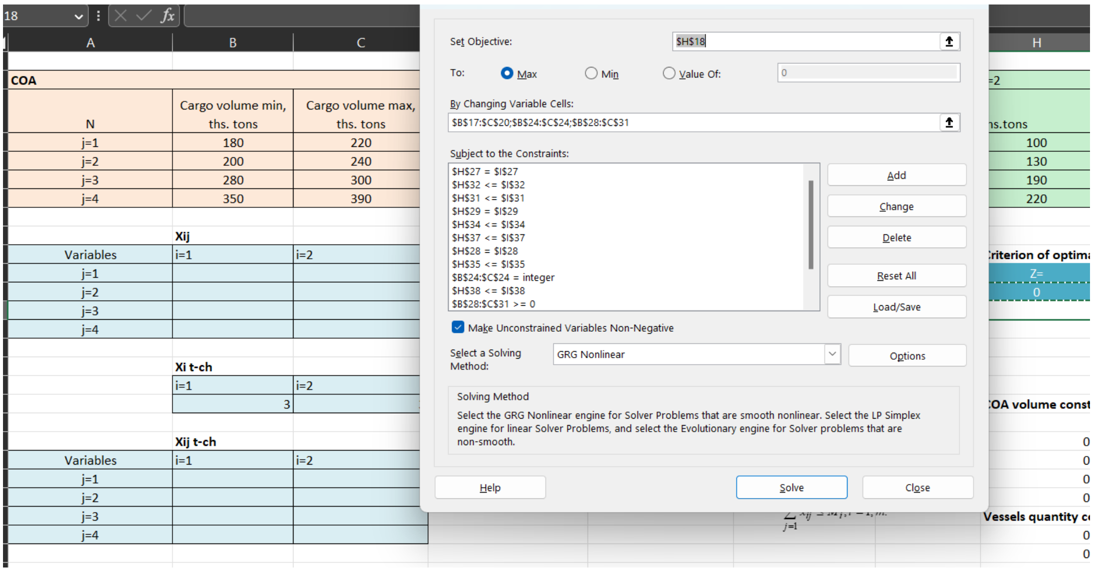

Fig. 3. The objective and the constraints of the model

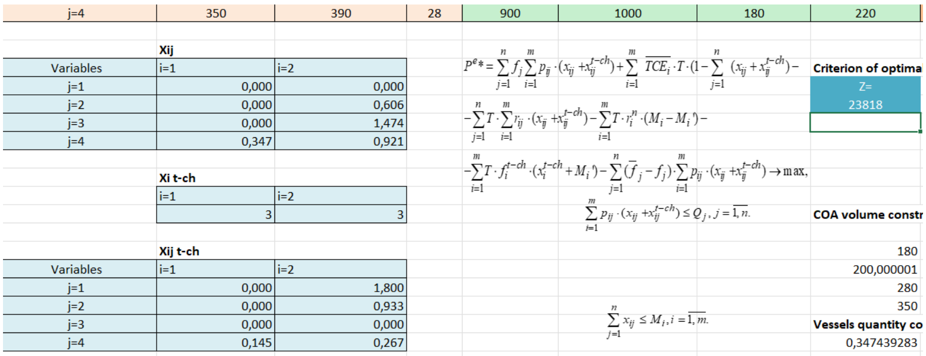

Fig. 4. The optimal vessels deployment

Then vessels deployment will change radically (Fig. 5-6): the operation of vessels of the second size group turns out to be profitable only under 3 and 4 COAs; vessels of the first size group are currently expedient to be used together with chartered vessels at the maximum allowable number of vessels on the open freight market. At the same time, the value of the objective function will be 27,468 USD.

Considering the risk of an increase in freight rates in the objective function, its value is adjusted by the value $-\sum_{k=1}^{4}\left(\overline{f_k}-f_k\right)\sum_{v=1}^{2}\left(x_{vk}+x_{vk}^{TC}\right)$

Let us suppose possible increases in freight rates on the trade routes corresponding with the COAs loading/discharging ports as following: $\overline{f_1}$= 21 USD/MT; $\overline{f_2}$= 22.5 USD/MT; $\overline{f_3}$= 26.5 USD/MT; $\overline{f_4}$= 28 USD/mt (no increase in freight rates is predicted, i.e. f_4= $\overline{f_4}$= 28 USD/MT).

Taking in mind the transportation of all cargo volumes under each COA and the changes in adjustments on the objective function, the solution obtained is presented in fig. 6. It should be noted that the vessels deployment changes slightly, increasing the volume of transported cargo under the COA 4, where there is no risk of an increase in the freight rate. Taking into account the possible risk, the value of the objective function was Z = 23398 USD.

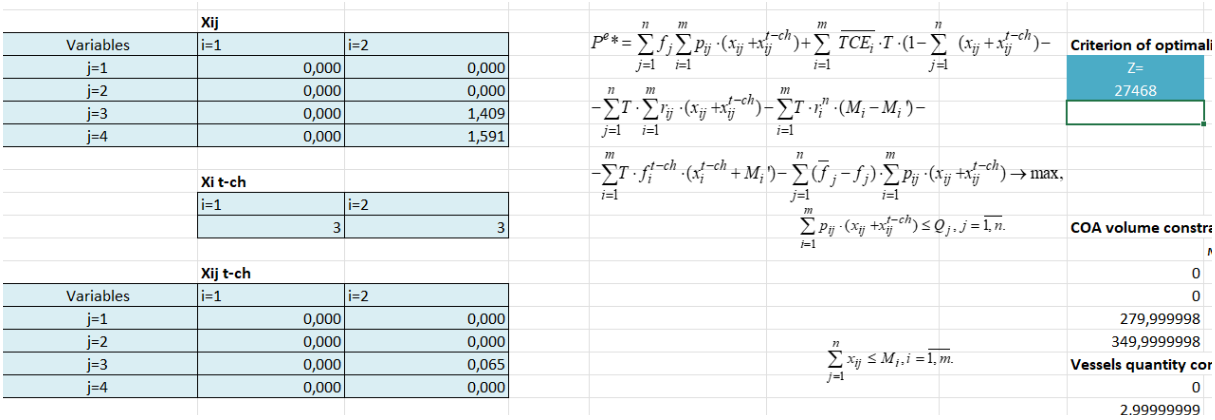

Fig. 5 The objective function value

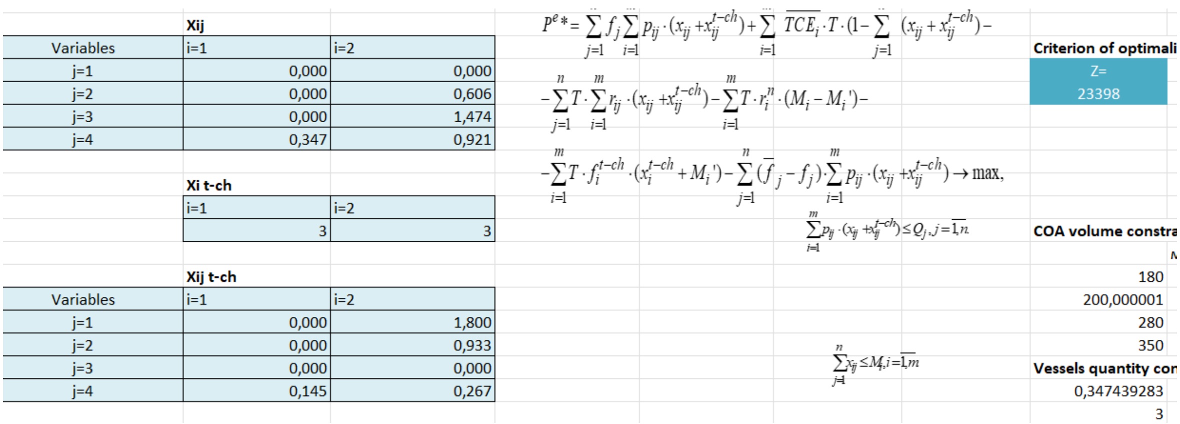

Fig. 6 The vessels deployment considering the changes in freight rates

4. CONCLUSIONS

Experiments with models like the ones presented above allow to assert that the models are reliable (that is, the calculation results correspond to the logic of the choice, changes in the input data are adequately reflected in the changes in the obtained decision) and corresponds to the practice of maritime business. Thus, the model can be used for long-term planning of vessels operating. The possibility of varying the input data (such as, for example, the time-charter equivalent) allows evaluating the efficiency of work under the COAs considering possible changes in the freight market environment. The information obtained in this way is a reference for making decisions on the deployment of vessels (owned and time-chartered) between operating both under long-term contracts and spot market voyages.

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