An optimization model for strategic fleet planning in tramp shipping

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Abstract

Maritime transportation is one of the most capital intensive industries. Fleet planning is vital but challenging to shipowners because the industry is extremely volatile. This paper presents a mixed integer programming optimization model for strategic fleet planning in tramp shipping. The model determines the best mix of long term and spot contracts for a given fleet, finds the optimal fleet size and mix for a set of contracts or a mix of both. The model can be used as a basis for a fleet renewal program, helping to decide when to sell and whether to buy old or new ships. It also takes into consideration the time charter market, recommending when to charter in/out vessels. Another area of application is for users that are only engaged in active vessel trading and not in transportation. A numerical example is given to illustrate how to use the model to evaluate different operations strategies.

Keywords: fleet planning; fleet size and mix; contract analysis; tramp shipping; optimization; mixed integer programming

1. Introduction

Maritime transportation is one of the most capital intensive industries. A ship usually costs millions of US dollars or even more for mega vessels. A ship has a life time of approximately 20-25 years. Strategic fleet planning deals with decisions related to ship acquisition, sale, chartering and scrapping. It is vital for shipowners and has long term implications for the profitability of a shipping business. The strategic fleet planning problem is challenging because freight markets and ship prices are highly volatile due to the cyclical nature of the shipping industry (Stopford 2009). It requires a lot of skill and also luck to choose the right timing for when to order new/second-hand ships, when to charter in/out ships, and when to scrap old ones. To succeed in the long run, it is essential for shipping companies to employ proper tools for strategic fleet planning.

There are three modes of shipping operations: industrial, tramp and liner shipping (Lawrence 1972). The industrial operators own the cargo and try to minimize the cost of transporting the cargo between ports. Tramp shipping can be compared to a taxi service as the ships follow available cargoes. A tramp shipping company often has some long term contracts and takes on optional spot cargoes to maximize profit. Liner shipping operates in accordance to pre-published itineraries and schedules. It is similar to a bus service (Fagerholt et al. 2010).

Extensive research has been conducted for fleet planning problems at tactical and operational levels, for example, routing and scheduling problems as reviewed by several papers (Ronen 1983; Christiansen, Fagerholt, and Ronen 2004; Christiansen et al. 2007; Kjeldsen 2010). However, limited research studies dealt with fleet planning problems at a strategic level. The research of strategic fleet planning was pioneered by Nicholson and Pullen (1971), and Taylor (1982). In the past two decades, most relevant studies were concerned with container liner shipping (Jaramillo and Perakis 1991; Perakis and Jaramillo 1991; Cho and Perakis 1996; Powell and Perkins 1997; Imai and Rivera 2001; Fagerholt, Johnsen, and Lindstad 2009; Meng and Wang 2010, 2011). Relatively less attention was given to strategic fleet planning problems in industrial/tramp shipping (Fagerholt and Lindstad 2000; Xie, Wang, and Chen 2000; Fagerholt et al. 2010; Alvarez et al. 2011).

This research develops an optimization model for strategic fleet planning in tramp shipping. It considers the unique requirement of contract analysis in tramp shipping as shipowners need to analyse the best mix of long term and spot contracts for a given fleet, find the optimal fleet size and mix for a set of contracts or a mix of both. To the best of our knowledge, only the work of Fagerholt, et al. (2010) considered strategic fleet planning together with contract analysis. However, their study covered long term contracts only and did not include spot market. Our optimization model aids the selection of both long term and spot contracts in multiple planning periods and maximizes total profit. It suggests when to buy/sell new or second-hand vessels, and when to charter in/out vessels. It is also flexible enough to help evaluate if it is more profitable to terminate freight operations and be engaged in vessel trading only in a given market condition.

The rest of this paper is organized as follows. Section 2 defines the research problem in details. Section 3 presents the optimization model. Section 4 gives a numerical example. Section 5 presents results and analysis. Section 6 concludes the research.

2. Problem description

In maritime transportation, a contract or charter-party sets out the terms between shipowners and charterers (Stopford 2009). There are several different charter-parties, differencing from each other in the way the risks and costs are divided between shipowners and charterers. The four common charter-parties are voyage charter, contract of affreightment (COA), time charter and bareboat charter. In a voyage charter, a shipowner gets paid a freight rate for every unit of cargo he transports from A to B. The shipowner usually has to pay all costs and bear operational and market risks. In a COA, a shipowner agrees to transport the goods belonging to one or many owners for a fixed price per ton. The charterer's interest lies in getting the cargo from A to B and leaves the shipowner to plan the voyage. In a time charter, a shipowner gets paid a fixed daily or monthly amount by a charterer. The charterer pays for the voyage related costs such as fuel, harbour and canal fees and cargo handling costs. The shipowner pays the operational expenditures (OPEX) and takes the operational risk, i.e. he has to pay if the ship breaks down. In a bareboat charter, the charterer takes over the full control of vessel operations and its expenses.

COA is the most common long-term contract in tramp shipping (Fagerholt et al. 2010). It is a relatively stable income source of shipowners because a COA usually has duration of several years and the freight rate is fixed during the contract period. As mentioned previously, tramp shipping has a unique requirement of contract analysis for strategic fleet planning. Fleet decisions are closely interwoven with the decisions of which contracts to enter into. Their interplay, as illustrated in Figure 1, leads to two different approaches for strategic fleet planning. Either the COAs a shipowner has committed himself to decide the size of the fleet or the fleet size decides the COAs he can enter into. If a shipowner does not have enough capital or is not able to get a loan in order to expand the fleet, he must plan with the existing fleet size as the decisive factor for which COAs he can enter into. On the other hand, if the required capital is available, planning can be conducted based on the availability of COAs in the market. These two types of decisions should be evaluated together in order to arrive at a most profitable solution.

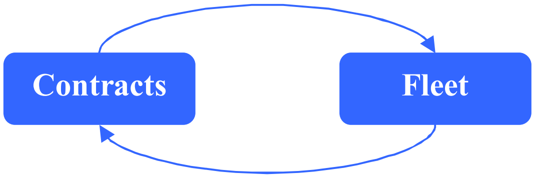
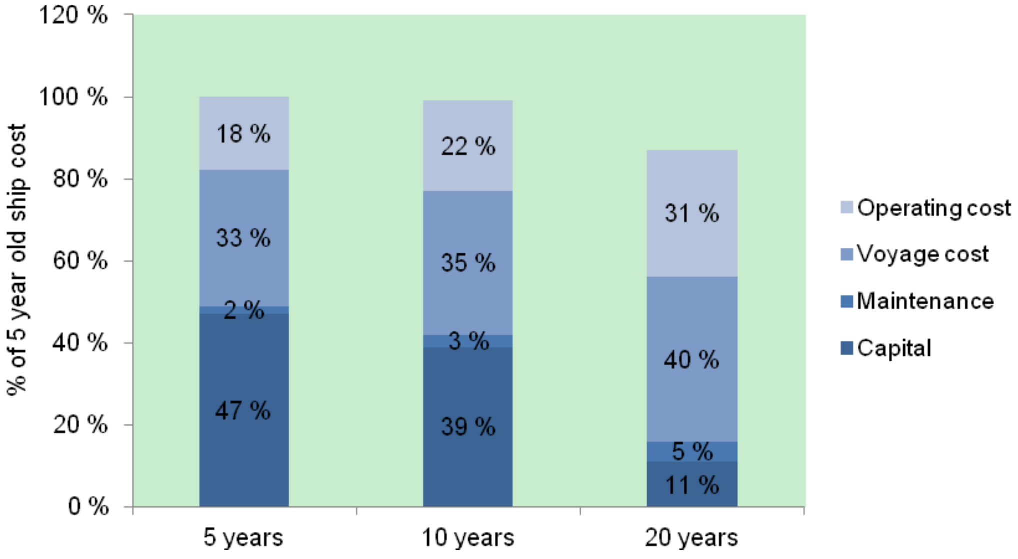


Figure 1. Relation between contracts and fleet

The strategic fleet planning problem in tramp shipping is complicated due to several reasons. First, more often than not a fleet is heterogeneous i.e. consists of several different vessel types/sizes. Cargo capacity, speed and operational cost vary with vessel types/sizes. It is often a challenging task to identify the optimal mix of vessel types/sizes, which is referred to as the fleet size and mix problem (Fagerholt et al. 2010). Note that some routes have size constraints (e.g. the Suez Canal and the Panama Canal) and some vessel types are thus more suitable than others on specific routes. Generally speaking, the optimal fleet mix varies from case to case depending on what kind of COAs a shipowner has committed himself to service.

Second, a shipowner needs to weigh the risk and cost associated with buying/chartering a vessel. A shipowner involved in tramp shipping usually has some long term COAs. He may or may not have spare capacity with its owned fleet to service spot contracts. However, the shipowner can time charter vessels and use them to service part of COAs and then free one or more vessels to service spot cargo, or he can use time-chartered vessels to take on the spot cargo. This will of course depend on the freight rates for servicing spot cargo being higher than the expenditures of using a time charter to service part of COAs. Chartering avoids the risk of buying a ship as ship prices are unpredictable and highly volatile. Buying a ship at a high price will have negative implications for the profitability of a shipping business if the market drops. However, chartering may be more costly over long term (Meng and Wang 2011). A shipowner has to optimize the timing of ship acquisition and/or time chartering.

Third, there are important tradeoffs to evaluate when it comes to buy either a second-hand vessel or a new vessel. The advantages of buying a second-hand vessel is that the vessel is ready to be put into service within a relative short period of time in comparison to a newbuilding that usually takes a couple of years, depending on the complexity of the ship and the yard building it. The disadvantages can be that an older vessel will be less attractive when rates are low, depending on the vessel's age and state. A new vessel can often be more fuel efficient due to newer technology and will thereby also have a lower operating cost. The relationship between cost and age for a Capesize bulk carrier is illustrated in Figure 2. As it is very difficult to guess how the rates will develop over several years, ordering a newbuilding is often a risky decision unless you have a long term contract to service.



Data source: Stopford (2009)

Figure 2. Capesize bulk carrier cost and age

Last but not least, strategic fleet planning is not just about when to acquire more fleet capacity, but also when to reduce or go 'short of tonnage'. This can either be done by selling vessels or scrapping them. Deciding when to scrap or sell vessels is not only dependent on the rates at that given time, but also on the duration of any COAs already engaged in. Deciding to scrap when committed to a COA may prove to be an expensive gamble if you have to use spot charters to cover for the scrapped vessel, for then only to realize that the rates start increasing. This should be taken into consideration if the need for scrapping is not imminent. This leads us back to the option of using time charters if the fleet is not sufficient to service all COAs or to charter out some vessels if one is not able to fully utilize the whole fleet. A shipowner will typically go for as many COAs as possible if he thinks there will be low spot rates and the opposite if he believes spot rates will be high. How much of the fleet capacity that should be covered by COAs and how much that should be open for spot cargoes is consequently an important strategic decision.

This all boils down to the following questions for the strategic fleet planning problem in tramp shipping.

- Which COA contracts and how many spot cargoes to take on?
- When to buy/sell new or old ships and which ship types/sizes?
- When to charter in/out ships and which ship types/sizes?

Note that it is not very often that one has to determine a whole new fleet. Often adjustments to an existing fleet are sufficient. Needs for adjustment can arise because vessels have to be sold or scrapped or because new COAs have been taken on. To simplify the problem, we consider scrapping a ship the same as selling a ship because what matters to the shipowner is the salvage value in both cases.

3. An optimization model

3.1. Model assumptions and notations

This section develops an optimization model to answer the questions presented above for the strategic fleet planning problem in tramp shipping. The model assumes that transport demand is sufficiently large on each route. Each vessel takes full loads and does not mix cargoes from different contracts (Xie, Wang, and Chen 2000), which is a standard practise in the coal/iron ore trade. The arrangement of backhaul cargoes, if any, is predefined in the routes. All decisions are made at the start of each planning period and time charter is only possible for one period at a time. All costs and profits are in constant dollars.

Before the presentation of model formulation, we define notations as listed in Tables 1, 2 and 3.

Table 1. Sets and indices

Set	Index	Description
T	t	Time periods, $T = \{0,1,2,...,T^{MAX}\}$, where period 0 corresponds to the time period when the planning is done and T^{MAX} is the number of time periods considered.
N^{COA}	i	Available contracts of affreightment
N^{SPOT}	i	Available spot cargo contracts
V	v	Available vessel types. Each type v also includes information of in which period a vessel was acquired, t_v, and its maximum lifetime, T_v^{LT}. Two vessels acquired in different years, but similar in all other ways will then have different indices.
T_v	t_v	Time periods for vessel type v, $T_v = \{t_v,... \min\{t_v + T_v^{LT}, T^{MAX}\}\}$, where T_v^{LT} is the number of time periods that corresponds to the vessel's

		lifetime.
R_v	r	Available sailing routes for vessel type v

Table 2. Parameters

Parameter	Description	Unit
T_{vr}	Time for vessel type v to complete one roundtrip on route r	Days
T_{vt}^{TOT}	Total available time for vessel type v in period t	Days
T_v^{LT}	Maximum lifetime of vessel type v	Periods
Q_{it}	Demand of COA i in period t	Ton
Q_v	Capacity of vessel type v	Ton
S_{it}	Upper limit of demand for spot contract i in period t	Ton
A_{ivr}	Binary parameter equal to 1 if it is feasible to assign contract i to vessel type v on route r	-
R_i^{COA}	Revenue of servicing COA i	USD
R_{it}^{SPOT}	Revenue per unit transported on spot trade i in period t	USD/ton
R_{vt}^{S}	Revenue of selling vessel type v in period t	USD
R_{vt}^{TC}	Revenue of time chartering out vessel type v in period t	USD
C_{vr}	Voyage cost of sailing route r with vessel type v	USD
C_{vt}^{I}	Cost of buying vessel type v in period t	USD
C_{vt}^{N}	Cost of ordering newbuilding of type v in period t	USD
C_{vt}^{TC}	Cost of time chartering vessel type v in period t	USD
C_{vt}^{O}	OPEX for a vessel of type v in period t	USD
C_{vt}^{C}	Capital expenditures (CAPEX) for a vessel of type v in period t	USD

Table 3. Decision variables

Decision variable	Description
y_{vt}^{TOT}	Total number of vessels of type v operated in period t
y_{vt}^{OWN}	Number of vessels of type v owned in period t
y_{vt}^{TCin}	Number of vessels of type v that are time chartered in period t
y_{vt}^{TCout}	Number of vessels of type v that are time chartered out in period t
y_{vt}^{I}	Number of vessels of type v acquired in period t
y_{vt}^{N}	Number of newbuildings of type v ordered in period t
y_{vt}^{S}	Number of vessels of type v that are sold in period t
δ_i	A binary variable that is 1 if COA i is selected and 0 otherwise

x_{vrt}	Number of roundtrips made by vessel type v on route r in period t
z_{it}	Quantity transported on spot trade i in period t

3.2. Model formulation

- ***Objective Function***

$$\begin{aligned}
\max z = & \sum_{i \in N^{COA}} R_i^{COA} \delta_i + \sum_{i \in N^{SPOT}} \sum_{t \in T} R_{it}^{SPOT} z_{it} \\
& + \sum_{v \in V} \sum_{t \in T} R_{vt}^{TC} y_{vt}^{TCout} + \sum_{v \in V} \sum_{t \in T} R_{vt}^{S} y_{vt}^{S} \\
& - \sum_{v \in V} \sum_{t \in T} C_{vt}^{TC} y_{vt}^{TCin} - \sum_{v \in V} \sum_{t \in T} C_{vt}^{I} y_{vt}^{I} \\
& - \sum_{v \in V} \sum_{t \in T} C_{vt}^{N} y_{vt}^{N} - \sum_{v \in V} \sum_{r \in R_v} \sum_{t \in T_v} C_{vr} x_{vrt} \\
& - \sum_{v \in V} \sum_{t \in T} \left(C_{vt}^{O} + C_{vt}^{C} \right) y_{vt}^{OWN}
\end{aligned} \tag{1}$$

The objective function (1) maximizes the profit. The first term calculates the revenue of servicing COAs and spot contracts. The second term calculates the revenue of time chartering out vessels and selling vessels while the third term gives the costs of chartering and buying vessels. The fourth term defines the cost of ordering new vessels and the voyage cost for the different routes and vessels. Finally, the fifth term defines the OPEX and CAPEX of owned vessels.

- ***Fleet conservation* constraints**

Constraint (2) ensures that the total numbers of owned vessels are preserved. Constraint (3) ensures the same for the total number of each vessel type controlled and operated by the shipping company is conserved. Constraint (4) defines that one does not charter out vessels that are not owned. Constraint (5) sets that vessels are sold/scrapped before their lifetimes expire.

$$y_{vt}^{OWN} = y_{v,t-1}^{OWN} + y_{vt}^{I} - y_{vt}^{S} + y_{vt}^{N} \qquad \forall \quad v \in V \quad t \in T_v \tag{2}$$

$$y_{vt}^{TOT} = y_{vt}^{OWN} + y_{vt}^{TCin} - y_{vt}^{TCout} \qquad \forall \quad v \in V \quad t \in T_v \tag{3}$$

$$y_{vt}^{OWN} \geq y_{vt}^{TCout} \qquad \forall \quad v \in V \quad t \in T_v \tag{4}$$

$$y_{v,t_v}^{OWN} = \sum_{t_v+1}^{t_v+T_v^{LT}} y_{vt}^{S} \qquad \forall \quad v \in V \tag{5}$$

Constraints (6) and (7) define the initial fleet, where F_v^0 is the number of owned vessels of each type. Constraint (8) ensures that no newbuildings can be acquired in the first period to account for the required order lead time.

$$y_{v,0}^{OWN} = F_v^0 \qquad \forall \quad v \in V \tag{6}$$

$$y_{v,0}^{TOT} = y_{v,0}^{OWN} + y_{v,0}^{TCin} - y_{v,0}^{TCout} \qquad \forall \quad v \in V \tag{7}$$

$$y_{v,1}^{N} = 0 \qquad \forall \quad v \in V \tag{8}$$

- ***Demand and capacity constraints***

Constraint (9) ensures that there is sufficient fleet capacity to fulfil the demand of selected COAs and spot cargo volumes. Constraint (10) provides an upper limit of cargo available for each spot trade. Constraint (11) ensures that the total duration of all roundtrips made on a route by each vessel type is equal to or less than the total available time.

$$\sum_{v \in V} \sum_{r \in R_v} Q_v A_{ivr} x_{vrt} \geq Q_{it} \delta_i + z_{it} \qquad \forall \quad i \in N^{SPOT} \cup N^{COA} \quad t \in T \tag{9}$$

$$S_{it} \geq z_{it} \qquad \forall \quad i \in N^{SPOT} \quad t \in T \tag{10}$$

$$T_{vt}^{TOT} y_{vt}^{TOT} \geq \sum_{r \in R_v} T_{vr} x_{vrt} \qquad \forall \quad v \in V \quad t \in T_v \tag{11}$$

- ***Other constraints***

Constraints (12)~(17) define the characteristics of variables. It should be mentioned that constraint (14) imposes integrality requirements and thereby makes it possible only to charter in or out for a whole period. Constraint (16) does not impose integrality requirements making it possible to let a roundtrip endure over a change of periods.

$$\delta_i \in \{0,1\} \qquad \forall \quad i \in N^{COA} \tag{12}$$

$$y_{vt}^{OWN}, y_{vt}^{S} \geq 0 \text{ and integer,} \qquad \forall \quad v \in V \quad t \in T \tag{13}$$

$$y_{vt}^{TOT}, y_{vt}^{TCout}, y_{vt}^{TCin} \geq 0 \text{ and integer} \qquad \forall \quad v \in V \quad t \in T_v \tag{14}$$

$$y_{vt_v}^{I}, y_{vt_v}^{N} \geq 0 \quad \text{and integer} \qquad \forall \quad v \in V \quad t \in T_v \tag{15}$$

$$x_{vrt} \geq 0 \qquad \forall \quad v \in V \quad r \in R_v \quad t \in T_v \tag{16}$$

$$z_{it} \geq 0 \qquad \forall \quad i \in N^{SPOT} \quad t \in T \tag{17}$$

A feature worth mentioning with the model is the artificial period, similar as the sunset period in the work of Alvarez et al. (2011). Because of the definition of T_v the model forces vessels to be sold before their lifetime ends or at the end of the planning period, whichever are the lesser in number of periods. However, this becomes a problem as soon as the number of periods in the planning interval is less than the number of periods left of a vessel's lifetime. Just because a company wants to plan for e.g. five years at a time does not mean that it would be correct to sell a new vessel after five years. Therefore an artificial period is created and added to the original set of periods. In this artificial period it is only possible to sell vessels. This implies that if the model suggests selling vessels in this period it means that it could be equally beneficial to keep them in the fleet.

The optimization model is a mixed integer programming model. It can be solved efficiently by any commercial optimization solver (Meng and Wang 2010). We implemented the model in optimization software Xpress on a laptop computer.

4. A numerical example

This section shows some of the areas of application for the optimization model. A realistic but simplified setting is presented where two bulk shipping operators just merged as a new company named WBC. The combined fleet consists of five Supramax, ten Panamax and five Capesize vessels. The management wants to investigate the profitability of different operations strategies and is interested in finding out if the existing merged fleet is sufficient for the new company or if they should consider replacing vessel types and/or acquiring additional vessels. Another option under evaluation is to terminate all cargo transportation activity and only focus on trading vessels and time charter out vessels.

There are four long-term COAs available and additional spot trade on three routes. Detailed information about these contracts is given in Tables 4 and 5. The value of a COA is based on the whole contract i.e. demand for all periods must be fulfilled in order to commit to the contract. The amount to be transported is given in ton and is specified for each period for a COA. For the spot contracts, Table 4 gives the revenue per ton transported and Table 5 specifies the upper limit of cargo volume.

Table 4. Contract data

Contract number	*Type*	*Commodity*	*Loading port*	*Unloading port*	*$/ton*
1	*COA*	*Iron ore*	*Tubarao, Brasil*	*Rotterdam, Netherlands*	
2	*COA*	*Iron ore*	*Tubarao, Brasil*	*Beilun, China*	
3	*COA*	*Coal*	*US East Coast*	*Rotterdam, Netherlands*	
4	*COA*	*Iron ore*	*Dampier, W Australia*	*Beilun, China*	
5	*Spot*	*Coal*	*US East Coast*	*Rotterdam, Netherlands*	*16*
6	*Spot*	*Iron ore*	*Tubarao, Brasil*	*Rotterdam, Netherlands*	*8.5*
7	*Spot*	*Iron ore*	*Dampier, W Australia*	*Beilun, China*	*8*

Table 5. Contract data cont'd

Contract number	*Value ($)*	*Period 1(ton)*	*Period 2(ton)*	*Period 3(ton)*	*Period 4(ton)*	*Period 5(ton)*
1	*255 000 000*	*10 000 000*	*10 000 000*	*10 000 000*	*0*	*0*
2	*476 000 000*	*20 000 000*	*20 000 000*	*20 000 000*	*20 000 000*	*0*
3	*448 000 000*	*0*	*20 000 000*	*20 000 000*	*0*	*0*
4	*336 000 000*	*0*	*15 000 000*	*15 000 000*	*15 000 000*	*15 000 000*
5		*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*
6		*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*
7		*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*	*5 000 000*

The management wants to evaluate the following three different cases.

- **Case 1**
  WBC continuous to operate in the coal/iron ore market without making any changes to the combined fleet. If possible, all COAs are serviced. Otherwise the COAs are chosen based on a maximal profit evaluation. The possibility to do this with and without using time charter (TC) should be investigated.
- **Case 2**
  WBC's fleet is optimized to handle all proposed COAs. The fleet mix and size is determined based on maximal profit. The options of buying second hand vessels, newbuildings and using TC are all to be considered together.
- **Case 3**
  Terminate all transporting activity and continue only with active vessel trading and TC.

Information about the vessels where collected from Fairplay (2009). Fuel consumption was updated to fit 2013 specifications if the comparison vessels were old. A modification made was to adjust sailing speed to 11 knots for all vessels types, so called 'slow steaming'. This has become more and more common in today's market due to an increase in the fuel prices while the rates continue to stay low. Relevant vessel types are Supramax (55,000 DWT), Panamax (75,000DWT) and two types of Capesize (150,000 DWT and 170,000 DWT respectively).

The planning interval is of five periods (1...5) where each period represent 1 year. The input data have been collected from various industrial companies, meaning that the data for the first period is representative for the industry. No effort has been put into obtaining forecast data as such data is highly costly. This is due to the various analyses that must be done as all the inputs are dependent on several macro economic factors. For a real case this should of course be obtained as the output will never be more reliable than the input. As this is purely an illustrative case to show the applicability of the model, the authors have used the same value of the data for all periods, i.e. a case where there is a steady market with zero development. The rates/cost for time chartering in vessels are set to be 5% higher than the rates/revenue of time chartering out vessels. The rate difference is meant to account for broker and management fees. It also prevents the model from chartering in a vessel for only to charter it out.

CAPEX are calculated based on the assumption that all vessels are acquired with a loan corresponding to 80% of the acquisition price and with an interest rate of 4% per year on that loan.

Ship sales prices are calculated by subtracting the ship's annual depreciation from its acquisition value. The model applies the straight-line depreciation method which implies that the value of the ship is written off in equal proportions over its expected lifetime (Stopford 2009). In addition the loan is subtracted (80% of the acquisition price) as it is assumed that no repayment is done.

5. Results and analysis

5.1. Case 1 without TC

From the summary in Table 6 we can see the result of the optimal solution when we forced the model to neither buy second-hand or new vessels while also refraining from TC engagements. Since the model is forced to 'sell' all vessels in period 6, the income of selling these vessels is not included in the result as they are still in the owned fleet.

Table 6. Result from Case 1 without TC

Profit:	*$ 180 940 215*						
Contracts served	*COA1*	*COA2*	*COA3*	*COA4*	*SPOT1*	*SPOT2*	*SPOT3*
Period 1	*1*	*0*	*0*	*0*	*5 000 000*	*2 183 775*	*0*
Period 2	*1*	*0*	*0*	*0*	*5 000 000*	*2 183 775*	*0*
Period 3	*1*	*0*	*0*	*0*	*5 000 000*	*2 183 775*	*0*
Period 4	*1*	*0*	*0*	*0*	*5 000 000*	*2 183 775*	*5 000 000*
Period 5	*1*	*0*	*0*	*0*	*5 000 000*	*5 000 000*	*5 000 000*

We also see that only COA1 is served, this being indicated by the value of 1 for all the period COA1 is valid. The number under the different spot routes shows how much of the available spot cargo [ton] that is being transported in each period. Table 7 shows an overview of changes made to the fleet during the planning period.

Table 7. Fleet changes in Case 1 without TC

Period	*Operated*	*Owned*	*Acquired*	*Newbuilding*	*TC in*	*TC out*	*Sold*
1	*20*	*20*	*0*	*0*	*0*	*0*	*0*
2	*20*	*20*	*0*	*0*	*0*	*0*	*0*
3	*20*	*20*	*0*	*0*	*0*	*0*	*0*
4	*20*	*20*	*0*	*0*	*0*	*0*	*0*
5	*20*	*20*	*0*	*0*	*0*	*0*	*0*
(6)	-	-	-	-	-	-	*20*

All vessels are being owned and operated through all periods in accordance with the limitations set to fleet changes by the case.

5.2. Case 1 with TC

When we let the model choose whether to engage in TC, we see that the expected profit would increase by 442% for the same planning periods. All COAs except COA2 are serviced and the majority of the available SPOT cargo.

Table 8. Result from Case 1 with TC

Profit:	*$ 979 952 898*						
Contracts served	*COA1*	*COA2*	*COA3*	*COA4*	*SPOT1*	*SPOT2*	*SPOT3*
Period 1	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*4 872 727*
Period 2	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*5 000 000*
Period 3	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*5 000 000*
Period 4	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*5 000 000*
Period 5	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*4 781 818*

As TC is now allowed, we can now observe a change in the number of operated vessels in almost every period, with a peak in periods 2 and 3. This corresponds to the amount of cargo lifted being the highest in these periods, ref. Table 5 and Table 8.

Table 9. Fleet changes in Case 1 with TC

Period	*Operated vessels*	*Owned*	*Acquired*	*Newbuilding*	*TC in*	*TC out*	*Sold*
1	*10*	*20*	*0*	*0*	*10*	*20*	*0*
2	*25*	*20*	*0*	*0*	*22*	*17*	*0*
3	*25*	*20*	*0*	*0*	*22*	*17*	*0*
4	*13*	*20*	*0*	*0*	*12*	*19*	*0*
5	*12*	*20*	*0*	*0*	*12*	*20*	*0*
(6)	-	-	-	-	-	-	*20*

A shipowner is often interested in finding out which type of vessels should be operated/owned/TC in/out etc. It may set a limitation on the number of vessels that could be TC in/out. When running the model, there was not set an upper boundary (UB) on how many vessels that could be TC in each period. This is however easy to configure independently for each desired case according to user preferences.

5.3. Case 2

In Case 2 we remove the constraints on fleet changes that we imposed in Case 1. We can observe in Table 10 that the selected COAs and transported SPOT cargo is almost the same except a slight difference in SPOT3 in Period 4. The expected profit is however higher in Case 2 than in Case 1 w/TC. We also see in Table 11 that the whole initial fleet is sold in Period 1, implying that, with the given input data, it is not beneficial to own vessels over this set of periods.

Table 10. Result from Case 2

Profit:	*$ 1 051 500 625*						
Contracts served	*COA1*	*COA2*	*COA3*	*COA4*	*SPOT1*	*SPOT2*	*SPOT3*
Period 1	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*4 872 727*
Period 2	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*5 000 000*
Period 3	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*5 000 000*
Period 4	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*4 781 818*
Period 5	*1*	*0*	*1*	*1*	*5 000 000*	*5 000 000*	*4 781 818*

Table 11. Fleet changes in Case 2

Period	*Operated vessels*	*Owned*	*Acquired*	*Newbuilding*	*TC in*	*TC out*	*Sold*
1	*10*	*0*	*0*	*0*	*10*	*0*	*20*
2	*25*	*0*	*0*	*0*	*25*	*0*	*0*
3	*25*	*0*	*0*	*0*	*25*	*0*	*0*
4	*12*	*0*	*0*	*0*	*12*	*0*	*0*
5	*12*	*0*	*0*	*0*	*12*	*0*	*0*
(6)	-	-	-	-	-	-	*0*

5.4. Case 3

The objective of this case was to investigate how profitable it would be to only be engaged in trading vessels, not taking on any contracts. This is done by setting the revenue of the COAs and the available SPOT cargo in the input file to 0. The options for the use of the initial fleet would then be to TC out or to sell the vessels.

Table 12. Result from Case 3

Profit:	*$ 67 280 000*						
Contracts served	*COA1*	*COA2*	*COA3*	*COA4*	*SPOT1*	*SPOT2*	*SPOT3*
Period 1	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Period 2	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Period 3	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Period 4	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Period 5	*0*	*0*	*0*	*0*	*0*	*0*	*0*

As we see in Table 13, all vessels are sold in the first period. The result in Case 3 is then only the revenue of selling the initial fleet. The reason for why this is so low is that R^{S}_{vt} is calculated by subtracting the ship's annual depreciation from its acquisition value and also the value of the initial, assuming only interests have been paid (incl. in CAPEX). It may be argued that this is more correct to do for vessels that are bought within the optimization periods and that the initial fleet might have a much lower loan to value ratio.

However, this will be different from case to case and the model must also be modified accordingly in real-life applications.

Table 13. Fleet changes in Case 3

Period	*Operated vessels*	*Owned*	*Acquired*	*Newbuilding*	*TC in*	*TC out*	*Sold*
1	*0*	*0*	*0*	*0*	*0*	*0*	*20*
2	*0*	*0*	*0*	*0*	*0*	*0*	*0*
3	*0*	*0*	*0*	*0*	*0*	*0*	*0*
4	*0*	*0*	*0*	*0*	*0*	*0*	*0*
5	*0*	*0*	*0*	*0*	*0*	*0*	*0*
(6)	-	-	-	-	-	-	*0*

5.5. Sensitivity analysis

The optimal solution is directly related to the input data and this data may or may not always be of absolute certainty. Such uncertainties are often present when using forecast data. Since the model is to be used as a support for strategic decisions, it is essential to know if the model is sensitive to variations in the input data. In order to do this, three forecast scenarios is used. These are *Recovery* (15% market increase per period), *Trough* (0% increase per period) and *Collapse* (15% decrease per period). With market increase/decrease we here mean developments in parameters such as freight rates, vessel prices, fuel price etc. as illustrated in Figure 3 for fuel prices. For the previous cases we have used the *Trough* scenario. It should be acknowledged that the designed scenarios are rather moderate and simplistic when considering the volatile nature of the maritime world. A more in-depth description of such relationships, e.g. between fuel prices and freight rates, can be found in UNCTAD (2010).

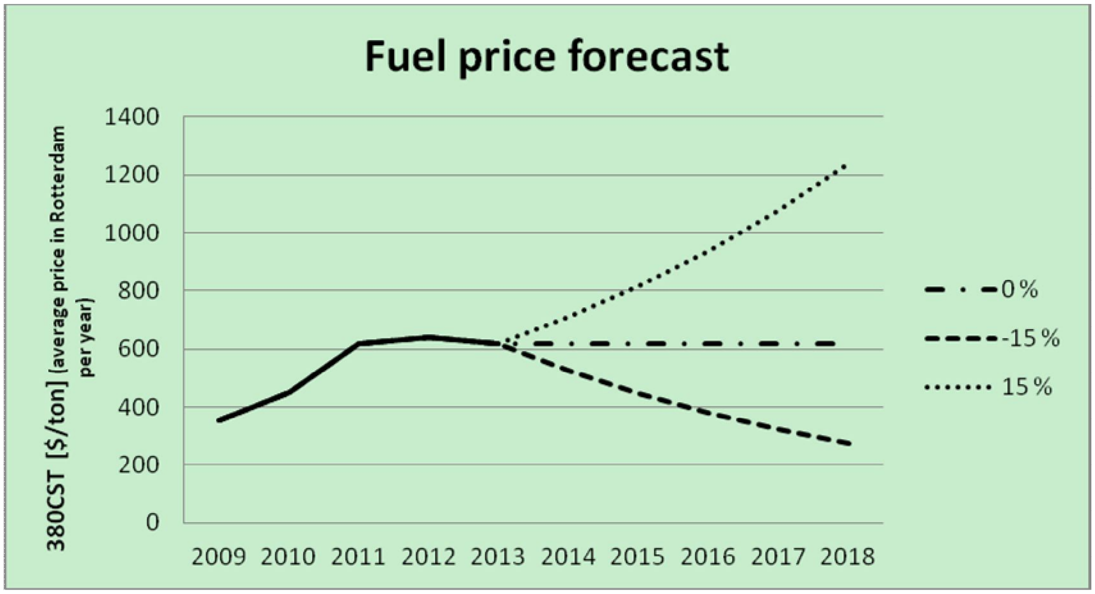


Figure 3. Historical fuel prices and scenario forecast

We investigated how sensitive the model was to changes in the input data. This was done by running the model for Case 2 with input data according to the three scenarios. This turned out to give quite different results, as shown in Table 14. For the *Through* and *Collapse* scenario we see that all vessels are sold in the first period (indicated by the OPEX being zero for both scenarios) while for *Recovery* some of the fleet are put on TC and also owned until the end of period 5.

Table 14. Results for Case 2 with different scenarios

	Through	***Recovery***	***Collapse***
Income	***1 727 334 545***	***2 792 869 500***	***1 946 973 436***
COA	*1 039 000 000*	*1 039 000 000*	*1 515 000 000*
SPOT	*621 054 545*	*1 249 454 545*	*383 363 636*
Selling vessels	*67 280 000*	*30 258 800*	*48 609 800*
TC income	-	*474 156 155*	-
Expenditures	***675 833 920***	***1 470 036 758***	***737 531 187***
TC costs	*314 112 330*	*569 434 155*	*246 775 978*
Buying second-hand	-	-	-
Buying newbuilding	-	-	-
Voyage costs	*361 721 590*	*543 014 198*	*490 755 209*
CAPEX	-	*58 719 000*	-
OPEX	-	*298 869 405*	-
Profit	***1 051 500 625***	***1 322 832 742***	***1 209 442 249***

It may seem peculiar that it is the *Trough* scenario with 0% changes that yield the lowest result and not the *Collapse* where the rates are lowest. This is because it is not only the rates that decrease by 15% yearly, but also the OPEX, the vessel prices and the fuel price. Similar is it for the *Recovery* scenario when the market goes up.

Having observed that the economical result is sensitive to changes in the input data it would be interesting to investigate how it affects the strategic decisions suggested by the model. If it is the similar decisions that have to be made in order to obtain optimal result for each scenario, then it can be argued that the model gives a rather robust solution. *When to order*, *buy* or *sell* vessels and *how many* are important decisions that will have large effects on the result. Also deciding which long term COAs to engage in has a significant impact. Decisions regarding spot cargo and time charter are also of importance, but the shorter time horizon for these decisions makes it easier to manage decision changes in real life.

From Table 15 we see that the numbers of vessels that are operated in each period are almost similar for the *Trough* and *Recovery* scenario but very different for owned vessels, while owned vessels is the same for *Through* and *Collapse*. This indicates that even if you plan for the *Trough* scenario and instead the *Collapse* scenario should occur, the decisions taken could still be close to the optimal solution as both involves TC of vessels. But what if the *Recovery* scenario should occur and you have sold all your vessels, what would be the consequences? By setting $y_{vt}^{OWN} = 0$ we can run the model and see that the expected profit would be \$ 1 264 983 992 which is a loss of \$ 57 848 750 or 4% compared to the optimal solution. This indicates that the optimization model provides a fairly robust solution that is equally valid for different scenarios. It must be taken into consideration that for those owners who have an in-house management there will be additional costs (depending on the size of the fleet) caused by selling all the vessels. This will be related to redundant personnel, restructuration of the organization, office etc. If it then later will be profitable to build up the owned fleet again, the additional costs will reoccur caused by the reversed process or you outsource the management. An owner with a 3rd party management will not be exposed to such costs, though whether to choose to have your management in-house or outscore it is another discussion which will not be covered here.

Table 15. Comparison of operated and owned vessels in Case 2 for the different scenarios

	Through		*Recovery*		*Collapse*	
Period	*Operated vessels*	*Owned*	*Operated vessels*	*Owned*	*Operated vessels*	*Owned*
1	*10*	*0*	*10*	*15*	*19*	*0*
2	*25*	*0*	*25*	*15*	*33*	*0*
3	*25*	*0*	*25*	*15*	*33*	*0*
4	*12*	*0*	*13*	*15*	*21*	*0*
5	*12*	*0*	*12*	*15*	*12*	*0*

For the three cases that we have discussed, the model suggests that WBC goes for the strategy proposed in Case 2. Even though this turns out to be the best strategy for this setting it is not given that it would be the best in other settings. Note that although the model grasps the main input parameters it is made simplifications. The calculations do not include several items costs including brokerage fees, port dues, and changes of fuel to more expensive diesel when sailing in emission controlled areas.

6. Conclusions

This paper presents an optimization model for the strategic fleet planning problem in tramp shipping. Strategic fleet planning is vital to shipowners as maritime transportation is very capital intensive. Existing studies on strategic fleet planning were mainly concerned with liner shipping. Little attention has been given to the unique requirement of contract analysis together with fleet planning in tramp shipping. This research develops a mixed integer programming model for these two intertwined decisions in tramp shipping. The model can be efficiently solved by any commercial optimization solver such as Xpress.

The optimization model is very flexible and can be employed for different fleet planning scenarios. It can be used to evaluate contracts up against each other and find the best mix of long term and spot contracts for a given fleet, find the optimal fleet size and mix for a set of contracts or a mix of both. It can aid decisions of a fleet renewal program, helping to decide when to sell and whether to buy old or new ships. It takes into consideration the time charter market, recommending when to charter in vessels and when to charter out. It also recommends vessel sizes/types for specific freight contracts/routes to maximize profits. Another area of application is for users that are only engaged in active vessel trading and not in transportation. A numerical example is given to illustrate the model application.

This research has its limitations. The optimization model presented is deterministic. It can be extended as a stochastic model to incorporate uncertainties in the model formulation.

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