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Bulk ship fleet renewal and deployment under uncertainty: A multi-stage stochastic programming approach

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ABSTRACT

Faced with simultaneous demand and charter cost uncertainty, an industrial shipping company must determine a suitable fleet size, mix, and deployment strategy to satisfy demand. It acquires vessels by time chartering and voyage chartering. Time chartered vessels are acquired for different durations, a decision made before stochastic parameters are known. Voyage charters are procured for a single voyage after uncertain parameters are realized. We introduce the first multi-stage stochastic programming model for the bulk ship fleet renewal problem and solve it in a rolling horizon fashion. Computational results indicate that our approach outperforms traditional methods relying on expected value forecasts.

1. Introduction

This paper investigates a multi-period maritime fleet sizing and deployment problem with uncertain customer demand and charter costs. An industrial bulk shipper, whose primary task is to transport raw materials produced or owned by a parent company from supply ports to demand ports, must determine the number of each vessel type and the fleet deployment strategy needed to reliably satisfy stochastic demand at minimum cost. A major challenge in constructing an appropriate fleet is the prevalence of severe market fluctuations in the maritime sector, where unpredictable shipping cycles are the norm, not the exception (Stopford, 2008).

Despite the recognition of significant uncertainty in the maritime sector, decision support tools that explicitly account for stochasticity are scarce (Pantuso et al., 2014a). Those models that do consider uncertainty focus almost exclusively on liner shipping applications and/or strategic planning problems with long planning horizons (on the order of a decade). In contrast, this work investigates a problem in bulk shipping and offers a model that can be used for tactical planning or for planning at the interface of the strategic and tactical level. Specifically, we consider a fleet sizing and deployment problem faced by a bulk shipper who operates a heterogeneous fleet composed of company-owned vessels as well as time and voyage chartered vessels. Every few months, prior to observing actual demand and future charter rates, the shipper determines how many time charter vessels to acquire and the charter duration for each vessel. Purchasing new vessels is not considered in this work. The planning horizon of interest is typically six months to three years with a time period representing three or six months. After demand in the current period is realized, the shipper must deploy her fleet to satisfy demand. If too few time

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Nomenclature

Indices and sets

$t \in \mathcal{T}$	set of time periods of the planning horizon with $T = \lvert\mathcal{T}\rvert$
$l \in \mathcal{L}$	set of loading ports with $L = \lvert\mathcal{L}\rvert$
$d \in \mathcal{D}$	set of discharging ports with $D = \lvert\mathcal{D}\rvert$
$j \in \mathcal{J}$	set of all ports: $\mathcal{J} = \mathcal{L} \cup \mathcal{D}$
$p \in \mathcal{P}$	set of vessel paths (sequences of port calls)
$p \in \mathcal{P}_l^{\text{Origin}}$	set of paths that have loading port l as origin
$p \in \mathcal{P}_l$	set of paths that include loading port l as a port call
$p \in \mathcal{P}_d$	set of paths that include discharging port d as a port call
$vc \in \mathcal{VC}$	set of vessel classes with $VC = \lvert\mathcal{VC}\rvert$
$f \in \mathcal{F}_{vc}$	set of fare classes for a vessel class vc
$k \in \mathcal{K}$	set of vessel types: $\mathcal{K} = \{\text{Owned}, \text{Time Chartered (TC)}, \text{Voyage Chartered (VC)}\}$
$k \in \mathcal{K}'$	subset of vessel types: $\mathcal{K}' = \{\text{Owned}, \text{Time Chartered (TC)}\}$

Deterministic parameters

$\overline{T}$	duration in days of each time period
$M_{vc,f}$	number of vessels in vessel class vc that can be chartered from fare class f
$P_{l,t}$	production limit at loading port l in time period t
Q_{vc}	capacity of a vessel in vessel class vc
$\overline{Q}_{vc,p,j}$	amount of product loaded or discharged at port j from a vessel in vessel class vc on path p
$D_{p,vc,t}$	time required to complete path p with vessel class vc beginning in time period t
$\overline{S}_{d,t}$	maximum amount of inventory that can be stored at discharging port d in time period t
$C^{\text{V+O}}_{p,vc,k,t}$	voyage and operating cost of deploying a type $k \in \mathcal{K}'$ vessel in vessel class vc on a voyage on path p beginning in time period t
$C^{\text{Repo}}_{l,l',vc,k,t}$	repositioning cost associated with reassigning a type $k \in \mathcal{K}'$ vessel in vessel class vc from loading port l to loading port l' at the beginning of time period t

Stochastic parameters

$\tilde{\Delta}_{d,t}$	demand at discharging port d in time period t
$\widetilde{C}^{\text{TC}}_{l,vc,f,t_1,t_2}$	time charter cost for a vessel in vessel class vc and fare class f based in loading port l for chartering at the end of time period t_1 until the end of time period t_2
$\widetilde{C}^{\text{VC}}_{p,vc,t}$	voyage charter rate for a vessel in vessel class vc serving path p in time period t

Decision variables

$x^{\text{TC}}_{l,vc,f,t_1,t_2}$	(integer) number of time chartered vessels initially based in loading port l, in vessel class vc and fare class f, chartered at the end of time period t_1 until the end of time period t_2
$y^{\text{TC,Exit}}_{l,vc,t}$	(integer) number of time chartered vessels in vessel class vc exiting the fleet at the end of time period t from loading port l
$y^{\text{Repo}}_{l,l',vc,k,t}$	(integer) number of type $k \in \mathcal{K}'$ vessels in vessel class vc repositioned from loading port l to loading port l' at the beginning of time period t
$y_{l,vc,k,t}$	(integer) number of type $k \in \mathcal{K}'$ vessels in vessel class vc assigned to loading port l for the duration of time period t after repositioning decisions have been made
$z_{p,vc,k,t}$	(continuous) number of trips made on path p using type $k \in \mathcal{K}$ vessels of class vc during time period t
$s_{d,t}$	(continuous) inventory level at discharging port d at the end of time period t

charter vessels are available, voyage charter vessels can be procured, each making a single voyage from a supply port to a demand port to fulfill remaining demand.

Amidst all of the complexity, the heart of this problem is to find an optimal balance of long-term time charter commitments and short-term voyage charter acquisitions on a recurring basis. With perfect demand and cost foresight, the shipper could construct her fleet rather easily by solving a deterministic optimization problem to identify the most cost effective vessels to acquire. The problem is that market cycles and demand can be difficult to predict. Consequently, "when trade is buoyant and voyage rates are rising, charterers, in anticipation of further rises, tend to charter for longer periods to cover their commitments; when rates are expected to fall, they tend to contract for shorter periods" (Branch, 2007, p. 194).