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A conditional value-at-risk based methodology to intermediate-term planning of crude oil tanker fleet

Atiq W. Siddiqui[a], Manish Verma[b,*]

[a] College of Business Administration, Imam Abdulrahman Bin Faisal University, Saudi Arabia
[b] DeGroote School of Business, McMaster University, Canada

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ABSTRACT

Crude oil suppliers usually meet intercontinental demand through a fleet of ocean tankers, which not only have very high fixed and operating costs but also carry considerable financial risks because of the volatilities in oil demand and spot freight rate markets. Hence, most oil suppliers maintain an under-capacity fleet, and manage additional requirements through periodically adjusting a mix of various charter contracts and/or their purchase options. For this periodic fleet adjustment problem, we propose a conditional value-at-risk based methodology to hedge against extreme losses. More specifically we develop a mixed integer nonlinear programming model, where parameters are estimated via Monte-Carlo simulation, to minimize both the chartering costs and the associated financial risks. The proposed methodology was applied to a number of problem instances, generated using the marine transportation network of a major oil supplier, and it was observed that: full use of a mix of charter contracts and its purchase options significantly reduce spot charter market related risks, while substantially increase the firm or oil demand-specific risks—a key relationship driving optimal fleet decisions; and, firm-specific (tanker under-utilization) risks become increasingly irrelevant during higher oil demand periods, and that the market risks show sensitivity to the starting spot charter prices as well as the scale of delivery operations.

1. Introduction

Crude oil, one of the most traded commodities, is primarily shipped between continents using (ultra) large crude oil tankers that have very high fixed and operating costs (Cheng & Duran, 2004; Iakovou & Douligeris, 1996; Siddiqui, Verma, & Tulett, 2013). These shipments are generally managed by the oil suppliers through shipping partners such as the operation of world's largest oil supplier Saudi Aramco (Estimo, 2014), or through subsidiaries as in the case of other major Middle-Eastern oil producers (ADNATCO, 2015; KOTC., 2015; NIOC, 2015). These shipments can also be handled by the customers themselves who then manage it through independent shippers. These shippers regularly face planning uncertainties due to fluctuating short-term oil demand, changing business cycles (Axarloglou, Visvikis, & Zarkos, 2013), as well as varying tanker availabilities and the tanker freight rates. These uncertainties are significant as most large shippers own a certain number of tankers based on expected long-term demand, and then make use of tanker chartering (different charter contracts) to fulfill the remaining requirements. Note that these shippers, in general, make use of spot charters and/or longer term charter contracts together with the embedded purchase (real) options (i.e., right to engage vessel on time charter when it becomes available for service) (Jørgensen & De Giovanni, 2010). The existence of this *mixed-fleet* structure is explained by Pirrong (1993), who suggested that temporal specificities (i.e., local vessels availabilities in the context of long travel times) in bulk shipping trigger costly bargaining in spot market, which can be compensated either by entering into longer term contracts or by becoming vertically integrated. From a financial point of view, this strategy exposes these shippers to different financial risks induced by uncertainties in both service demand as well as the charter markets. Thus, the oil shipper faces a fleet size and mix problem, which would entail periodically managing a fleet of owned vessels plus a portfolio of chartered assets (i.e., tankers on various charter contracts and/or the corresponding purchase options). Note that the tanker acquisition and layoff decisions are strategic, whereas managing a portfolio of non-owned assets can be categorized as a tactical problem involving (fleet size and mix) periodic adjustment decisions over an intermediate time horizon. It should be clear that such tactical decisions would be driven not only by the logistic requirements of the oil supplier or their customers, but also by the chartering costs and the associated

* Corresponding author at: 1280 Main Street West, Hamilton, ON L8S 4M4, Canada.
E-mail addresses: awsiddiqui@iau.edu.sa (A.W. Siddiqui), mverma@mcmaster.ca (M. Verma).

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financial risks.

Although we provide an extensive review of the relevant literature in Section 2, to the best of our knowledge, the financial implications of chartering contracts and its purchase options, and the corresponding mechanism to deal with the periodic adjustments of a crude oil tanker fleet have not been investigated. This is quite surprising due to the prevalent scale of operations of these shippers and corresponding costs and risks associated with it, and the attention fleet management problems have received for other modes of transportation (Díaz-Madroñero, Peidro, & Mula, 2015; Eksioglu, Vural, & Reisman, 2009). In an effort to fill this gap, we propose a methodology that first identifies (and quantifies) the inherent financial risks, which is then incorporated into a mathematical model that seeks to minimize the sum of chartering costs and associated financial risks. More specifically, the latter is a mixed integer nonlinear program that makes use of Monte Carlo simulation to estimate the stochastic input parameters, which in turn also facilitates model linearization. Though the proposed methodology was tested on the realistic size problem instances of an oil supplier's subsidiary, we note that it could be applied to other settings involving shipping partners or large independent suppliers since each of them are exposed to the similar types of risks, and thus need to make the same fleet size and mix decisions. The resulting computational experiments enabled us to conclude three things. *First*, firm-specific financial risk resulting from under-utilization of contracted tankers is sensitive to the current oil demand level. That is, it remains relevant if the starting oil demand (and thus the corresponding tanker demand) is below the long-term mean, but becomes irrelevant at higher oil demand values. *Second*, full use of a portfolio consisting of various time charter contracts and their purchase options will be most useful in reducing the non-firm-specific risk (i.e., freight market risk), which is true in both the cases of spot freight rates starting lower or higher than the expected long-term mean. *Finally*, we note that it is in the interest of the shipper to understand the converse behavior of the two types of risks when making the fleet size and mix decisions.

The rest of the paper is organized as follows. Section 2 contains a review of the relevant works, followed by the problem description in Section 3, and a brief outline about the nature of financial risks and the corresponding management policy in Section 4. A flow chart providing a high level overview of the proposed methodology is presented in Section 5, followed by the optimization program in Section 6, and the details of the methodology in Section 7. Section 8 analyzes the results from a numerical study based on the existing infrastructure of an oil shipper, while the conclusion and directions of future research are presented in Section 9.

2. Literature review

The relevant works are organized under two main research streams: *fleet management*; and, *charter contracts and options*. The first stream contains works dealing with strategic and tactical level problems, wherein the former includes discussion on vessel acquisition, layoff and long-term chartering while the latter includes tanker-chartering, which is mainly dealt within the present routing and scheduling literature. At the strategic level, Dantzig and Fulkerson (1954) were the first to consider both fixed acquisition and variable transportation costs while minimizing fuel oil tankers under a fixed oil supply schedule. On the other hand, Jin and Kite-Powell (2000) proposed an optimal control theory based model dealing with vessel replacement schedule and utilization. Most recently, Q. Meng and Wang (2011) presented a scenario-based dynamic programing model for the multi-period fleet development and deployment problem. In contrast, Fagerholt, Christiansen, Magnus Hvattum, Johnsen, and Vabo (2010) considered uncertainty in planning, and developed a decision support methodology that combined Monte Carlo simulation for the parameter estimation and an optimization model for the tramp and the industrial shipping applications.

At the tactical level, Brown, Graves, and Ronen (1987), while dealing with a routing and scheduling problem for shipping crude oil from the Middle East to Europe and to North America, proposed a model that also determined the number of spot chartered vessels required. Sherali, Al-Yakoob, and Hassan (1999) considered spot charter contracts to facilitate routing and scheduling a fleet of heterogeneous vessels carrying petroleum products. We invite the reader to refer to Christiansen, Fagerholt, and Ronen (2004) and Christiansen, Fagerholt, Nygreen, and Ronen (2007, chap. 4) for a review of these and the general fleet management literature. To the best of our knowledge, all the published peer reviewed efforts in the fleet mix domain are based on short-term time horizons, which in turn imply that only spot charters could be used in the fleet adjustments decisions. But as noted earlier, fleet size adjustments are actually done through several complex charter contracts and their respective options that can span up to a year forward (Bjerksund & Ekern, 1995; Koekebakker, Adland, & Sodal, 2007; Pirrong, 1993). Hence, the prevalent approach is suboptimal because of two reasons: *first*, it does not capture the tactical level fleet size and mix decisions, which should entail considering all the appropriate contracts and options; and *second*, given the short-term deterministic planning, the inherent uncertainties and relevant financial risks are ignored.

The second stream of research, i.e., charter contracts and valuation of associated options, has received a lot of attention. In oil transportation, a variety of short to medium term contracts –such as the single voyage spot charter and over-the-counter forward contracts, as well as some limited futures are traded on various freight exchanges. Although freight futures contracts market started in 1980s, due to its lower hedging efficiency and its inability to deal with the market demand of route-specific contracts led to its termination and the subsequent replacement by the mostly over-the-counter (principal-to-principal) forward freight agreements (Kavussanos, Visvikis, & Batchelor, 2004; Koekebakker et al., 2007). It is important that pricing of these derivatives make use of spot charter rates on the underlying assets, which in turn could be modeled under different assumptions. For instance, Dixit and Pindyck (1994) and Tvedt (1997) assumed that spot rates follow the geometric Brownian motion, while Bjerksund and Ekern (1995) and Tvedt (2003) argued for a mean reverting nature evident in the Ornstein-Uhlenbeck Process (OUP). Glen and Martin (1998) and (Kavussanos, 2003) use GARCH type models suggesting fat tailed distribution; and an ability to capture short run behavior and the estimation of time varying volatility that allows explicit comparison of risks across different periods. More recently, Adland and Cullinane (2006) suggested a non-parametric Markov diffusion model, and then a stochastic partial equilibrium framework for capturing the behavior of spot freight rates (Adland & Strandenes, 2007). These models are used in pricing the freight derivatives under the expectation hypothesis of term structure, i.e., the value of a longer term contract determined as an expected sum of a series of short term spot contracts (Kavussanos & Alizadeh-M, 2002). Under this hypothesis and assuming the spot rates following OUP, Bjerksund and Ekern (1995) proposed a European call options pricing model, while Koekebakker et al. (2007) determined a closed-form expression for Asian options. Recently, Nomikos, Kyriakou, Papapostolou, and Pouliasis (2013) presented a model that considered jumps over a traditional lognormal spot freight model, which are then used for the valuation of options based on average freight rates, though applied to bulk cargo Capesize and Handymax class ships market. For pricing an embedded purchase option over a time charter contract between a ship owner and a ship charterer, closed form solutions are provided for some simple derivatives (Jørgensen & De Giovanni, 2010).

In summary, to the best of our knowledge, none of the existing works makes use of a full portfolio of chartering contracts and their purchase options for the fleet size and mix problem. The methodology proposed in this paper seeks to fill this gap. To this end, we first provide a description of the managerial problem in Section 3, and then outline