Optimal Scheduling of Tanker Lightering Operations

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Abstract

In this paper, we address a special case of the general chemical transshipment problem, namely the tanker lightering problem. When tankers are fully loaded with crude oil, they may not be able to enter the shallow channels or refinery ports due to the draft limitation. Under such circumstances, it is necessary to transfer some part of the crude oil from the tanker to lightering vessels in order to make the tanker "lighter". After such transshipment operation, the tanker can travel to the refinery port, which it previously cannot. And, the lightering vessels also travel to the refinery port to deliver the lightered crude oil. With tanker lightering operation, large tankers can also deliver crude oil to shallow-draught refinery ports. Furthermore, it helps to reduce the demurrage costs of tankers as well as inventory holding costs (Chajakis, 2000) at the refinery. During congested time, tankers could spend days awaiting lightering service. Since the demurrage costs of tankers are extremely high, effective scheduling of lightering operation is crucial for minimizing the system cost by reducing the waiting times of tankers and increasing the utilization of lightering vessels.

We consider a scheduling problem faced by a shipping company that provides lightering services to multiple refineries clustered in a region. The company operates a fleet of multi-compartment lightering vessels with a mix of different configurations such as numbers of compartments, sizes, speeds, heating equipment, and so on. When a tanker arrives at the lightering location, one lightering vessel pumps off crude oil from one side of the tanker. Therefore, at most two lightering services can take place simultaneously for a tanker, one at each side of the tanker. And, these multi-compartment lightering vessels can pick up multiple types of crude from the same/different tankers during a voyage. After enough crude oil has been offloaded, the tanker leaves the lightering system and travels to its designated refinery port. However, lightering vessels travel to the refinery ports, deliver the crude oils, and then return to the lightering location to continue their service. In other words, the lightering vessels make multiple voyages among the refinery ports and lightering location in order to service multiple tankers. Furthermore, we consider a two-stage lightering practice for large tankers, first stage at an offshore location farther from the refinery and the second stage at the lightering location closer to the refinery. Chajakis (1997) has described this problem in detail, while Lin et al. (2003) addressed a limited form of the same using an event-based approach. They assumed single-compartment vessels, did not restrict the number of simultaneous services for a single tanker, did not allow pickups from more than two tankers within one voyage of a lightering vessel, ignored differences in crude densities, and did not allow the freedom to select lightering crudes. In this paper, we develop two alternate continuous-time MILP formulations that address all of the above drawbacks. Thus, we allow multi-compartment lightering vessels, restrict the number of simultaneous transfers to two, allow more than two pickups in one voyage for any lightering vessel, consider the impact of varying crude densities, select optimally the right lightering crudes, and most importantly use two realistic cost-based scheduling objectives, either considering demurrage or time-

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chartered cost of tankers. Often, these features are real and important in the tank lightering problem. In contrast to the general chemical transshipment problem, the volumes and assignments to lightering vessels in this case are decided by the optimization model. In addition, the system cost here is an indicator of the customer satisfaction level as well as the utilization of fleet of lightering vessels. Our MILP model generates optimal lightering schedule with lightering volumes, sequence per voyage, times, and assignments, which minimizes the operating costs of lightering vessels, the demurrage or time-charter costs of tankers as well as the delivery times of crude oil from the lightering location to refinery ports.

Generally, the schedule that considers tanker demurrage is more flexible than the schedule that minimizes the time-chart cost of tankers. It is thus easier to solve the demurrage problem with shorter CPU times. In addition, the utilization of lightering vessels in the demurrage problem is normally higher than that in the time-charter cost problem. Both two alternate linearization methods (M1 and M2) are capable of finding optimal solutions. However, M2 is simpler with fewer constraints and nonzeros. As a result, M2 performs better than M1 in most cases. Furthermore, we have developed some heuristic methods to reduce slot-tanker combinations, thus the problem size. By doing this, the model is capable of obtaining a good solution within a reasonable time for large size problem. We considered a large size problem with seven tankers, eight crudes and four service ship. Without heuristic methods, the models require 171 discrete variables and do not converge after 6500 s. However, with heuristic methods, the models require only 131 discrete variables (23.40% size reduction) and converge to optimum within 5500 s. Lastly, the comparison of model performances between slot-based and event-based formulations shows that slot-based formulation is generally simpler and more effective. It is smaller in size and has tighter formulation, thus is faster than the event-based formulation.

Keywords: transshipment operations, scheduling, tanker lightering, shipping, maritime transportation

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