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Discrete Optimization

Inventory constrained maritime routing and scheduling for multi-commodity liquid bulk, Part I: Applications and model

Faiz Al-Khayyal [a,*,1], Seung-June Hwang [b,1]

[a] *School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0205, United States*
[b] *Department of Business Administration, Hanyang University, Ansan, Gyeonggi, 426-791, Korea*

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Abstract

This paper formulates a model for finding a minimum cost routing in a network for a heterogeneous fleet of ships engaged in pickup and delivery of several liquid bulk products. The problem is frequently encountered by maritime chemical transport companies, including oil companies serving an archipelago of islands. The products are assumed to require dedicated compartments in the ship. The problem is to decide how much of each product should be carried by each ship from supply ports to demand ports, subject to the inventory level of each product in each port being maintained between certain levels that are set by the production rates, the consumption rates, and the storage capacities of the various products in each port. This important and challenging inventory constrained multi-ship pickup–delivery problem is formulated as a mixed-integer nonlinear program. We show that the model can be reformulated as an equivalent mixed-integer linear program with special structure. Over 100 test problems are randomly generated and solved using CPLEX 7.5. The results of our numerical experiments illuminate where problem structure can be exploited in order to solve larger instances of the model. Part II of the sequel will deal with new algorithms that take advantage of model properties.

Keywords: Maritime transportation; Liquid bulk; Multi-commodity; Petrochemical logistics; Inventory dependent time windows; Ship routing and scheduling

* Corresponding author. Tel.: +1 404 864 3037; fax: +1 404 894 2301.
E-mail addresses: faiz@isye.gatech.edu (F. Al-Khayyal), sejhwang@isye.gatech.edu (S.-J. Hwang).
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1. Introduction

This paper addresses the problem of determining a minimum cost routing schedule for a heterogeneous fleet of ships engaged in pickup and delivery of various liquid bulk products across a set of supply and demand harbors with specified product availabilities and needs, respectively. Due to the nature of the products, it is impossible to carry more than two products without being separated into dedicated compartments of the ships. The optimal routing schedule should specify how much of each product to carry from which port to which port, at what time, and on which ship, subject to the conditions that all ports must have sufficient product for consumption, and the stock levels of the products cannot exceed the inventory capacity of that port.

This problem is motivated by a real logistics problem faced by an oil company in Asia Pacific serving an archipelago of islands. This company has a fleet of tankers and barges that transport petrochemical products between various plants and has many storage terminals and direct customers. Since plants and customers are dispersed over many islands, and since there is no terrestrial transportation infrastructure, such as a pipeline network connecting the islands, it is necessary to carry all inter-island supply and demand by ships. Each island has a different production and consumption rate for specified products, and the inter-island transport schedule should be such that proper stock levels for the petrochemicals are maintained at each island during the planning horizon. The problem is further complicated by the fact that the ships are able to carry a number of different products at the same time, and since some of these products cannot mix, these need to be carried in separate dedicated compartments. Fig. 1 illustrates the problem for eight harbors, four products, and three ships in the Philippines.

In this paper, we first identify the most important logistics considerations for this difficult ship-routing problem. Next, using a network flow model, we formulate the problem as a combined multi-ship pickup–delivery problem. The interaction between multiple ships arriving at the same destination makes the formulation bilinearly constrained. We use novel linearization schemes to develop an *equivalent* mixed-integer linear programming reformulation for the problem.

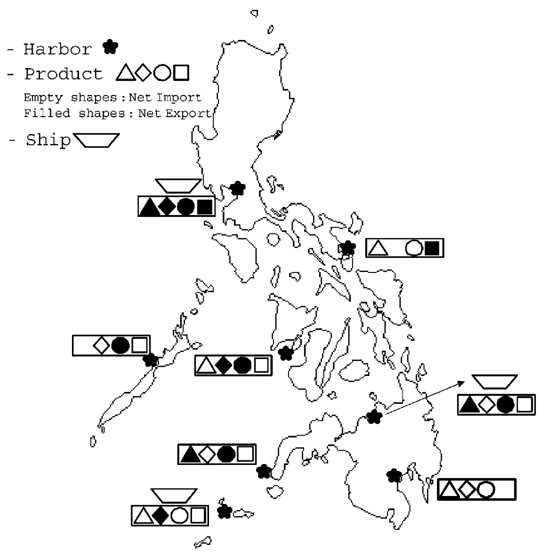

Fig. 1. A 4 product problem with 8 harbors and 3 ships.