Multi-Item Inventory Routing Problem for Ship Distribution of Liquid Oil Bulk Products

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The importance of maritime transport to the world economy is enormous; roughly 90% of total volume and 70% of the value of all goods are transported by sea (Psaraftis, 1999). Bulk transportation has the lowest cost per ton-mile transported and accounts for approximately 80% of total ton-miles transported by maritime transportation. Therefore, operational efficiency of maritime transportation can have a huge impact on consumers by reducing final product costs.

In this work a real ship operational planning problem is presented, which is a combined multi-item inventory management and a ship routing problem. In this sea transportation system, a fleet of ships transport multiple liquid oil bulk products from a set of production harbors, wherein refineries are located, to a set of consumption harbors wherein different customers have their tanks located. Customers in this system operate under Vendor Managed Inventory (VMI) agreements in which the supplier takes control of their tanks' inventory levels, ensuring that adequate service levels are maintained. Thus, the supplier needs to determine ships routes, i.e. sequence of harbors to be visited for each ship, quantities to be loaded and discharged for each product at each harbor, and oil products allocation to different ships' compartments so that security regulations are satisfied, in order to maintain adequate service levels for all customers.

An extensive review of previous research on Ship Routing and Scheduling Problems is presented by Christiansen et al (2004). More recently, Hwang (2005) presented a MIP formulation for Multi-Item maritime inventory routing problem (MIRP) with dedicated compartments, and Christiansen et al (2006) presented ongoing work on heuristics to multi-item problems.

The problem studied in this paper considers a set of different oil bulk products that must be transported by a heterogeneous fleet of multi-compartment ships. This problem differs from previous research in the literature in that there are two set of products clean and dirty, and several compatibility constraints in terms type of products that cannot travel in adjacent compartments. In addition, ships draught is a function of the weight of the load carried, and must respect navigable water depth when leaving or entering each port.

In order to address this Multi-Item MIRP, consumption and production rates per product are assumed to be fixed at each terminal during the planning horizon, and a two stage decomposition approach is used. First, the number of visits and associated time windows are established for each terminal. Then, a mixed integer programming (MIP) formulation is used to determine the route and schedule of ships, and allocation of products to compartments. In this problem, the objective function is to minimize the sum of total transportation costs, loading and unloading costs, port fees, and penalties associated to stock-outs, safety stock violations and minimum inventory targets at the end of the planning horizon.

Since the proposed MIP cannot be solved in reasonable computation time, a decomposition approach to solve this problem is proposed. This solution approach considers three stages: i) a greedy or GRASP heuristics are used to identify an initial feasible solution; ii) a sequential optimization procedure is used to improve a set of ship schedule at a time without considering compartments constraints; and finally, iii) given the set of routes obtained in (ii) product allocations are optimized considering all product-compartment allocation constraints.

In the first stage, only a predefined set of routes are considered, which are reasonable sequences, starting at a production harbor and visiting a sequence of consumption terminals. At each step, considering only already programmed visits to each terminal, the terminal that sooner will run out of inventory on any of its products is selected. Then, all combinations of routes that visit that terminal and feasible ships are evaluated, and the one with minimum cost is chosen. The allocation of products to be transported is obtained such that the next stock-out at each terminal is delayed as much as possible. This process is repeated iteratively until a plan for the complete planning horizon is constructed. In the case of the GRASP heuristic, instead of selecting the most urgent terminal and/or most economical ship-route combination, randomization is introduced in the selection process among the three most urgent terminals and/or cheapest ship-route combinations.

In the second stage, given the set of feasible routes obtained in the first stage, a subset of ships is selected and their routes are re-optimized. In this re-optimization a relaxed version of the MIP problem developed is used, where compartments and product compatibility constraints are ignored, and routes of ships not in the subset are fixed. This process is repeated iteratively until all ship routes have been re-optimized.

Finally, in the third stage, given the ship routes obtained in the previous stage, the quantities to be loaded and unloaded at each compartment at each stop are optimized taking into account all product compatibility constraints.

In tests performed with real-life instances, the proposed approach can solve problems up to six ships and twelve terminals for 15 days in less than an hour of computation time. In addition, initial results show reductions in variable operational costs of nearly 10% and important reductions in stock penalties compared to plans made by experienced personnel.

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