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A mixed-integer linear programming model for bulk grain blending and shipping

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Abstract

This paper addresses a blending and shipping problem faced by a company that manages a wheat supply chain. The problem involves the delivery of bulk products from loading ports to destination ports, which may be served by different vessel types. Since the products demanded by customers are mainly exported in bulk to overseas customers, the shipment planning is of great economic importance. The problem is formulated as a mixed-integer linear programming model. The objective function seeks to minimize the total cost including the blending, loading, transportation and inventory costs. Constraints on the system include blending and demand requirements, availability of original and blended products; as well as blending, loading, draft and vessel capacity restrictions. When solved, the model produces: (1) the quantity of each original product to be used to make blended products, (2) the quantity of each product to be loaded at each port and to be transported from each port to each customer, and (3) the number of vessels of each type to be hired in each time period. Numerical results are presented to demonstrate the feasibility of the real world bulk grain blending and shipping model.

Keywords: Distribution planning; Blending; Maritime transportation; Supply chain management; Mixed integer linear programming

1. Introduction

This paper was motivated by a problem faced by a company that manages wheat distribution planning. In the specific problem, which is the focus of this paper, products are loaded on bulk vessels of various capacities for delivery to overseas customers. A vessel involves a major capital investment, and its daily operating cost often amounts to several thousands of dollars. Proper shipment planning may, therefore, result in significant improvements in economic perfor mance, which means survival in an increasingly competitive market. The distribution network consists of a number of loading ports and destination ports (customers) that may be served by different vessel types. The vessels under consideration are hired for a single voyage at a time. In each voyage the assigned vessel may be loaded in at most two ports, and discharged in a single destination port, where the customer is located. Different original products may be blended at ports prior to loading. The problem is to assign an appropriate type and number of vessels to each customer order, while determining the quantities to be blended, and loaded at each port, and transported from each port to each customer.

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The planning process for blending and shipping should take into account the original and blended product availability at ports, vessel capacity and blending requirements, loading, blending and draft capacity restrictions at ports, and demand satisfaction. This problem is solved to minimize the total cost, which includes the blending, loading, transportation and inventory costs. A planning horizon of up to 3 months has been considered.

A mixed-integer linear programming (MILP) model is formulated to represent the bulk grain blending and shipping problem. The model can be used both as a tool for tactical planning, and a strategic tool to analyze the effects of cost components on the model in various situations. This paper points out the unique and practical contribution of the proposed optimization model for solving a real life bulk grain blending and shipping problem.

Our mathematical model includes several components from traditional optimization models. The shipping aspect of the distribution system can be considered as a specialized version of a transshipment model. The blending aspect of the problem falls into the category of a capacity allocation problem. Finally, we also have a time-expanded model, as we deal with a multi-period problem.

The paper is organized in the following manner. The next section provides a review of the related research. Section 3 describes the distribution-planning problem in detail. The problem is formulated as an optimization model in Section 4. In Section 5, a small example problem is presented to illustrate the applicability of the model. Computational results using the data from a real-life case study are reported in Section 6. Finally, the last section gives some concluding remarks.

2. Related research

Maritime transportation is the major transportation mode for international trade. Previous surveys by Ronen (1983, 1993) indicate that optimization models for maritime transportation have not been widely used. In the last decade, a growing body of advancements concerning several aspects of maritime transportation has appeared in the operations research literature. In general, the literature has shown an increase in the number of papers on ship scheduling and routing (Christiansen et al., 2004). The problem treated in this paper is not directly concerned with ship scheduling and routing problem. For an extensive modeling-oriented discussion of ship scheduling and routing problems, the interested reader is referred to several research works by Ronen (1986), Brown et al. (1987), Sherali et al. (1999), Christiansen and Fagerholt (2002). Few studies integrating ship routing with inventory can be found in Christiansen and Nygreen (1998a, b), Christiansen (1999), and Ronen (2002).

Little work has been done on maritime shipping problems with focus on the whole supply chain (Christiansen et al., 2004; Bilgen and Ozkarahan, 2004). At this point, it is suitable to mention the literature where maritime shipping is an important issue within supply chain optimization. Mehrez et al. (1995) report the modeling and solution of a real industrial ocean cargo-shipping problem, which involves the delivery of bulk products from an overseas port to transshipment ports on the US Atlantic Coast, and then over land to customers. The decisions made include the number and size of ships to be hired in each time period during the planning horizon, the number and location of transshipment ports to use, and transportation quantities from ports to customers. In addition to solving ocean-shipping problem, the system they present includes the warehousing decisions, complex cost structures, and land transportation. Shih (1997) presents a mixed integer programming (MIP) model for the planning and scheduling of coal imports from multiple suppliers for the Taiwan Power Company. The objective is to minimize total cost including the procurement, transportation, and holding costs. Constraints on the system include company procurement restrictions, power plant demand, harbor unloading capacity, inventory balance equations, blending, and safety stock requirements. The model aims to determine the amount and shipment schedules of the fuel coal imports. Liu and Sherali (2000) extended the problem studied by Shih (1997) and included coal blending and environmental issues in the mathematical model. They present a MIP zero/one model to find optimal shipping and blending decisions of coal fuel from each overseas supplier to each power plant. They seek to make cost-effective distribution and allocation decisions while considering supply, quality and price from each overseas supplier; as well as demand, quality requirements, supply resources capacities and presence of blending facilities at each power plant.

Recently, in the supply chain literature different industrial problems including decisions concerning