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Innovative Applications of O.R.

Speciality oils supply chain optimization: From a decoupled to an integrated planning approach

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ABSTRACT

We study a problem of tactical planning in a divergent supply chain. It involves decisions regarding production, inventory, internal transportation, sales and distribution to customers. The problem is motivated by the context of a company in the speciality oils industry. The overall objective at tactical level is to maximize contribution and, in order to achieve this, the planning has been divided into two separate problems. The first problem concerns sales where the final sales and distribution planning is decentralized to individual sellers. The second problem concerns production, transportation and inventory planning through refineries, hubs and depots and is managed centrally with the aim of minimizing costs. Due to this decoupling, the solution of the two problems needs to be coordinated in order to achieve the overall objective. In the company, this is pursued through an internal price system aiming at giving the sellers the incentives needed to align their decisions with the overall objective. We propose and discuss linear programming models for the decoupled and integrated planning problems. We present numerical examples to illustrate potential effects of integration and coordination and discuss the advantages and disadvantages of the integrated over the decoupled approach. While the total contribution is higher in the integrated approach, it has also been found that the sellers' contribution can be considerably lower. Therefore, we also suggest contribution sharing rules to achieve a solution where both the company and the sellers attain a better outcome under the integrated planning.

1. Introduction

Integrating decisions about production with other functions in the supply chain, such as inventory and distribution, has proved to be of significant relevance in organizations. An important body of Operations Research literature has been devoted to this issue, as reviewed by Erengüç et al. [10]. The basic idea of an integrated model is to simultaneously optimize decision variables of different functions that have traditionally been optimized in a sequence where the output of one stage was used as the input to other stage [27]. Aligning decisions under the same goal can be challenging when the objectives of the different functions are in conflict or not fully aligned with each other. Successful implementations in practice, such as King and Love [16] in the tyre industry and Martin et al. [20] in the flat glass industry, have reported significant benefits through the use of linear programming models under an integrative perspective.

In this paper, we address a problem of tactical planning in a divergent supply chain. Our motivation comes from working in a project with a company in the speciality oils industry. The logistics network is composed of refineries, hubs, depots and sales offices. Refineries and hubs act as production units. Hubs and depots serve as storage of saleable products. Sales offices are the channel for fulfilling demand from customers (but the products are never handled at the offices). Although owned by the company, the sales offices are managed independently and the decision on how to ship to customers is decentralized. According to the demand they observe, the sellers make decisions on type and amount of products to order, and from which storage location to order from. This decision is mainly driven by an internal price set by the company and the distribution cost calculated by the seller. The internal price aims at reflecting all variable costs caused by a product until it is ready to be shipped to the market. This price is set for each product and each location where it is stored. After a sale is realized, the seller receives a percentage of the contribution margin (revenue minus the internal price and minus the cost of distribution to customers), and the rest of the revenue is received by the company itself.

The production is conditioned by fixed proportions between the output of different products, while the demand for different

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products does not necessarily have the same proportions as the output from production. The supply chain planning of the company thereby faces conflicts when aligning operations activities with sales requirements.

We formulate linear programming models to represent this supply chain, considering decisions on production, inventory, internal transportation, sales and distribution to customers. In an initial approach we propose decoupled models to represent the situation where sales and distribution to customers are decided separately from the rest of the functions in the supply chain. Then, we integrate all the decisions into one model and analyze its potential to improve the performance in comparison to the decoupled models.

Integrating planning has been one of the main topics studied by recent literature in the oil supply chain. From earlier simple representations, as in the logistic planning model by Sear [28], more complex works have been reported recently. Pinto et al. [23] work on planning and scheduling applications for refinery operations. Neiro and Pinto [21] propose a model for a petroleum supply chain in the context of the Brazilian company Petrobras, integrating sources, terminals, refineries, distribution centres and consumers. Bengtsson et al. [3] integrate production and logistics decisions under uncertainty in ship arrivals. Guyonnet et al. [14] explore the potential benefits of an integrated model involving three parts of the crude oil supply chain: unloading, oil processing, and distribution. To build the unloading model, they use the scheduling model in Reddy et al. [26] as a base, while their production planning model is based on the model by Pinto and Moro [24]. For the distribution part, they develop a third model. Then, the three models are linked assuming the unloading section, the refinery, and the distribution centre are connected by pipelines. In these works, one of the main challenges is given by the numerous non-linear constraints originating from computing the properties of the products after being processed. When the planning horizon consists of various time periods, it becomes quite hard to solve real-world instances. In fact, a recent overview of refinery planning and scheduling by Bengtsson and Nonås [4] have identified the handling of non-linearities as one of the main issues in the agenda for future work.

A distinction of the problem we deal with is that fixed and unique recipes are used to mix each final product from semifinished products. These recipes are found through test runs at the refinery or solving short term operational planning problems to ensure detailed product quality requirements. This characteristic allows us to approach the problem by linear programming, in both the decoupled and the integrated approaches. A second distinction of our problem is the sales mechanism involved in the supply chain. Normally, in the oil planning literature it has been assumed that the objectives of the sales units are aligned with the objectives of the whole company. This assumption is reflected in the use of a revenue term in the objective function without discussion on how the revenue is shared among the different actors in the supply chain. The agreement among the actors has been identified by Erengüç et al. [10] as a particularly important issue on the integration of production and distribution planning in supply chains, because these agreements will determine to a large extent whether each component of the chain will be motivated to achieve the cost reductions by integrating decisions across the chain. In the decoupled version of the problem approached in this article, we give insights in the case where the interests of different decision makers in the oil supply chain are not aligned. This has been a research topic in other industrial contexts (see, for example, the problem of a furniture company by Ouhimmou et al. [22], and the problem of an oriented strand board manufacturing company by Feng et al. [11,12]).

Our contribution is threefold. First, we formulate a series of linear programming models to approach a real-world problem in the speciality oils supply chain where the current planning is based on a decoupled decision making mechanism. These models are critical to model the behavior of the coordination between sales and production. Earlier the planning did not take into account the behavior of the sellers. These models also include an important part with coordination prices at the depots. Second, we propose an integrated planning model which maximizes the contribution of this supply chain. Although the integrated planning outperforms the decoupled planning from the whole company's perspective, the sellers echelon may be left with a worse outcome. As third contribution, we identify this issue as a shortcoming of the integrated planning and discuss allocation rules to overcome it, leading to a solution where both the sellers and the company are better off in the integrated case.

The remainder of this article is organized as follows. In Section 2, we present the production process and supply chain involved in our problem. In Section 3, we describe planning and management issues in this supply chain. In Section 4, we formulate linear programming models to represent sales and operations as decoupled problems. In Section 5, we propose a linear model that integrates sales and operations decisions. In Section 6, we provide numerical results of the models, compare their outcomes and discuss premium allocations. Our concluding remarks are presented in Section 7.

2. Specialty oils supply chain

The oil industry faces a number of problems that have caught the attention of the Operations Research field. Bodington and Baker [5], Cooper [8] and Iachan [15] document that during several years the oil industry and OR have been linked in a number of applications. The oil industry has also been identified as a typical example of a divergent supply chain [29,17]. This is the case of the supply chain for speciality oils that we face in our problem, which is characterized by a divergent product structure as well as a divergent physical structure. A representation of the supply chain is presented in Fig. 1. Next, we describe its main parts.

2.1. Refineries and products

The refineries are supplied with crude oil from external suppliers. There are different types of crude oil, some of them containing more percentage of one or another component. This determines if a type of oil is more suitable to produce one or another final product. In the refineries, the crude oils are exposed to a series of processes, in order to generate saleable products. There are two product segments, that we call *basic oil products* and *speciality oil products* (or simply *basic oils* and *speciality oils*). The processes in the refineries and hubs differ somewhat for different products, but they can be simplified to the following three steps: distillation, hydrotreatment and blending.

2.1.1. Distillation

During the distillation process the crude oil is divided into several fractions. The characteristics of the fractions depend on which crude oil and *run-mode* are used and the run-mode defines the division between the fractions contained within the crude oil. This determines the characteristics of the different distillates, for instance, in terms of the hydrocarbons that will be contained within them, viscosity and point of ignition. There are several run-mode alternatives. Given a run-mode and a type of crude oil, the proportions between the distillates obtained from the process are fixed and hence, if generation of more of a certain distillate is desired, then more of the other distillates obtained in this run-mode will also be generated.