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A heuristic algorithm for a supply chain's production-distribution planning

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ABSTRACT

In this paper we consider the problem of planning the production and distribution in a supply chain. The situation consists in a set of distribution centers seeking to serve to a set of retailers; these distribution centers are supplied by a set of plants trying to minimize the operation and transportation costs. The problem is formulated as a bilevel mathematical problem where the upper level consists of deciding the amount of product sent from the distribution centers to the retailers trying to minimize the transportation costs and also by considering the costs of acquiring the products that come from the plants. Meanwhile the lower level consists in minimizing the plants' operations cost meeting the demand grouped in the distribution centers. We propose a heuristic algorithm based on Scatter Search that considers the Stackelberg's equilibrium; numerical tests show that our proposed algorithm improves the existing best known results in the literature.

1. Introduction

Nowadays, companies have noted the importance of decision making in business processes and have realized that empirical decisions may cost a lot of work, time and effort for the company. Making decisions solely based on the experience tends to be reflected in the loss of resources, especially in systems that involve operative processes such as supply chains. Consider a supply chain as the system that integrates all the components participating in the life cycle of a product, thus from the processing of raw materials to the final stage where the products are reached by the consumer. The actors involved in this process are suppliers, manufacturers, distributors, customers, among others. According to Beamon [2] these systems are classified into two basic processes: (1) The production planning and inventory control; and (2) The distribution and logistics processes. Throughout the time most researchers have studied these processes separately, that is to say they do not involve more than one component in a single system. These situations are known as mono-objectives because they only have one objective to focus in. Due to the importance of transportation costs in the final value of a product, a lot of effort has been done in order to develop more efficient techniques for decision-making in the distribution process. For example, a fact that affirms what we mention above is the amount of papers related to the vehicle routing problem and its many variants. An interesting review on the vehicle routing problem where we can find models and proposed solution techniques can be found in Toth and Vigo [32], Golden et al. [17] and Choong et al. [8].

However it should be mentioned that over the past two decades there has been an increased interest in modeling situations that involve more than one element of a supply chain. The most important components in the supply chain that need to be integrated in the same problem are the production and distribution processes. In the literature we can find two main particularities in those kinds of models: in the first one, a company controls all the decisions in a supply chain; and in the second one, more than one company may be controlling specific decisions, but all of them with the same goal in common. As we can see from the description of these two variants, they both have common goals; these kinds of situations can be properly modeled with multi-objective programming. This is the most common approach for the development of models and implementations within the union of different stages in a supply chain. Multi-objective programming problems tend to be interesting and challenging problems for their analysis. An extensive literature review of production and distribution models is presented in Vidal and Goetschalckx [33]; in Sarmiento and Nagi [28] and Goetschalckx et al. [16] a comprehensive literature review related to this integrated problems is presented. In Chen [7] a taxonomy of these kinds of models based on the structure of the integration, the level of the decisions and the parameters of the problems is done. In Fahiminia et al., [12] this integrated problem is classified according to its complexity (this is, based on one or multiple products, multiple plants, the

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number of stores, single or multiple vehicles, the number of periods as well as vehicles), and a reclassification based on the implementation techniques that were used for resolution.

These production-distribution problems have been exactly solved by using optimization software, however those optimizers have only been able to solve accurately small instances and case studies of small dimensions; the main reason is because they contain a large number of constraints and variables (see Dhaenens-Flipo and Finke [10], Jayaraman and Pirkul [20], Jang et al. [19]). Exact methods such as Lagrangian relaxations, column generation, interior points methods, among others have been used for solving or approximating these problems. One of the most used methods is the Lagrangian relaxation technique, we can find the application of this technique to production-distribution problems in Barborosoglu and Özgür [1] and Elhedhli and Goffin [11].

Also, heuristic algorithms have been developed for dealing with this problem. For example, in Cohen and Lee [9] they solved the problem in a hierarchical way fixing variables, Keskin and Üster [22] proposed various constructive heuristics in order to obtain good solutions for a specific part of the problem and then solving the resulting subproblems to optimality. Also in Williams [35] seven heuristics to solve a simultaneous production-distribution problem can be found. Motivated by the challenge of obtaining a good quality solution in a reasonable computational time, metaheuristics have been developed for these kinds of problems; Keskin and Üster [22] presented an algorithm based on scatter search with path relinking, trajectory based, and a tabu search algorithm; Boudia et al. [3] proposed a GRASP and path-relinking algorithm for a production-distribution problem; genetic algorithms can be found in Syarif et al. [30], Chan et al. [6] and Kazemi et al. [21]; and a memetic algorithm is proposed by Boudia and Prins [4].

Most of the papers that involve the production and distribution processes in one system analyze the problem with multi-stage approaches but focusing on a common objective for all the processes. Now, consider the case in which the production and distribution are controlled by different companies and each of them has its particular objective; however there is a dependency relationship between them to ensure their proper functioning, so the decisions made at each process need to consider and interact with the decisions taken in the other process. This approach is suitable for being modeled as a bilevel programming problem where there exists a hierarchy between the distribution stage over the production decision. The first bilevel production-distribution problem was introduced in Calvete et al. [5], they considered a company that is dedicated exclusively to the distribution of products and another company that is aimed to produce these products. The justification of the proposed model is natural and intuitive, because there can be many different companies in charge of a specific process within a supply chain. The company intended to distribute the products must purchase them from some plants, then the distribution centers will transport them to their customers meeting their requirements in order to minimize the distribution costs. On the other hand, the other company decides its own production plan based on their production capacity and by considering the requirements of the demand grouped in the distribution centers seeking to minimize the operation costs.

In the literature, only two techniques have been developed to solve this problem. The first technique was proposed in the seminal paper by Calvete et al. [5]. Their proposed algorithm was based on the ant colony optimization method, which finds feasible solutions within the distribution process by creating routes that simulate the behavior of an ant colony. After obtaining this decision, the information is updated at each distribution center generating orders and then solving exactly the production problem by using an optimizer. Finally, the distribution company considers the decision made by the production company and evaluates the final cost of their decision; that interaction was repeated until a stop criterion was met. That algorithm finds the Stackelberg equilibrium in each iteration. Later, Legillon et al. [25] considered the same problem and divided their research in two directions: first, they developed an algorithm called COBRA which is based on a system of parallel coevolution considering one population for each level of the problem; at each level they shared information between them and improved the current pair of decisions, they also developed another algorithm which is based on local improvements of the solution in the lower level (repair algorithm); the second part of their research was dedicated to add another objective function in the lower level of the model, thus they have a bilevel programming problem where the production company objective function was a bi-objective optimization problem. They presented numerical experimentations by considering both models and by using their proposed algorithms, but since these algorithms do not consider Stackelberg's equilibrium they do not perform any comparisons of their results against the existing benchmark instances for this problem. It is worthy to mention that, neither the objective function value nor the time obtained in the cited paper improved the ones showed in Calvete et al. [5].

This article is organized as follows: in Section 2 we present a detailed description of the problem and its mathematical formulation. In Section 3 we describe our proposed algorithm based on Scatter Search. The numerical experimentation and the results obtained by the proposed algorithm are presented in Section 4. Finally, Section 5 shows the final remarks and the opportunity areas for further research.

2. Problem's description

The problem can be described as follows: consider two different companies, one is responsible for the distribution of certain products in a supply chain and the other one is in charge of the production of these products. The first company is responsible (at each distribution center) for acquiring the items from the plants where they are produced, this acquisition creates a cost depending on the plant from which the products come, and there is also a handling cost included at the distribution centers. After that, the distribution company has to meet the demands of the retailers by creating routes that begin at the distribution centers and at the end of the route return to the same distribution center where the route started. Those routes must satisfy the demand of all the retailers, which can only be visited by a single vehicle. The vehicle fleet is homogeneous, that is, all the vehicles have the same capacity; and the length of the route is limited by the duration of a specified working day. Furthermore, distribution centers may not be connected to each other, so a route cannot involve different distribution centers. Considering all these characteristics, the objective of the company is to minimize the transportation costs and the acquiring cost.

Moreover, the production company is subject to expect delivery orders to manufacture the products by taking into account some issues related to the plant operation. The plants are capacitated and must supply the demands grouped in all the distribution centers in order to minimize their production costs. In the description presented above, it is evident that both companies have different objectives and do not cooperate with each other. It is common that in most cases the best decision made by the distribution company in order to create the routes of their vehicles is not going to be the best decision for the company responsible of producing these items. Therefore, for the own benefit of the distribution company, it needs to take into account the decision of the production company. Due to this, the problem can be