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A metaheuristic algorithm to solve the selection of transportation channels in supply chain design

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ABSTRACT

This paper addresses a supply chain design problem based on a two-echelon single-product system. In the first echelon the plants transport the product to distribution centers. In the second echelon the distribution centers transport the product to the customers. Several transportation channels are available between nodes in each echelon, with different transportation costs and times. The decision variables are the opening of distribution centers from a discrete set, the selection of the transportation channels, and the flow between facilities. The problem is modeled as a bi-objective mixed-integer program. The cost objective aggregates the opening costs and the transportation costs. The time objective considers the longest transportation time from the plants to the customers. An implementation of the classic epsilon-constraint method was used to generate true efficient sets for small instances of the problem, and approximate efficient sets for larger instances. A metaheuristic algorithm was developed to solve the problem, as the major contribution of this work. The metaheuristic algorithm combines principles of greedy functions, Scatter Search, Path Relinking and Mathematical Programming. The large instances were solved with the metaheuristic algorithm and a comparison was made in time and quality with the epsilon-constraint based algorithm. The results were favorable to the metaheuristic algorithm for large instances of the problem.

1. Introduction

In recent years Supply Chain Design has been addressed by many authors, and several reviews have been published (Aikens, 1985; Thomas and Griffin, 1996; Vidal and Goetschalckx, 1997; Beamon, 1998; Klose and Drexl, 2005; Sahin and Sural, 2007; Melo et al., 2009). The decisions imply strategic aspects related with location, capacities and technology selection, and tactical aspects like product allocation and transportation flows, among others.

In this paper we address a previous work by the authors (Olivares-Benitez et al., 2012) where a supply chain design problem, based on a two-echelon single-product system was introduced. The problem considers the location of facilities, the selection of transportation channels, the calculation of the flows between facilities, and the time-cost tradeoff. In particular, the selection of transportation channels produces a bi-objective optimization problem where cost and lead time must be minimized. The transportation channels can be seen as transportation modes (rail, truck, ship, airplane, etc.), shipping services (express, normal, overnight, etc.) or as transportations offers from different companies. Each option has a cost and time associated, and one must be selected to transport the product between nodes in each echelon. The problem was solved in an *a posteriori* approach, obtaining the non-dominated solutions set to be presented to the decision maker.

The objective in this new research was to develop a metaheuristic algorithm to solve the problem introduced by Olivares-Benitez et al. (2012). It was demonstrated that the problem belongs to the NP-Hard type. Hence it is necessary to use a heuristic method to solve large instances of the problem. The metaheuristic algorithm proposed here hybridizes elements from greedy functions, Scatter Search, Path Relinking, and Mathematical Programming. This type of hybrids, also named matheuristics, is being used in recent research but there are not applications in supply chain design yet.

The review in Section 2 describes works that connect the cost-time tradeoff in supply chain design, and in the most recent studies, the consideration of time tied to transportation decisions in multiobjective problems. According to the analysis, the use of matheuristic algorithms and transportation channel selection in

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the context of supply chain design represent major contributions of this paper.

The problem addressed along with the mathematical model is described in detail in Section 3. The methods used to solve the problem are detailed in Section 4. For small instances the epsilon-constraint based algorithm proposed by Olivares-Benitez et al. (2012) was used to obtain the true efficient sets. The largest instance solved with the epsilon-constraint based algorithm to obtain its true efficient set has 5 plants, 5 potential distribution centers, and 20 customers. To construct approximate efficient sets for larger instances the same method was used with a time limit of 3600 seconds per point. Given the complexity of the problem, a metaheuristic algorithm was developed in this work to obtain approximate efficient sets for large instances. The largest instance where an approximate efficient set was obtained has 50 plants, 50 potential distribution centers, and 100 customers. The generation of instances and the computational evaluation are described in Section 5. Finally, Section 6 presents the conclusions of this work.

2. Literature review

One characteristic that differentiates the problem introduced by Olivares-Benitez et al. (2012) from previous works in the literature is the study of the tradeoff between lead time and cost in the supply chain design, related to transportation choices. The review by Current et al. (1990) makes evident that the balance of these criteria had not been studied extensively. After that, Arntzen et al. (1995) addressed the supply chain design problem for a company that handled the cost-time tradeoff as a weighted combination in the objective function. The decision variable was the quantity of product to be sent through each transportation mode available. Transportation time was variable with respect to the quantity shipped. The problem was solved using elastic penalties for violating constraints, and a row-factorization technique. Zeng (1998) emphasized the importance of the lead time-cost tradeoff, associated to the transportation modes available between pairs of nodes in the network. A mixed-integer programming model was proposed to design the supply chain optimizing both objectives. In this work facility location was not addressed. The method proposed was a dynamic programming algorithm to construct the efficient frontier assuming the discretization of time. In the model proposed by Graves and Willems (2005) cost and time were combined in the objective function. The supply chain was configured selecting alternatives at each stage of the production and distribution network. A dynamic programming algorithm was used to solve this problem.

In recent years multiobjective problems in supply chain design have been treated with more emphasis taking advantage of increased computational resources and new methods. Chan et al. (2006) presented a multi-objective model that optimized a combined objective function with weights. Some of the criteria included cost and time functions, and one of the components of time was transportation time. Transportation time varied linearly with the quantity transported. The model included stochastic components, but facility location was not considered. A genetic algorithm was the base of an iterative method where scenarios with changing weights were solved. Altiparmak et al. (2006) proposed a model with three objective functions: to minimize total cost, to maximize total customer demand satisfied, and to minimize the unused capacity of distribution centers. Here, transportation time was handled as a constraint that determined a set of feasible distribution centers able to deliver the product to the customer before a due date. They proposed a procedure based on a genetic algorithm to obtain a set of non-dominated solutions. In the work by ElMaraghy and Majety (2008) a model was proposed to optimize cost, including the cost of late delivery. The model considered the dynamic nature of the decisions. They used commercial optimization software to solve the model, analyzing different scenarios. The review by Farahani et al. (2010) about multi-criteria models for facility location problems describes some works where metrics of cost and service level are considered. The metaheuristic methods mentioned include multi-objective versions of Scatter Search, Tabu Search, Simulated Annealing, Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO). However, some other metaheuristics that were created for multiobjective applications were also mentioned, like Simple Evolutionary Algorithm for Multi-Objective Optimization (SEAMO), Strength Pareto Evolutionary Algorithm version 2 (SPEA2), Pareto Envelop based Selection Algorithm (PESA), Non-dominated Sorting Genetic Algorithm II (NSGA-II), Vector Evaluated Genetic Algorithm (VEGA), and the Multi-Objective Genetic Algorithm (MOGA).

More recently, several works have appeared for multiobjective supply chain design. Pishvaee et al. (2010) studied a model for a forward/reverse logistics network design from a bi-objective optimization perspective. The objectives to optimize were the total cost of the system and the fulfillment of the demand and return rates. Although they considered lead time into their model, similar to Altiparmak et al. (2006) it was considered in the meeting of a due date, and not related to transportation alternatives. They developed a memetic algorithm to solve this NP-hard problem. Moncayo-Martinez and Zhang (2011) proposed a model similar to that of Graves and Willems (2005) where activities must be selected to design the supply chain. This was a bi-objective model that optimized cost and lead time in a multi-echelon network. The decision variable is the selection of the resource for a certain activity in the supply chain. They used a Pareto Ant Colony Optimization metaheuristic to obtain the Pareto Optimal Set. Liao et al. (2011) also studied a multiobjective problem for supply chain design. In this case they integrated location and inventory decisions. The objectives were the minimization of cost, the maximization of the fill rate, and the maximization of demand fulfilled within a coverage distance. The lead time was implied in the cost of the safety stock, but it was not related to transportation decisions. The method proposed was a hybrid of NSGA-II and an assignment heuristic. Pinto-Varela et al. (2011) presented a bi-objective optimization model for the design of supply chains considering economic and environmental criteria. In their model, time was considered since the point of view of a multi-period approach. Different transportation modes may exist, but they are not associated to the time. They solved three small examples with mathematical programming commercial software. The review by Mansouri et al. (2012) emphasized the importance of multiobjective optimization techniques as decision support tool in supply chain management. Although order promising decisions and network design decisions were identified as important criteria, none of the works reviewed integrated them in a multiobjective approach. Chaabane et al. (2012) presented a multi-period multiobjective optimization problem where cost and environmental objectives were optimized. In their mixed-integer programming model, the selection of transportation modes was considered as a decision variable but it was not connected with time. They used mathematical programming commercial software to solve small instances of the problem. Sadjady and Davoudpour (2012) studied a problem for supply chain design where cost and time were tied to transportation alternatives. The approach, however, was to optimize a single objective function where lead time from the transportation alternative was transformed into a cost function. The cost objective function is optimized using a Lagrangian relaxation method. As proposed by Olivares-Benitez et al.