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A bilinear goal programming model and a modified Benders decomposition algorithm for supply chain reconfiguration and supplier selection

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ABSTRACT

The problem addressed in this paper is related to an aerospace company seeking to change its outsourcing strategies in order to meet the expected demand increase and customer satisfaction requirements regarding delivery dates and amounts. A bilinear goal programming model is developed to achieve the company's objectives. A modified Benders decomposition method is successfully applied to handle bilinear goal programming models in which the complicating binary variables affect the values of the deviational variables of goals attainment. This influence leads to formulate the master and the sub-problem as two goal programming models with different objective function decompositions as compared to the classical Benders one. Computational experiments show that the modified Benders algorithm outperforms a generic linearization method by reaching the optimal solution for larger problem with about 75% reduction in computation time.

1. Introduction

Improving the efficiency of supply chain partners has become a major requirement of any supply chain due to highly competitive nature of the current marketplace. This requirement may lead the decision makers to reconfigure their supply chains towards achieving a better performance of their incorporated tiers. The decision of reconfiguring the supply chain includes which suppliers to select, how to distribute materials among them, and how to better allocate their capacities. Hence, the supply chain reconfiguration problem presents itself as a major challenge in this regard.

There are many reasons to which the need for supply chain reconfiguration may be attributed. For example, the rapid advancement of technologies in the computer industry is the main driver behind reconfiguring the Digital Equipment Corporation supply chain, Arntzen et al. (1995). The new strategy reduced the cumulative cost by $1 billion, the assets by $400 million and increased the unit utilization by 500%. P&G's supply chain has been reconfigured to optimize the product sourcing problems, Camm et al. (1997). After two years of implementing modeling recommendations, 12 sites have been closed and annual savings have reached $250 million per year. The BASF North America's distribution system is also a good example for a company that realized great benefits from reconfiguring its network, Sery et al. (2001). The main objectives of reconfiguring their network are to reduce the distribution costs and provide a sufficient level of customer service. The proposed model outcomes resulted in cost savings of $10 millions and increasing the percentage of volume delivered within one day from 77% to 90%. Hewlett-Packard (HP) achieved cost savings of $10 million by reducing the number of contract manufactures, Laval et al. (2005). For a divergent supply chain reconfiguration, Vila et al. (2006) analyze the raw materials processing when there is a limited and regulated availability of raw materials. The study was applied in a partnership with three large Canadian lumber companies and a 15.4% increase of after tax profits was attained.

In this paper, we are dealing with a supply chain that needs to be reconfigured as a result of increasing customer demand and poor on time delivery performance of the company. The company looks for the minimum cost policy that better utilizes suppliers' capacities in order to face the demand increase, and improve the on time delivery performance of the chain. A bilinear goal programming reconfiguration model is developed to achieve these new objectives. The proposed model is solved through decomposition using a modified Benders decomposition technique that decomposes the model into a binary supplier selection model and a mixed-integer distribution planning model.

The paper is organized as follows; the next section is a review of the related literature to the problem of interest and the used approach. The problem is defined in Section 3 while Section 4 describes the proposed goal programming model to handle this

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problem. Section 5 illustrates the generic linearization scheme proposed by Peterson (1971) and the proposed algorithm is explained in Section 6. Section 7 shows the computational efficiency of the developed method compared to Peterson's linearization scheme. Then the paper ends with the summary and conclusion.

2. Literature review

In this review we focus on the research dealing with supplier selection and supply chain configuration problems simultaneously, to show the different criteria used to select suppliers and the techniques being applied. Also, the application of Benders decomposition technique to supply chain related problems is reviewed.

Supplier selection criteria may differ from one problem to another. Among these criteria, cost minimization is the most common one used to decide on the selected suppliers. For example, in Yan et al. (2003) cost is the single criterion that carried out the supplier selection decision process using some logical constraints representing the relationships among products, producers and suppliers through the bill of material constraints. These logical constraints are incorporated with the system constraints in a mixed integer programming model to minimize the total cost of the supply chain. In Tanonkou et al. (2006) suppliers are selected based on shipment and ordering cost, and safety stock cost at the supplied distribution centre. The work integrates the facility location problem with the supplier selection problem in a nonlinear programming model that is solved using Lagrangian relaxation method. Akanle and Zhang (2008) tackle the problem of satisfying customer orders by choosing the optimum set of resources, suppliers of various components, assembly plants and transportation options at minimal cost. The time involved in delivering and manufacturing the components and assembling the final products is restricted by the due date of the order. A multi-agent system is developed to model the resource options existing in the supply chain. An iterative agent bidding process is proposed to allow the agent-based supply-chain model to interact with customer orders representing the future demand.

Other criteria such as delivery performance, customer satisfaction, quality, flexibility and environmental performance are also used to decide which suppliers are selected. Ehap and Benita (2000) develop an iterative method to solve a multi-objective model handling both strategic and operational decisions of the supply chain. Each level of decisions is represented by a sub-model. The strategic sub-model aims at optimizing supply chain configuration and material flow decisions, while the operational model aims at achieving a trade-off among cost, service level and flexibility measures and accommodating for anticipated demand. Altiparmak et al. (2006) propose a mixed integer nonlinear model with three conflicting objectives: cost, service level and capacity utilization balance. The set of Pareto optimal solutions is obtained using a genetic algorithm. The model offers different alternatives to the decision maker by applying two different weighting approaches to the conflicting objectives. Cost, delivery performance and environmental performance are the three multi-objectives of the genetic algorithm proposed by Komoto et al. (2005). The proposed algorithm selects a suitable reconfiguration rule that governs the distribution of orders to suppliers. A discrete event simulation technique is used to evaluate these objectives. The reconfigured chain is examined to check whether it is capable of satisfying the environmental and delivery requirements or not. In Dotoli et al. (2005), a hierarchal decision system is proposed to design an integrated e-supply chain. At the first level, candidates for each stage of the chain are ranked based on their financial return and cost, risk management, flexibility, service quality, service time and environmental performance. Then a network design module that represents the integrated e-supply chain with a digraph describing partners, material and information links determines the configuration of the network. The selected network configuration is evaluated through a validation module by comparing tactical and operational performance indices. Zhiying and Jens (2007) propose a multi-objective supplier selection model and solve it by using a genetic algorithm to recover the nonlinearity of the model. A trade-off among four criteria (cost, quality, delivery and flexibility) is used to support the decision of selecting suppliers keeping in mind demand and capacity constraint. Huang and Keskar (2007) integrate strategic thinking with quantitative optimization in order to make the optimal decisions on supplier selection that match the business strategy. They propose a set of comprehensive metrics categorized under seven categories: reliability, responsiveness, flexibility, cost and financial, assets and infrastructure, safety and environmental metrics. These metrics can be configured by the management based on its business model to guide the quantitative optimization.

Other researchers use special techniques to assign weights to the criteria controlling the decision. William (2007) combines the analytic hierarchy process (AHP) and goal programming (GP) to model a multi-objective decision making problem aiming at selecting the best warehouses among the candidates. The AHP is used to give weights or priorities to the warehouses based on two conflicting criteria; customer satisfaction level and operational cost. These priorities are incorporated in a GP model that considers system and goal constraints. Demirtas and Üstün (2008) integrate the analytic network process (ANP) and multi-objectives mixed integer linear programming (MOMILP) model to solve supplier selection and order allocation problem. Weights are assigned to the multi-criteria using ANP approach that extends the concepts of AHP. The set of the efficient solutions of the model is obtained using the ε-constraint and reservation level driven Tchebycheff procedure (RLTP) methods. The quality of the solutions obtained by these two algorithms is compared using an additive utility function. The suppliers are evaluated according to 14 criteria that are involved in four control hierarchies: benefits, opportunities, cost and risks.

Huang and Qu (2008) deal with a specific type of supply chain in which the alternative suppliers of a stage have the right to decide autonomously for configuring their respective upstream stages. The applied methodology to configure this kind of chains is the analytical target cascading (ATC) in which each alternative enterprise of a stage should be modeled as an individual ATC element. They introduce new kinds of elements (“OR” elements) to the ATC in order to represent the alternative enterprises at each stage. Each “OR” element will select its best alternative element based on predefined internal working logic and evaluation criteria.

Benders decomposition technique has been applied to solve supply chain network design problems after the generalization of the technique to handle nonlinearity using nonlinear duality theory (Geoffrion, 1972). In Geoffrion and Graves (1974), a multi-commodity capacitated distribution system design problem is solved to optimality using a small number of Benders cuts. Van Roy (1986) introduces a unified framework that combines Benders decomposition and Lagrangian relaxation to solve the capacitated facility location problem. For the same problem, Wentges (1996) strengthens Benders cuts through two heuristics that modify the new cut in order to accelerate the bounds convergence. Üster et al. (2007) also accelerate the classical Benders technique through introducing three different