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Production stage allocation problem in large corporations ☆

Lu Zhen [a,*], Dan Zhuge [a], Sheng-Lei Zhu [b]

[a] School of Management, Shanghai University, Shang Da Road 99, Shanghai 200444, China
[b] Shanghai Automotive Industry Corporation (SAIC Motor) Group, Wei Hai Road 489, Shanghai 200041, China

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ABSTRACT

This paper studies a strategic-level decision problem on assigning production stages to geographically distributed subsidiaries in a large corporation so as to minimize the fixed cost and the expected value of the production/transportation costs under stochastic demands of customers. The influence of the economies and diseconomies of scale on unit production cost is considered. A nonlinear mixed integer programming model is designed for this problem. A local branching based solution method and a particle swarm optimization based solution method are developed for solving the model. Computational tests on real world data of Shanghai Volkswagen Auto Corp. are conducted. The results show that the proposed model can save about 2.5% of its revenue by comparing with the current decisions.

1. Introduction

Products made by large manufacturing corporations are often complicated. The production process of fabricating parts and assembling products is also very complex. The process usually contains plenty of production stages, which are connected in either sequential or parallel ways and construct a complex production flow network. On the side of the large corporations, they usually contain many nationwide or worldwide distributed subsidiaries (or factories). Determining how to allocate the production stages to the subsidiaries of a large corporation is an important strategic-level decision for executive officers of the corporation.

This problem is motivated by our recent collaboration with an automobile manufacturing corporation in Shanghai, China. In recent years, both the annual yield and the annual sales of automobiles in China have been the largest in the world. The yield and the sales volume in 2014 are 23.7 and 23.5 million, respectively. About 80% of the volume is contributed by six auto groups in China, among which the Shanghai Auto Industry Corp. (SAIC Motor) Group is the largest one and makes/sells about 5.6 million automobiles in 2014. The competition of the auto market in China is very fierce. The pace of the auto product upgradation becomes more and more frequent. It is quite common for these large auto corporations to launch new models of automobiles in each year. The production of automobiles is a complex process and needs huge investments as fixed costs. In an auto corporation, the capacity, strength, condition of its subsidiaries (or factories) are different from each other. Due to the large production volume, the economies and diseconomies of scale affect the unit production cost in each subsidiary. Moreover, the automobile demands in each district are also uncertain. Efficient management of production and transportation flows among the auto corporation's subsidiary network requires systematic considerations of the above mentioned miscellaneous issues (e.g., subsidiaries' heterogeneity, stochastic demands, the economies and diseconomies of scale, etc.) in a comprehensive way. In realistic environment, this strategic-level decision was usually reached according to the experience of the auto corporation's executive officers. However, the corporation gradually realized that scientific approaches on production stage allocation, rather than 'common-sense' heuristics, are the roads to achieve sustainability, profitability, growth, and competiveness. Thus, we designed a decision model to determine a suitable allocation of production stages in its subsidiaries for minimizing the total cost, which includes the fixed, production, and transportation costs. This is a commonly faced problem, not only at the auto corporations, but also at many large manufacturers in other industries.

This paper makes an explorative study on the production stage allocation problem with considering the factors of uncertain demands and the economies/diseconomies of scale. By using the methodology of stochastic programming model formulation, a nonlinear mixed integer programming model is designed for this problem. Some linearization methods are proposed to linearize the model. Some lower and upper bounds are also developed for analyzing the properties of the model. A local branching based solution method and a Particle Swarm Optimization (PSO) based solution method are developed for solving the proposed model. Numerical experiments using real world instances are conducted

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* Corresponding author.
E-mail addresses: lzhen@shu.edu.cn (L. Zhen), zhugedan@shu.edu.cn (D. Zhuge), zhushenglei@saicmotor.com (S.-L. Zhu).

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to validate the effectiveness of the proposed model and the efficiency of the proposed solution method.

The remainder of this paper is organized as follows: Section 2 reviews the related works; Section 3 elaborates on the problem background; a model is formulated in Section 4; and some model analysis is given in Section 5. Two solution methods are developed in Section 6. Experiments are elaborated in Section 7, and closing remarks are outlined in the last section.

2. Related works

Although the problem in this study is about the production stage allocation in subsidiaries of a corporation, its essence is like a supply chain network design problem with an assumption that the supply chain network is made up by the suppliers that belong to one corporation or group. In this study, the notion of the subsidiary network in a corporation is not the generic concept of the supply chain network. As there are few studies in the literature that are directly related with the production stage allocation problem, the related works are mainly reviewed through the perspective of supply chain network design.

Supply chain network design is about the decisions on the structure of a chain and the effects on the costs and performance. It deals with a variety of decisions such as determining number, size and location of facilities in a supply chain and may include tactical decisions (such as distribution, transportation and inventory management policies) as well as operational decisions (such as fulfilling customers demand). Supply chain network modeling has gain a great research interest. Klibi, et al. [15] gave a review for the literature on the supply chain network design problems under uncertainty. Santoso et al. [23] proposed a stochastic programming model and solution algorithm for solving supply chain network design problems under uncertainty. The mixed-integer linear programming (MIP) models were widely formulated in this area for optimizing decisions on supply chain network design. For example, Georgiadis, et al. [9] proposed a MIP model for designing supply chain networks which comprise multiproduct production facilities with shared production resources, warehouses, distribution centers and customer zones and time varying uncertain demand. The standard branch-and-bound technique was used to solve their model. Sadjady and Davoudpour [22] studied a two-echelon supply chain network design problem in deterministic, single-period, multi-commodity contexts. A MIP model was designed to locate and size manufacturing plants and distribution warehouses, assign the retailers' demands to the warehouses, and the warehouses to the plants, as well as select transportation modes. In addition, the methodology of nonlinear MIP modeling was also used for optimizing the supply chain network decisions. Özceylan, et al. [21] designed a nonlinear MIP model which jointly optimizes the strategic and tactical level decisions in a closed-loop supply chain. The total costs of transportation, purchasing, refurbishing, and operating the disassembly workstations are minimized in their model. Sarrafha, et al. [24] integrated the flow-shop scheduling decisions in the multi-echelon supply chain network design. A bi-objective non-linear MIP programming model was formulated with considering the shortage in the form of backorder in each period. They designed a multi-objective biogeography based optimization solution method with tuned parameters to find a near-optimum solution. Longinidis and Georgiadis [17] designed a non-linear MIP model to integrate the strategic level supply chain network design and some advance financial management methods, such as sale and leaseback technique. A solution method was also developed to solve the model to global optimality. Longinidis et al. [18] further considered the factor of exchange rate risk in the supply chain network design, because the exchange rate considerations have become more and more important for the global supply chain operations. In the area of supply chain optimization under global context, Dong et al. [4] analyzed the influence of operational flexibility on companies' economic exposure to currency fluctuations in the presence of global competition. In addition, the factor of uncertainty is a nonnegligible issue for the supply chain design related studies. Klibi and Martel [16] proposed a risk modeling approach to facilitate the evaluation and the design of supply chain networks operating under an environment with random, hazardous and deeply uncertain events.

An important reason for why the supply chain network design problems have a voluminous literature is that each study may consider one or several realistic factors under some specific environments that are unique and different from existing studies. In the fields of the supply chain network design, there are a lot of possible realistic factors that can be considered [11]. For example, Lu et al. [19] considered the influence of the economies and diseconomies of scale on marginal cost, which was usually regarded as a constant. When considering a large production spectrum, the marginal cost tends to initially decrease as volume increases, and when past a certain production level, it starts to increase. This study also takes account of the above realistic factor. Gong, et al. [10] studied the logical interdependencies between the supply chain network and the possible disruptions to infrastructures. They designed a supply chain restoration model with considering infrastructure. Besides the above studies focusing on economic performance, Devika et al. [3] considered the three pillars of environmental sustainability, and proposed a multi-objective model for a closed-loop supply chain network with six echelons. Three hybrid meta-heuristic methods were developed. Cruz and Liu [2] derived a network equilibrium pattern of production, transactions, prices, and levels of social relationship for a multi-period supply chain network so as to investigate the interplay of the heterogeneous decision-makers (subsidiaries, manufacturers, and retailers) associated at different tiers. Jabbarzadeh, et al. [13] investigated an emergency blood supply network design problem for the supply of blood during and after disasters. Some insights from tradeoff between solution robustness and model robustness were obtained and discussed. Wang et al. [26,] studied container supply chain network design problems for shipping line companies. The factor of 'elastic demand' was considered in the network design [26]. In their problem, shipment demand is dependent on the freight rate. In addition, a novel concept of segment-based network alteration was proposed as an alternative way for facilitating supply network optimization [27]. Another realistic factor in supply chain design is about the competition. In reality, a decision maker cannot just deal with a single supply chain and ignore the existing competitors and future emerging ones [20]. Although the competition issue is not taken into account in this study, the supply chain competition becomes a more and more interesting research topic recently. There are abundant literatures in this area. Farahani et al. [6] gave a comprehensive review on the literatures which focus on the effects of competitive environment on supply chain design. They also proposed a general framework for modeling the competitive supply chain network design problems and some potential areas for future research.

Although the field of supply chain network contains abundant related works, this study differs from them in the following aspects. This study is concerned with an interaction between two complex networks: one is the supply chain network (or subsidiary network); the other is the production flow network, which is constituted by interrelated production stages. Most of the existing related studies usually assumed a simplified production flow with only a few of sequentially connected stages. And the underlying multiple-to-multiple mapping between the stages and subsidiaries (or suppliers) was often implicitly simplified as one-to-multiple or multiple-to-one mapping. Therefore, a more exact and rigorous name of this problem should be: complex production flow network oriented production stage allocation among