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An outer approximation method for an integration of supply chain network designing and assembly line balancing under uncertainty ☆

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ABSTRACT

In this paper a new model is proposed for the integrated problem of supply chain network designing and assembly line balancing under demand uncertainty. In this problem there are three types of entities: manufacturers, assemblers and customers. Manufacturers provide assemblers with components and assemblers use these components to produce the final products and satisfy the demand of the customers. This problem involves determining the location of manufacturers and assemblers in the network, balancing the assembly lines, and transportation of materials and products throughout the network. A mixed integer nonlinear programming formulation based on two stage stochastic programming method is developed to solve this problem to optimality. Moreover, an outer approximation (OA) method is proposed to efficiently solve this problem. The computational results show efficiency of the proposed OA method.

1. Introduction

Designing a distribution network involves making several decisions in different levels. At the top strategic level, location of different facilities such as manufacturers and warehouses has to be determined (Levi, Kaminsky, & Levi, 2003). In lower tactical levels, mid-term and short-term decisions of transportation of materials and products, inventory decisions, lot sizing ad scheduling decisions are made (Mula, Peidro, Díaz-Madroñero, & Vicens, 2010). Because of high dependency among strategic and tactical decisions, it is beneficial to integrate these decisions to obtain a more general model.

Nowadays increased span of supply chains and emerging global distribution networks along with increasing competition in the production environment have highlighted the importance of optimizing these networks to enhance their performance and increase their responsiveness to the customers' changing demands (Badri, Bashiri, & Hejazi, 2013; Goetschalckx, Vidal, & Dogan, 2002). One way to improve the performance of supply chains is to integrate the strategic and tactical decisions (such as inventory control, lot sizing, and scheduling) in a more general model (Goetschalckx et al., 2002). Therefore, some research papers have attempted to obtain a more comprehensive model by simultaneously considering some of these decisions in their models. However there has been little attention towards integrating assembly line balancing with supply chain designing decisions.

Assembly line balancing is a tactical decision problem that arises when mass production of a standardized commodity is required but it can also be used in low-volume production of customized products. An assembly line consists of several stations that are linked together by a conveyor or a similar material handling system. This system provides the material needed to assemble the final product; it also moves the work-pieces through the line. The production process starts from the first station, where a set of tasks are performed on the work-piece, then it is transferred to the next station to perform the next set of tasks on the work-piece. This procedure continues until the complete product is produced in the final station.

The total amount of work that is needed to be done to assemble the final product is divided into N basic operations $I = \{1, 2, \ldots, N\}$ called tasks. Each task $i \in I$ has a processing time of t_i which is called task time. Moreover, due to some technological constraints, each task has a set of predecessors that must be completed before its starting time. These precedence constraints can be represented in a precedence graph, vertices of this graph represent the tasks and

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every arc represents a precedence relation between tasks; in other words each arc (i, h) indicates that task h is a successor of task i.

The problem of partitioning the set of tasks I among stations to optimize some objective functions is known as assembly line balancing problem (ALBP) (Baybars, 1986). The first research to formally present assembly line as a mathematical formulation is performed by Salveson (1955). Since then, numerous researches have been conducted to model this type of production system. The most studied problem in the field of assembly line research is called simple assembly line balancing problem (SALBP). SALBP can be described as follows: given a list of tasks, the time required to perform each task and the precedence constraints between tasks, partition these tasks into stations such that either:

(1) For a given cycle time *(CT)* the number of stations (J) is minimized (SALBP-1).
(2) For a given J, CT is minimized (SALBP-2).
(3) J and CT are simultaneously minimized (SALBP-E).
(4) For a given J and CT, a feasible assignment of tasks to stations is obtained (SALBP-F).

SALBP has the following properties: (Becker & Scholl, 2006)

- Mass production of one homogenous product.
- Given production process.
- Paced line (no buffer between the stations).
- Deterministic and integer operation times.
- No assignment constraints other than precedence constraints.
- Straight line layout.
- All stations are equally equipped with respect to machines and workers.

The assembly line balancing decisions fall in the category of tactical mid-term decisions among the decision problems that arise in managing production systems (Scholl & Becker, 2006; Paksoy, Özceylan, & Gökçen, 2012). Integrating the assembly line balancing decisions with other supply chain designing decisions results in a better coordination of assembly lines with other operations of the supply chain (Paksoy et al., 2012).

Feasibility of a supply chain design is affected by different uncertain factors such as seasonal fluctuation of supply and demand variability. Ignoring these uncertainties may result in infeasible or sub-optimal designs. Demand uncertainty of customers in the supply chain can be reflected in the model using scenario based stochastic programming models.

Contrary to the deterministic models, in which perfect knowledge of the future is available and the decision variables are selected according to this knowledge, scenario-based stochastic programming models consider a number of possible futures. This is done by categorizing the decisions into first stage 'here and now' decisions, and second stage 'wait and see' decisions. The 'here and now' decisions are made before realization of uncertain parameters, but 'wait and see' decisions are made after their realization. Therefore 'wait and see' decisions are dependent on which scenario unfolds (Kall & Wallace, 1994). This is a perfect fit for supply chain network designing problems, where strategic decisions, such as facility location, can be considered as first stage decisions and tactical decisions, such as transportation of materials, can be considered as second stage decisions (Mirhassani, Lucas, Mitra, Messina, & Poojari, 2000). Addressing uncertainties in the supply chain designing results in a better design that is more robust and resilient when facing uncertainties (Santoso, Ahmed, Goetschalckx, & Shapiro, 2005).

In this paper, assembly line balancing and supply chain network designing decisions are simultaneously considered with uncertain demands. This problem involves determining the location of manufacturers and assembly lines, assigning tasks to stations in assembly lines, and transporting the components and products through the distribution network in order to minimize the average cost of the system. Cycle times of each assembly line and their locations are considered as decision variable. The contribution of this paper is twofold: (1) developing a better model for the integrated problem of supply chain network designing and assembly line balancing by addressing the location and capacity decisions for the manufacturers and assemblers. (2) Developing an efficient outer approximation method to efficiently solve the problem.

According to the literature review in Section 2 there is no model for the integrated problem of supply chain network designing and assembly line balancing that considers the location and capacity of the manufacturers and assemblers as a decision variable. Moreover, demand uncertainty has not been addressed in the literature of this problem. In addition, this paper makes the first attempt to use outer approximation to solve this problem.

This paper is organized as follows. In Section 2 the literature of supply chain network designing problem and assembly line balancing is reviewed. In Section 3 the proposed problem is described and a mixed integer nonlinear programming model is developed for this problem. In Section 4 an outer approximation method is developed to efficiently solve the problem. Section 5 presents the computational results. Finally in Section 6 the paper is concluded and suggestions for the future research in this area are presented.

2. Literature review

Supply chain management has received a lot of attention from researchers for several decades and supply chain network designing and optimization is one of the most popular problems in this field. Therefore many methods have been used to model and optimize supply chain networks. Generally, the supply chain network designing problem is defined with three considerations: (i) location of facilities. (ii) Designing the network configuration. (iii) Satisfying the demand of customers while minimizing the total cost, including transportation costs, fixed opening costs of facilities and purchasing costs. Moreover, some of the research papers in this field have tried to address other, more tactical, functions of supply chains in their models. Some examples are considering inventory control, lot sizing and scheduling decisions in supply chain designing.

Incorporating inventory decisions in supply chain designing problems have been studied in several papers. For example Daskin, Coullard, and Shen (2002) considered working and safety stock inventory decisions at the distribution centers in a facility location model. They developed a solution method based on Lagrangian relaxation for a special case of the problem. They also developed efficient heuristic algorithms to solve their model. Wadhwa, Bibhushan, and Chan (2009) investigated the impact of demand disturbances on the performance of some inventory control policies in a supply chain. They found that independent decision making by each supply node result in a bullwhip effect. Moreover, their results show that the inventory policy which is the most efficient for a single supply node generally performs poorly from a supply chain perspective. Arora, Chan, and Tiwari (2010) developed policy analysis for an integrated inventory and logistic problem. They addressed a supply chain consisting of distributors and retailers, where distributors send the delivery vehicles to the retailers. They employed the concept of vendor managed inventory for the retailers and an order up to quantity (q, Q) policy for the distributor. The vehicle routing decisions are determined using a dynamic ant colony algorithm. Chan and