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Coordination of production scheduling and delivery problems with heterogeneous fleet

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ABSTRACT

In a production scheduling with delivery problem, there are different types of products processed by a distribution center and then delivered to retailers. Each retailer order might be consisted of different products. The resolution of this problem is to determine the production sequence, retailers' needs to heterogeneous fleet of vehicles and the visiting sequence of each vehicle for delivery goods within time windows. In this article, a nonlinear mathematical model is proposed with minimizing the total cost which includes transportation cost, vehicle arrangement cost and penalty costs, subjected to satisfy all demands of each retailer. Following, two adaptive genetic algorithms (AGAs) are designed and tested in variety of production and delivery scenarios. The computational experiments show that the total cost gradually decreases as the vehicle type employed in the delivery stage increasing. In addition, more kinds of vehicle types provided in the delivery stage could reduce fixed vehicle cost and variable routing cost.

1. Introduction

Under the current competitive environment, coordination production and delivery problems have been widely discussed in many industries. Consider the distributor stage and the retail stage of two echelon supply chain; it is an important element of reducing the retailer's inventory to achieve the goal of just-in-time. The distribution center has to deliver the products within a limited time to fulfill their order from retailers in order to be more competitive. This paper investigates a practical scheduling and delivery problem of a distribution center (logistics plant). In the distribution center, handling of a retailer's order is looked as an operation such as picking, packing, processing, and should be completed on a single workstation. A variety of products which a retailer required in an order is processed as a batch and put it into a container for delivery convenience. A completed batch might be delivered immediately or group delivered with other batches (retailers' order) to the corresponding retailers depending on the required performance measures such as minimization of total cost, minimization of total delivery distance or minimization of total delivery time deviation. This kind of production scheduling and delivery scenario between distribution center and retailers are popularly seen in the real world such as two echelon supply chain of 7–11 convenience stores, and McDonald's corporation. Traditional research has separately and sequentially investigated scheduling and order delivery without effective coordination. However, making two individual but uncoordinated decisions will not produce a global optimal solution. Furthermore, a good scheduling plan or delivery plan cannot guarantee a good performance of an integrated plan.

Besides, because the retailer's warehouse capacity is quite limited, they prefer to receipt merchandise on time to increase turnover of internal products. Hence, each order requires processing in the distribution center and delivery it to a predetermined location within a time window. The distribution center is required to pay the penalty cost for retailer if the vehicle arrival time later or earlier than retailer's time window. The decision maker has to decide how many vehicles of each type to use given a mix of vehicle types differing in capacity and costs, when the producing orders should start to be picked up and when they can be assigned to a vehicle so that the orders can be optimized into a delivery route. The operational decision-making is to determine the minimum total cost including fixed vehicles cost, variable routing cost and penalty cost of violation time window.

In the recent years, for the two echelon supply chain problems, most of articles focused on production and distribution planning such as Liang (2008) and Safaei et al. (2010), Samaranayake et al. (2011) and Steinrücke (2011). However, this study is related to research concerned with production scheduling and delivery (Chang and Lee, 2004; Zhong et al., 2007; Li and Yuan, 2009; Zdrzalka, 1995; Lu et al., 2008; Wang and Cheng, 2009; Adulyasak et al., 2014a, 2014b). Chang and Lee

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(2004) studied machine scheduling problems with explicit transportation considerations. Each finished job has a different size during delivery. Three scenarios of the problem are discussed. In addition, the authors provide a proof of NP-hardness and a heuristic with worst-case analysis. Zhong et al. (2007) dealt with two production environments, single machine and parallel machines, and delivery to single customer set. For the first problem, in which jobs are processed on a single machine and a best possible approximation algorithm with a worst-case ratio arbitrarily close to 3/2 is proposed. An improved algorithm with a worst-case ratio 5/3 is proposed where jobs are processed in two parallel machines case. Lu et al. (2008) developed a single machine scheduling problem incorporated the routing decisions of a delivery vehicle which at most c jobs at a shipment. When the preemption is not allowed, they showed that this problem is strongly NP-hard for each fixed $c \geq 1$. Although the joint production and delivery scheduling problem has received significant attention, the previous research has focused on delivering to customers who are located in a few areas ($n<3$) or where few vehicles are available to deliver the products to specified customers. It may not occur in every industrial environment in practice. Therefore, the detailed planning between each customer's ($n \geq 3$) delivery will be proposed in this study. In addition, a 5/3-approximation algorithm was proposed for solving this problem. For the related research in production routing problem, Adulyasak et al. (2014a) introduced an optimization-based adaptive large neighborhood search heuristic for this category. In the heuristic, binary variables representing setup and routing decisions are handled by an enumeration scheme and upper-level search operators, respectively, and continuous variables associated with production, inventory, and shipment quantities are set by solving a network flow subproblem. Adulyasak et al. (2014b) extended the topic to inventory routing problem and branch-and-cut algorithms were proposed to solve the different formulations.

Although the production scheduling with delivery problem has received significant attention, few papers applied to practical production environment. The literature on practical issues is discussed as follows: Naso et al. (2007), Chen et al. (2009), Geismar et al. (2008), Day et al. (2009), Bredström and Ronnqvist (2008), and Low et al. (2013). In those papers, Naso et al. (2007) focused their work on ready-mixed concrete delivery. In their work, a genetic algorithm is applied to solve the integrated production planning and distribution routing problem. The strict time-constraints forbid both earliness and lateness of the supply to be taken into account as well. Chen et al. (2009) addressed the integrated production and distribution problem for perishable food products. The demands at retailers are assumed stochastic and they will be a random variable with a probability density function. The authors elaborate a solution algorithm composed of the constrained Nelder–Mead method and a heuristic is then proposed for solving the vehicle routing with time windows problem. Low et al. (2013) developed an adaptive genetic algorithm for solving integrated scheduling and delivery problem.

We first present an integer nonlinear programming model for the addressed problem which is the integration of a production scheduling and vehicle routing problem with a time window constraint. Following, two evolutionary algorithms are developed for obtaining better solution for the medium to large scale problems, and numerical results are provided as well.

2. Model formulation

2.1. Description of problem

Considering a two echelon supply chain with one distribution center and N retailers production scheduling – delivery problem. In the distribution center, handling of a retailer's order is looked as an operation such as picking, packing, processing, and should be completed on a single workstation. A variety of products which a retailer required in an order is processed as a batch and put it into a container for delivery convenience. A completed batch might be delivered immediately or group delivered with other batches (retailers' order) to the corresponding retailers depending on the required performance measure, minimization of total cost. The total cost includes transportation cost, vehicle arrangement cost and penalty costs. For a set of retailers, $N=\{1,2,3,\ldots,n\}$; each has a geographic location and a demand, d_i, $i \in N$, to be satisfied within a time window $[a_i,b_i]$. The heterogeneous fleet is taken into account in the delivery stage as well.

The vehicle capacity Q_k determines the size of different type of vehicles T, $T=\{1,2,3,\ldots,t\}$, and corresponds to the fixed acquisition cost of w_k, $k \in T$. We assume that as long as the total physical space of the products loaded into the vehicle does not exceed Q_k, they can be arranged to fit in the physical space provided by the vehicle. Each trip starts at the distribution center (location 0), travels to a sequence of retailer locations, and returns to the distribution center. We assume that each retailer is visited only once and that all demands must be satisfied. Other assumptions in formulation are given as follows:

(1) The setup time for producing different batches is negligible.
(2) The vehicle loading time is negligible.
(3) The travel distances of delivery network are symmetric and satisfy the triangle inequality.
(4) An infinite supply of each vehicle type is available.

2.2. Notations

The notations which are used to develop a mathematical model of the problem are defined and interpreted as follows:

Decision variables:

C_{ik}	makespan of retailer i in the distribution center for vehicle type k,
Z_{ij}	a binary decision variable indicating if retailer i is performed before retailer j in the distribution center,
y_{0i}	a binary decision variable indicating if retailer i is delivered after depot,
x_{ijk}	a binary decision variable indicating if vehicle type k travels the arc (i, j),
t_i	arrival time at retailer i,
u_{ij}	the penalty due to the violation the time windows at the end of each arc (i, j).

Non-decision variables and parameters:

p_i	unit processing time of retailer i,
d_i	demand of retailer i,
τ_{ij}	cost of travel from retailer i to j,
s_i	service time at retailer i,
r_i	flow variables associated with retailer i,
w_k	fixed acquisition cost of vehicle k,
P_e	early delivery penalty per order,
P_l	late delivery penalty per order,
N	retailer set,
N_0	retailer set including depot,
M	A very large positive number.

2.3. Mathematical models

The addressed problem with minimization of the total cost objective can be formulated as follows:

$$\min \sum_{k \in T} w_k \sum_{j \in N} x_{0jk} + \sum_{k \in T} \sum_{i \in N_0} \sum_{j \in N_0} \tau_{ij} x_{ijk} + \sum_{k \in T} \sum_{i \in N_0} \sum_{j \in N_0} u_{ij} x_{ijk} \quad (1)$$