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Genetic algorithms for coordinated scheduling of production and air transportation

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ABSTRACT

A main issue in supply chain management is coordinating production and distribution decisions. To achieve effective logistics scheduling, it is critical to integrate these two functions and plan them in a coordinated way. The problem is to determine both production schedule and air transportation allocation of orders to optimize customer service at minimum total cost. In order to solve the given problem, two genetic algorithm (GA) approaches are developed. However, the effectiveness of most metaheuristic algorithms is significantly depends on the correct choice of parameters. Hence, a Taguchi experimental design method is applied to set and estimate the proper values of GAs parameters to improve their performance. For the purpose of performance evaluation of proposed algorithms, various problem sizes are utilized and the computational results of GAs are compared with each other. Moreover, we investigate the impacts of the rise in the problem size on the performance of our algorithms.

1. Introduction

The integration of supply chain systems has been the subject of significant debate and discussion. In comparison with the traditional manufacturing environments, the possession of concurrency, agility and collaboration between supply chain partners becomes one of the main goals of most global companies (Chen, 1996; Jung & Jeong, 2005).

Some studies have tried to integrate production and distribution decisions. The main reasons of integration are increasing levels of global competition, which creating a more demanding customer, demand driven markets and the emergence of just in time delivery. Research in this area is mainly focused on road transportation and there has been a relative neglect of other transportation modes while there are sizable sectors of industry such as air transportation. Many companies need to reduce their penalty costs to remain in competitional global markets and also they have a great desire to satisfy their customer's needs within fast and in time delivery, so focusing on air transportation is inevitable.

Although air transportation is costly, it reduces other costs such as earliness and tardiness delivery costs. Because our goal is to minimize the total cost, we would consider the tradeoff between all costs occurred in a product to choose the best strategy. Hence, in this research, we study the problem of integration of production and air transportation scheduling to achieve accurate scheduling minimizing total cost. Integrated schedule of production and air transportation is very important, because the cost of missing a shipment in a scheduled flight is quite heavy as it should be transported by charter flights. Therefore in this paper, there is an extra cost corresponding to charter flights considered as 'departure time tardiness'. The 'departure time earliness' cost happens as a result of the need to store the order at the production facility or waiting charges at the airport. Delivery penalties are incurred by delivering an order either earlier or later than the committed due date to customers. The 'delivery tardiness' cost includes customer dissatisfaction, contract penalties, loss of sales, and potential loss of reputation for manufacturer and retailers. If the arrival time of allocated orders in air transportation model is earlier than its due date, retailers encounter the storing cost of orders which is considered as 'delivery earliness' cost.

There is a little research on production scheduling considering air transportation. Li, Sivakumar, Mathirajan, and Ganesan (2004) studied the synchronization of single machine scheduling and air transportation with single destination. The overall problem is decomposed into air transportation problem and single machine scheduling problem. They formulated two problems and then presented a backward heuristic algorithm for single machine scheduling. They extended their previous work to consider multiple destinations in air transportation problem (Li, Ganesan, & Sivakumar, 2005). They showed the air transportation allocation has the structure of regular transportation problem, while the single machine scheduling problem is NP-hard (Li, Ganesan, & Sivakumar, 2006a). They also proposed a forward heuristic and a backward heuristic for single machine (Li, Ganesan, & Sivakumar, 2006b). They extended their work by considering parallel

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machines in production (Li, Sivakumar, & Ganesan, 2008). The problem was formulated as a parallel machine with departure time earliness penalties. They also showed that the parallel machine scheduling problem is NP-complete and then presented a simulated annealing based heuristic algorithm to solve the parallel machine problem. They compared their simulated annealing algorithm with an operation method of a factory in Singapore (Li, Sivakumar, Fu, & Jin, 2007). Zandieh and Molla-Alizadeh-Zavardehi (2008) proposed some mathematical models for two problems with different delivery assumptions (with delivery tardiness and without delivery tardiness) regarding due window. Zandieh and Molla-Alizadeh-Zavardehi (2009) extended their work considering various capacities with different transportation cost and also charter flights (commercial flights). There have been considerable researches conducted in production–distribution integration with emphasis on the road transportation and vehicle routing problem. There are also reviews on integrated analysis of production–distribution systems (Erenguc, Simpson, & Vakharia, 1999; Goetschalckx, Vidal, & Dogan, 2002; Sarmiento & Nagi, 1999; Vidal & Goetschalckx, 1997).

Four sections follow this Introduction. The next section describes the problem's details and elaborates the mathematical formulation of our model. The proposed GAs are explained in Section 3. Section 4, describes the Taguchi experimental design and compares the computational results. Finally, in Section 5, conclusions are provided and some areas of further research are then presented.

2. Mathematical model and descriptions

In this section, we provide a mathematical programming model for integrated production and air transportation scheduling problem. The aim is to determine an optimal allocation of orders to the existing transportation capacities and also specify sequence and completion times of these orders in production in such a way that the total cost of supply chain is minimized. The model is based on the model developed by Zandieh and Molla-Alizadeh-Zavardehi (2009) for synchronized production and air transportation scheduling problem. The assumptions used in this problem are:

1. The plant is treated as a single machine.
2. No idle time is allowed.
3. There are multiple flights in the planning period with different transportation specifications such as cost, capacity, etc.
4. Business processing time and cost, together with loading time and loading cost for each flight are included in the transportation time and transportation cost.
5. Local transportation transfers products from the plant to the airport. Local transportation time is assumed to be included in transportation time.
6. Local transportation can transfer an order to the airport when the order is produced completely.
7. Orders released into plant for the planning period are delivered within the same planning period, which means there are no production backlogs.

The notations that will be used to describe the problem and algorithm are as follows:

Indices

i, i'	order/job index, $i, i' = 1,2,\ldots,N$
f, f'	ordinary flight index, $f, f' = 1,2,\ldots,F$
k	destination index, $k = 1,2,\ldots,K$
p, p'	position or sequence of order i, $p, p' = 1,\ldots,N$

Parameters

D_f	departure time of ordinary flight f at the local airport
A_f	arrival time of ordinary flight f at the destination
Q_i	quantity of order i
α_i	delivery earliness penalty cost (/unit/h) of order i
β_i	delivery tardiness penalty cost (/unit/h) of order i
d_i	due date of order i
Des_i	destination of order i
des_f	destination of ordinary flight f
Cap_{tf}	available tth capacity type of ordinary flight f
Tc_{tf}	transportation cost of each product unit when allocated to tth capacity type of ordinary flight f
p_i	processing time of order$i$ (/unit)
α'_i	departure time earliness penalty cost (/unit/h) of order i
β'_i	departure time tardiness penalty cost (/unit) of order i
MD_i	maximum departure time of charter flight for order i that can reach to its due date (it is equal to delivery due date of order i subtract from the time of charter flight for order i)

Constant

LN	a large positive number

Variables

q_{tif}	quantity of portion of order i allocated to tth capacity type of ordinary flight f
$q_{(T+1)i}$	quantity of portion of order i allocated to its charter flight
c_i	completion time of order i
u_{ip}	1 if order i is in position p, 0 otherwise

Li et al. (2005, 2006a, 2006b, 2007, 2008, 2004) and Zandieh and Molla-Alizadeh-Zavardehi (2008) used two type capacities in each ordinary flight with two different transportation cost. For extension of their work and generating more realistic schedule, similar to Zandieh and Molla-Alizadeh-Zavardehi (2009) we assumed that in many industries, we may have only one or even more than two type capacities in each flight. Therefore, we considered T type capacities by Cap_{tf} in the notation. However, if we have h $(h < T)$ type capacities for an ordinary flight f, then the Cap_{tf}, i.e. $t = h + 1,\ldots,T$ will be fixed to zero. In addition, considering charter flights and delivery tardiness, the orders can be transported by charter flights. With respect to the problem defined above, a mathematical programming model is formulated as follows:

$$\begin{aligned}
\min \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{f=1}^{F}\Bigg(\Bigg(\Bigg(\frac{\min\left(0, c_i - D_f - \frac{1}{LN}\right)}{c_i - D_f - \frac{1}{LN}}\Bigg)\big((Tc_{tf} * q_{tif})\\
+ (\alpha'_i * (D_f - c_i) * q_{tif}) + ((\alpha_i * \max(0, d_i - A_f) * q_{tif})\\
+ (\beta_i * \max(0, A_f - d_i) * q_{tif}))\Bigg)\Bigg)\\
+ \Bigg(\Bigg(1 - \Bigg(\frac{\min\left(0, c_i - D_f - \frac{1}{LN}\right)}{c_i - D_f - \frac{1}{LN}}\Bigg)\Bigg)\big((\beta'_i * q_{tif})\\
+ (\min(\alpha'_i, \alpha_i) * \max(0, MD_i - c_i) * q_{tif})\\
+ (\beta_i * \max(0, c_i - MD_i) * q_{tif})))) + \sum_{i=1}^{N}\Big(\Big(\beta'_i * q_{(T+1)i}\Big)\\
+ \Big(\min(\alpha'_i, \alpha_i) * \max(0, MD_i - c_i) * q_{(T+1)i}\Big)\\
+ \Big(\beta_i * \max(0, c_i - MD_i) * q_{(T+1)i}\Big)\Big)
\end{aligned} \tag{1}$$

s.t.

$$\left(\sum_{t=1}^{T} q_{tif}\right) * (Des_i - des_f) = 0, \quad i = 1,\ldots,N;\ f = 1,\ldots,F \tag{2}$$

$$\sum_{i=1}^{N} q_{tif} \leqslant Cap_{tf}, \quad t = 1,\ldots,T;\ f = 1,\ldots,F \tag{3}$$