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A bi-objective model for integrated scheduling of production and distribution in a supply chain with order release date restrictions

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ABSTRACT

We study an integrated production and distribution scheduling model in a supply chain. In this problem, there is a set of orders from several customers that has to be processed on a single machine located in a factory. Each order has a release date imposed by the corresponding supplier for delivering the order. In the factory, orders must be batched and routed to be delivered to the corresponding customers. We propose a bi-objective model in order to find a joint schedule of production and distribution to optimize the customers' service level, measured as the mean delivery time and the total transportation cost. An integer linear programming model, in which a weighted sum of both objectives is converted to a single objective, is developed and solved. In addition, two local search algorithms and a metaheuristic algorithm based on tabu search are developed to solve large-scale problems at reasonable times. Moreover, two bi-objective solution methods are developed to find the Pareto solutions for the bi-objective problem. Finally, the performances of all developed solution approaches are analyzed and compared using randomly generated test sets and managerial insights are drawn from multiple numerical experiments.

1. Introduction

Depending on the number of stages in a supply chain, the supplier, manufacturer, and customers may be involved as decision makers. Supply chain activities cover the transportation of raw material, production processes and the transportation of finished goods. The products' cost consists of those imposed by converting raw materials into finished goods and the logistics expenditures such as delivering and services to customers. In particular, the main issue in the supply chain management is the coordination between decisions made at different stages, and supply chain scheduling integrates the three stages of material supply, production arrangement and product delivery to achieve optimal performance of the system through coordination of these stages. The management of the supply chain and the coordination between all stages usually lead to more savings in comparison to the case where each stage is managed separately. As a result, companies require an integrated plan of all activities in the supply chain.

Traditional scheduling models deal with the production scheduling problem without taking into account the other stages such as transportation. In these models, the assumption is that an unlimited number of vehicles are available for delivering finished products to the related customers, so that the products can be transported to customers without any delay. However, in several real world applications, the number or the capacity of the vehicles may be limited and, to increase their utilization, vehicles may need to distribute the products of multiple customers in a single trip.

The literature on the supply chain management can be divided into two main categories. Essentially, some studies focus on the two stages of a supply chain such as manufacturer and customers, while others deal with all three stages. Although there is an extensive literature on scheduling and vehicle routing problems, the integration of these problems has been rarely studied. Due to the complexity of the three-stage supply chain, publications in this area usually do not consider the vehicle routing problem. Chang and Lee [1] address a single/parallel machine scheduling problem, in which a vehicle with limited loading capacity delivers all the orders processed by the machine(s) to one or two customers. All orders require different amounts of storage space during delivery and the problem is to find a schedule for processing and delivering orders to minimize the last order's arrival time at its destination. Most articles published in this field consider a single machine manufacturing system. Selvarajah and Steiner [2] study a two-stage supply chain with a single machine system, considering the inventory holding cost and delivery cost for each batch. The objective is to minimize the costs incurred by batch scheduling and delivering to the customers. The problem proposed in [3] involves earliness, tardiness

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and inventory cost in a single machine and batch delivery problem. Condotta et al. [4] describe a metaheuristic method based on tabu search for combined production-transportation problem, in which orders have to be processed on a single machine and are delivered to a customer.

Moreover, there are studies that consider other machine environments such as parallel machine or flow shop. The proposed parallel machine scheduling problem by Wang and Cheng [5] focuses on optimizing the customer's service level and transportation costs. In this study, both job class setups for job processing and job delivery are considered at the same time. Lee and Chen [6] study scheduling problems in manufacturing and distribution systems with parallel machine environment and considering transportation of semi-finished orders, which is done between machines at the production site, and final products to the customer or warehouse. Soukhal et al. [7] investigate two-machine flow shop scheduling problem with a material handling system that considers the transferring of orders from processing facility to customers. Finally, Cakici et al. [8] focus on a two-stage supply chain problem in a single machine environment to optimize the trade-off between total weighted tardiness and distribution cost and provide a multi-objective analysis of the problem.

There are several publications which consider multiple customers and delivery routing decisions while delivering. Li et al. [9] study a single-machine scheduling problem in which all orders belong to one or two customers and the objective is to minimize the total orders' arrival time. Chen and Vairaktarakis [10] consider two machine environments, i.e. single machine and parallel machine, in the processing facility. The proposed objective function takes into account both arrival time and distribution cost. For the integrated production and distribution scheduling problem in the parallel machine environment, Chang et al. [11] present a problem in which the goal is to find a schedule that minimizes the overall cost, consisting of the total weighted job delivery time and the distribution cost. Ullrich [12] also adds some assumptions to a two-stage supply chain problem in which machine-dependent ready times, job-dependent processing times, delivery time windows, and service times were taken into account. The goal of the problem is to optimize the total tardiness of a production-distribution schedule proposed for a set of orders on parallel machines.

There are a few articles considering all three stages of a supply chain. Hall and Potts [13] address a problem consisting of a supplier, several manufacturers and several customers. The objective is to minimize the overall delivery cost and scheduling cost based on the orders' delivery time. The objective is achieved by scheduling the orders and forming them into batches, each of which is delivered to the next downstream stage. In the three-stage supply chain proposed in [14], the warehouse, factory and the customer are located at three different sites and the objective is to minimize the arrival time of the last delivered order to the customer. In [15], a logistic scheduling model is formulated where a manufacturer receives raw materials from a supplier, processes them on a single machine and delivers the finished product to a customer. The objective is to minimize the total work-in-process inventory and transportation costs by planning the size, arrival times and departure times of supply and delivery batches, respectively. It is worth mentioning that routing is not considered in any of these three-stage problems.

Another group of studies in supply chain management consist of coordination of product recovery and production processes. This field of study, namely closed-loop supply chain (CLSC), aims at integrating return products in the traditional supply chain process in order to save disposal cost and reduced environmental dilemmas. As regards these researches, there are some article connected with CLSC optimization. Priyan and Uthayakumar [16] address a problem to optimize the order quantity lead time and total number of deliveries in a supply chain, with the objective of minimizing system total cost. In [17] a supply chain model based on simulation and multi-objective optimization is proposed to optimize control policies for multi-echelon supply chain with returned products.

According to the literature review, all the integrated problems of scheduling and supply chain addressing routing decisions, consider only two stages of a supply chain. In this paper, we propose a three-stage logistic scheduling model in which a manufacturer receives raw materials from a supplier, processes them on a single machine, batches and distributes the finished products to a set of known customers using an unlimited number of capacitated vehicles. The objective is to minimize the mean delivery time and the transportation cost by determining the best production scheduling and routing of orders to the related customers. We formulate the problem as a bi-objective model and propose several heuristic algorithms. In the first algorithm, the two objective functions are integrated and converted into a single objective function using the weighted-sum method. This case has been modelled as a linear integer programming problem in Section 2 and a set of heuristic algorithms and a tabu search (TS) metaheuristic solution approach are developed to solve the problem (see Section 3). In Section 4, we develop several bi-objective heuristic algorithms based on the combination of the developed tabu search algorithm with the multi-objective adaptive memory programming method and the adaptive weighted-sum method. Section 5 is dedicated to the computational experiments. Finally, conclusions and future research directions are provided in Section 6.

2. Problem statement and formulation

The problem involves a production stage with a single machine environment which processes the orders to be transported to related customers. At the distribution stage, there is an unlimited number of homogeneous vehicles with a capacity constraint, to deliver the prepared orders. As there are several suppliers providing the material required for the production part, for each order a release date is considered; therefore, an order cannot be processed before its release date. We consider a set of orders $\boldsymbol{J} = \{1, 2, \ldots, n\}$ from k customers ($k \le n$) located at different locations. Each order $j \in \boldsymbol{J}$ has a processing time p_j and a release date r_j imposed by the supplier $s \in \{1, 2, \ldots, \eta\}$ ($\eta \le n$). So in each feasible solution, the process of each order $j \in \boldsymbol{J}$ cannot be started before r_j. In the transportation part, due to the capacity of each vehicle, the number of orders to be delivered in each trip of each vehicle cannot exceed the vehicle capacity (w). So all the orders are divided into a set of batches $\boldsymbol{B} = \{1, 2, \ldots, n\}$ where each batch $b \in \boldsymbol{B}$ constitutes the orders of a subset of customers which has to be transported by a dedicated vehicle in a single trip. The assumption of unlimited number of vehicles to deliver the orders is realistic when third-party logistics companies participate in the transportation and distribution stage of the supply chain. Departure time of each batch $b \in \boldsymbol{B}$, denoted by t_b, indicates the latest completion time of the orders dedicated to that batch. In addition, d_j denotes the delivery time of order j to its corresponding customer and can be obtained based on the route taken by the corresponding vehicle. The transportation cost for each batch consists of a fixed cost f and a variable cost dependent on the total distance of the route travelled by the vehicle. Finally, the travelling time (cost) from the customer i to the customer j is denoted by τ_{ij} (c_{ij}) in which a zero index indicates the manufacturer location. The problem is to find a schedule minimizing 1) the average of delivery times (D_{mean}), and 2) the distribution cost (T).

In this model, the two objectives are integrated and converted into a single-objective problem by using the parameter α ($0 < \alpha < 1$) which represents the decision maker's preference on the objectives.