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An exact algorithm for solving the economic lot and supply scheduling problem using a power-of-two policy

Heinrich Kuhn *, Thomas Liske [1]

Catholic University of Eichstaett-Ingolstadt, Supply Chain Management & Operations, Auf der Schanz 49, 85049 Ingolstadt, Germany

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ABSTRACT

It is not sufficient for a manufacturer of products to merely optimize lot sizes and production schedules to reduce company-wide costs. Optimal policies for raw materials purchasing, stock keeping of input material, inventory management of end products and customer demand fulfillment also have to be implemented in an integrated manner. The economic lot and supply scheduling problem (ELSSP) deals with the problem of the simultaneous planning of raw materials purchasing, production planning and storage of finished goods. The underlying assumptions of an ELSSP can be observed in several industrial areas, e.g., the retailing and automotive industries. After a brief problem description and a literature review, this paper presents a complete mathematical model and an exact procedure to solve the ELSSP using a power-of-two policy. The solution procedure is based on the junction point method. Analytical results for a broad range of test instances are calculated comparing the results of a power-of-two policy to the results from applying a common cycle policy. The results emphasize the economic advantages of the power-of-two policy especially for certain parameter values.

1. Introduction

We investigate the economic lot and supply scheduling problem (ELSSP) using a power-of-two policy. The ELSSP merges the assumptions of the economic lot-sizing and scheduling problem (ELSP) as specified in Carstensen [9], and the capacitated vehicle routing problem (CVRP) as defined for example in Toth and Vigo [44]. A detailed description of the ELSSP is given in Kuhn and Liske [28].

Fig. 1 shows the main physical structure of the system being investigated. The supply and production system consists of a transportation fleet, an input materials warehouse, a production facility and an end items warehouse. The end items are stored in the end items warehouse until the delivery to the customers. The manufacturer receives the required input materials from an input materials warehouse, storing the necessary input materials. The stock of the input materials warehouse is replenished by having input materials collected from geographically dispersed suppliers by the transportation fleet operated by the manufacturer.

We assume an assembly production structure. The corresponding bill of materials (BOM) is specified in Fig. 2, whereby a_{ij} denotes the amount of input material i needed for the production of one unit of end item $j, j \in P$. S_j denotes the set of input materials needed to produce end item j. However, we assume that each input material is needed for exactly one end item only. The general aim is to determine an optimal production sequence, production lot sizes, delivery quantities and delivery dates for the input materials and routes for the collection of the input materials from the suppliers. The target of the planning problem is to minimize the overall costs, including the inventory holding costs of the input materials and the end items, the production costs as setup costs or related cost parameters, and the costs for the collection of the input materials from the suppliers. In addition, a stationary demand rate and an infinite planning horizon are assumed. Kuhn and Liske [28] were the first to define the ELSSP. However, they assume a common production cycle policy. Applying this policy assumes that the production cycle times (T_j) of all end items $j, j \in P$ are identical and equal to T, i.e., $T_j = T$, $\forall j \in P$.

This assumption is now relaxed and we assume that end items may be produced by different production cycles, however, a common basic period (B) still exists. The individual cycle time of end item j is then given by an integer multiplier of this basic period, i.e., $T_j = m_j B$, $\forall j \in P$. The overall cycle time T is then the maximum multiplier multiplied by the basic period, $T = m_{\max} B$. In addition, we assume that the integer multipliers have to be a power-of-two number, which restricts the solution space and provides latitude for more effective solution methods to this restricted version of the problem. In the literature this policy is commonly known as "power-of-two production policy".

* Corresponding author. Tel.: +49 841 937 21820; fax: +49 841 937 21955.
E-mail addresses: heinrich.kuhn@ku.de (H. Kuhn), thomas.liske@ku.de (T. Liske).
[1] Tel.: +49 841 937 21823.

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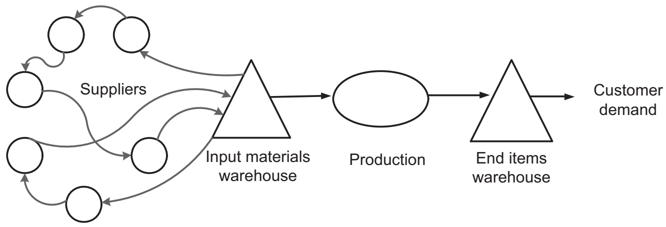

Fig. 1. Physical structure of the ELSSP.

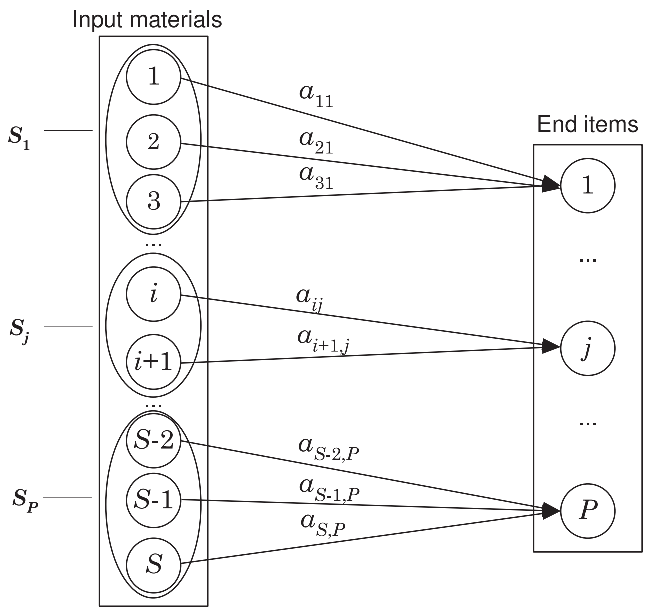

Fig. 2. Bill of materials.

In accordance with Kuhn and Liske [28], we assume that the delivery dates of the input materials are equal to the production start time of their associated end items. In addition, we assume one pickup from each supplier to retrieve the required input materials for each production run. Multiple pickups during one production run are not considered. All types of input material and their related suppliers (S_j) that correspond to the same end items $j, j \in P$ can therefore be considered in one common capacitated vehicle routing problem (CVRP). However, since a power-of-two policy is assumed, the end items can be produced more than once during the overall production cycle T. A common basic period therefore has to be determined, and a multiplier has to be established for each end item $j, j \in P$ that is of the form $m_j = 2^{\pi_j}$, in which $\pi_j, j \in P$ is a positive integer.

2. Literature review

The integrated production and transportation problem may be considered from different perspectives. On the one hand it may be viewed as a production distribution problem (PDP), considering a producer or a retailer who distributes products to one or several customers (stores) (see Kuhn and Sternbeck [29] for example). On the other hand it may be considered from the perspective of an inbound logistics system where a producer or a buyer procures products from one or several suppliers, i.e., a sourcing production problem (SPP).

In addition to that, these two fundamental problem situations may be differentiated in terms of the supply chain structure, i.e., the number of producers (vendors) and the number of customers (buyers) involved. Basically, published models in the literature examine a scenario regarding either single or multiple vendors (SV or MV) mixed with single or multiple buyers (SB or MB). This results in four possible supply chain structures: SVSB, MVSB, SVMB, MVMB (s. [11]).

These four supply chain structures could be combined with the two distinctive market perspectives mentioned above, PDP or SPP, resulting in eight distinguishable problem classes.

Models concerning PDP: Most available approaches in the literature consider production distribution problems (PDP). In these cases the production part is completed first and the products are distributed afterwards.

A general review of integrated production distribution systems is given in Sarimento and Nagi [39]. The focus of this research is on how the logistics aspects are represented in such models, and the advantages of these planning approaches.

Chandra and Fisher [10] develop a combined vehicle routing and production scheduling model assuming a finite planning horizon with known dynamic demand. A solution for the model is found by solving the multi-item lot-sizing problem first and defining a distribution plan afterwards. Fumero and Vercellis [16] present a similar model for a combined vehicle routing and production scheduling problem in the context of production and distribution planning. But in contrast to Chandra and Fisher [10], a Lagrangian decomposition method is used to solve the model by separating the model's production and distribution problem, but still aiming at a global optimum. Kaminsky and Simchi-Levi [27] study a two-stage production system where production takes place at both stages and transport occurs from one stage to the other. In most cases, the transportation costs result from the solution of a vehicle routing problem.

However, all of these models assume a dynamic demand structure and thus neglect the advantages in solving the considered production and transportation problem when stationary demands and an infinite planning horizon can be assumed.

The link between the ELSP and the problem of delivering the items produced to the customers is treated by the economic lot and delivery scheduling problem (ELDSP) [14,22,24,25,23,26]. A single production facility is assumed that can produce several items, each with an individual but constant production rate; each item is requested with a constant demand rate. The items are pooled into subsets with a common production cycle and a common delivery date.

However, the ELSDSP neglects the specific features of a CVRP: the transportation costs considered do not result from the solution of a specific vehicle routing problem. The transportation costs are assumed to be independent of the customer's location, and so the vehicle routing does not affect the pooling of the items. Another type of ELSP extension is suggested by Banerjee [3]. He assumes that finished goods inventories are shipped in full truckloads (TL) to succeeding stages of the distribution channel.

The coordination of outgoing deliveries from a central warehouse to geographically dispersed regional warehouses facing a constant demand rate is the focus of the inventory routing problem (IRP) [2,5,7,8,41,46]. This means that the overall costs, consisting of transportation costs for the deliveries and inventory costs arising from storing the items at the regional warehouses, have to be minimized. One important fact is that the transportation costs are the result of a specific vehicle routing problem that has to be solved. This implies that optimal routes along the regional warehouses and optimal order quantities have to be determined within the IRP. However, in contrast to the ELSSP, the IRP only considers the vehicle routing and the storage of the products, but not the limited capacity of the production facility incorporated into these modeling approaches.

Nevertheless, all these ELSDSP and IRP models are concerned with distribution inventory and outbound vehicle routing integration, and not with purchasing inventory and inbound vehicle routing integration models.