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Optimization of mixed integer nonlinear economic lot scheduling problem with multiple setups and shelf life using metaheuristic algorithms

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ABSTRACT

This paper addresses the economic lot scheduling problem where multiple items produced on a single facility in a cyclical pattern have shelf life restrictions. A mixed integer non-linear programming model is developed which allows each product to be produced more than once per cycle and backordered. However, production of each item more than one time may result in an infeasible schedule due to the overlapping production times of various items. To eliminate the production time conflicts and to achieve a feasible schedule, the production start time of some or all the items must be adjusted by either advancing or delaying. The objective is to find the optimal production rate, production frequency, cycle time, as well as a feasible manufacturing schedule for the family of items, in addition to minimizing the long-run average cost. Metaheuristic methods such as the genetic algorithm (GA), simulated annealing (SA), particle swarm optimization (PSO), and artificial bee colony (ABC) algorithms are adopted for the optimization procedures. Each of such methods is applied to a set of problem instances taken from literature and the performances are compared against other existing models in the literature. The computational performance and statistical optimization results shows the superiority of the proposed metaheuristic methods with respect to lower total costs compared with other reported procedures in the literature.

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1. Introduction

Economic lot scheduling problem (ELSP) is concerned with scheduling the production of multiple items in a single facility on a periodical basis with the restriction that one item is produced at a time. Narro Lopez and Kingsman [1] provided an excellent review of this problem and the solution approaches. Throughout the past half century, a considerable amount of research on this problem has been published with several directions of extensions. Subsequently, various heuristic approaches have been suggested using any of the basic period approach [2], common cycle approach [3], or time-varying lot size approach [4]. This study deals with common cycle approach, where the objective is to determine the optimal cycle time.

In industry, products are stocked and used up during the production cycle. If they are stored more than a specified period of time, some products may get spoiled. This time restriction of life for a product is called shelf life. Shelf life constraints directly influence the wastage, out-of-stock rates, and inventory levels [5]. Generally, the inventory systems assume implicitly unlimited shelf lives for the stored items. However, storing products beyond a specific shelf life may bring about the deterioration or diminution of the products. It might also lead to loss of the profitable or fruitful life of a product in an emerging market of new competitive products [6]. Therefore, when the optimal cycle time goes beyond the time restriction of life for an item, the cycle time period must be decreased to less than or equal to the shelf life to ensure a feasible schedule. This storage time can be lowered by regular restocking of the items, and subsequently decreasing the inventory maintained in the stock [7].

Silver [8] studied the ELSP with shelf life constraint while disallowing the production cost under the postulation that the production rate variation does not impose any further cost. Two options of decreasing the cycle time and the production rate were investigated, and it was concluded that it is more cost-efficient to reduce the production rate. Sarker and Babu [7] exploited the Silver's models [8,9] by considering production time cost, and a limited

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shelf life for each item. They found that when the production cost is included into the model, it might be more efficient to reduce the cycle time rather than the manufacturing rate.

Goyal [10] investigated the results obtained by Sarker and Babu [7], and suggested that their proposed model can be improved by allowing the production of items more than one time in a cycle. Viswanathan [11] implied that Sarker and Babu's model [7] offers a feasible schedule only when all the items produced have the same frequency. Viswanathan [11] also stated that although Goyal's suggestion [10] can incur a lower inventory cost, his method does not assure a feasible production schedule. Yan et al. [12] tackled the problem of schedule infeasibility, and made the production of each item more than once in every cycle permissible. Yan et al. [12] indicated that advancing or delaying the manufacturing start times of some items can lead to a feasible production plan. Accordingly, costs associated to the adjustment schedule must be taken into account.

Since ELSP is categorized as NP-hard [13] which leads to difficulty of checking every possible schedule in a reasonable amount of computational time, recently, metaheuristic algorithms have been implemented effectively to solve the problem.

Khouja et al. [14] proposed a genetic algorithm (GA) for solving the ELSP applying the basic period approach, and showed that the GA is appropriate for solving the problem. Moon et al. [15] addressed the ELSP based on the time-varying lot size method, and suggested a hybrid genetic algorithm (HGA) to solve the model. The obtained results by the HGA surpassed the best-known Dobson's heuristic [16]. Chatfield [17] proposed a GA, namely, genetic lot scheduling procedure, to solve the ELSP using the extended basic period (EBP) approach. Their method was compared with the well-known benchmark problem presented by Bomberger [18]. The results outlined that the proposed approach offers better optimization reliability. Jenabi et al. [19] solved the ELSP in a flow shop setting utilizing the HGA and simulated annealing (SA) algorithm. Their computational results indicated the superiority of the proposed HGA compared to the SA with respect to the solution quality. However, the proposed SA outperformed the HGA in terms of the required computational time.

Chandrasekaran et al. [20] investigated the ELSP with the time-varying lot size approach and sequence-independent/sequence-dependent setup times of parts, and applied the GA, the SA, and the ant colony optimization (ACO) algorithms. The computational performance analyses revealed the effectiveness of the proposed metaheuristic methods. Raza and Akgunduz [21] examined the ELSP with time-varying lot size approach using the SA, and conducted a comparative study of heuristic algorithms on the problem. They compared the results with Dobson's heuristic [16] and Moon et al. [15], and concluded that the SA finds the best-known solution for the suggested problem. Bulut et al. [22] proposed a GA for the ELSP under the EBP approach and power-of-two (PoT) policy. The experimental results showed that the proposed GA is highly competitive to the best-performing algorithms from the existing literature under the EBP and PoT policy.

To the best of the authors' knowledge, there has been no research on the ELSP with multiple products having various production frequencies, and respecting the shelf life and backordering constraints using the metaheuristic methods. In this paper, the proposed ELSP model by Yan et al. [12] is modified. A computational study of the well-known metaheuristic algorithms, namely the GA, the SA, the particle swarm optimization (PSO), and the artificial bee colony (ABC) algorithms are presented to solve the proposed model. Accordingly, the performance of the best existing approach presented by Yan et al. [12] and the proposed metaheuristic algorithms are evaluated and compared.

The rest of this paper is organized as follows: Section 2 presents the mathematical formulation. In Section 3, applied methods are explained. Section 4 demonstrates numerical examples and discusses the computational results. Finally, conclusions are given in Section 5.

2. Problem description and model formulation

In this section, a mathematical model for the ELSP is presented based on the integration and modification of the models presented by Goyal [10] and Yan et al. [12]. Consider N types of items are produced on a single machine in the manufacturing cycle time of T, investigating the effect of constituent costs in an inventory system with shelf life constraint and production of items more than once in a cycle. The objective is to minimize the total cost, in addition to obtaining a feasible production schedule, the optimum production frequency, production rate, backorder level, batch size for each item, and optimal production cycle time for the family of items using optimization engines.

The mathematical model studied throughout the paper is based on the following assumptions and notations:

Assumptions

i. Each item has a deterministic and constant demand rate
ii. Each item has a deterministic and constant setup time
iii. Each item has a finite production rate
iv. Each item is produced per cycle
v. Each item has a specified shelf life
vi. Backordering is permissible
vii. The first in first out (FIFO) rule is considered for the inventory transactions

Indices

i	Product (i = 1, 2, ..., N)
N	Total number of products
b, w	Production batch ($b, w = 1, 2, \ldots, \omega = \sum_{i=1}^{N} \varphi_i$)
j	Batch number (j = 1, 2, ..., φ_i)

Parameters

D_i	Demand rate for item i (units/year)
$P_i^{\max}$	Maximum possible production rate for item i (units/year)
$R_i^{\min}$	Ratio of demand to maximum production rate
L_i	Shelf life of item i (years)
t_i	Setup time for item i (years)
S_i	Setup cost for item i (dollars/year)
H_i	Inventory holding cost for item i (dollars/unit/year)
B_i	Backordering cost for item i (dollars/unit/year)
O	Machine operating cost (dollars/year)

Variables

p_i	Production rate for item i
r_i	Ratio of demand to production rate for item i
φ_i	Production frequency for item i per cycle
τ_i	Cycle time for item i
ς_i	Production start time for item i
Q_i	Production batch size for item i
M_i	Maximum backorder level for item i
λ_i	Machine time for item i
X_i	Production time for item i
γ_i^b	$\begin{cases} 1, & \text{if item i is produced in the } b^{\text{th}} \text{ batch} \\ 0, & \text{otherwise} \end{cases}$
α_i^j	Production start time advancement for item i in its j^{th} production batch

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