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Optimization of economic lot scheduling problem with backordering and shelf-life considerations using calibrated metaheuristic algorithms

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ABSTRACT

This paper addresses the optimization of economic lot scheduling problem, where multiple items are produced on a single machine in a cyclical pattern. It is assumed that each item can be produced more than once in every cycle, each product has a shelf-life restriction, and backordering is permitted. The aim is to determine the optimal production rate, production frequency, cycle time, as well as a feasible manufacturing schedule for the family of items, and to minimize the long-run average costs. Efficient search procedures are presented to obtain the optimum solutions by employing four well-known metaheuristic algorithms, namely genetic algorithm (GA), particle swarm optimization (PSO), simulated annealing (SA), and artificial bee colony (ABC). Furthermore, to make the algorithms more effective, Taguchi method is employed to tune various parameters of the proposed algorithms. The computational performance and statistical optimization results show the effectiveness and superiority of the metaheuristic algorithms over other reported methods in the literature.

1. Introduction

The economic lot scheduling problem (ELSP) is concerned with scheduling the production of multiple items in a single facility environment on a continual basis. ELSP typically imposes a restriction that one item can be produced at a time, so that the machine has to be stopped before commencing the production of a different item. Therefore, a production scheduling problem appears due to the need for incorporating the setups and production runs of various items [1]. The first published work in this area dates back to 1958, that the need of scheduling the production of different items on a single manufacturing center was introduced with the aim of meeting demands without backorders, while minimizing the long run average costs, namely setup and holding costs [2]. 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, common cycle, or time-varying lot size methods [3–5].

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In a multiple product manufacturing environment where lots have diverse production times and sizes, the main purpose is to determine an optimal cycle time in which all the items are produced. When the optimum cycle time goes beyond the time restriction of life for an item, known as shelf-life, the cycle time period must be decreased to less than or equal to the shelf-life to ensure a feasible schedule [6]. If the products are stored more than a specified period of time, some products may get spoiled. Recently, shelf-life constraint is taken into account with the implementation of the three options, namely cycle time reduction, production rate reduction, and simultaneously cycle time and production rate reduction. This constraint appends another feature to the ELSP. The ELSP with shelf-life has been received less consideration in the literatures.

Silver [7] examined the ELSP with shelf-life constraint in his rotational cycle model. Two options of the cycle time decrement and the production rate reduction were taken into consideration. He proved that it is more cost-efficient to diminish the production rate. Sarker and Babu [6], on the other hand, reversed the presumption implied by Silver [7], and showed that if a machine operating cost is inserted to the model, decreasing the cycle time can be more efficient. However, Sarker and Babu [6] interpreted that such postulations depend on the problem parameters such as production time cost, setup time, setup cost, and shelf-life. Viswanathan and Goyal [8] developed a mathematical model to obtain the optimum cycle time and manufacturing rate in a family production context with shelf-life constraint while disallowing the backordering. Viswanathan and Goyal [9] modified their earlier model by considering backorders, and proved that backordering can decrease the total cost significantly.

The ELSP is categorized as NP-hard [10], which leads to difficulty of checking every feasible schedule in a reasonable amount of computational time. Most researchers have focused on the generation of near optimal repetitive schedules. Recently, metaheuristic algorithms have been implemented effectively to solve the ELSP.

Khouja et al. [11] solved the ELSP with consideration of basic period approach using genetic algorithm (GA), and showed that GA is preferably appropriate for solving the problem. Moon et al. [1] utilized a hybrid genetic algorithm (HGA) to solve the single facility ELSP based on the time-varying lot size method, and compared the performance of HGA with the well-known Dobson's heuristic (DH) [12]. Numerical experiments showed that the proposed algorithm outperformed DH. Jenabi et al. [13] solved the ELSP in a flow shop setting employing HGA and simulated annealing (SA). Computational results indicated the superiority of the proposed HGA compared to SA with respect to the solution quality. However, SA algorithm outperformed the HGA with respect to the required computational time.

Chatfield [14] developed a genetic lot scheduling (GLS) procedure to solve the ELSP under the extended basic period approach. The procedure was applied to the well-known Bomberger's benchmark [15] problem, and compared with the proposed GA by Khouja et al. [11]. It was shown that GLS produces regularly lower cost solutions than Khouja et al. [11]. Chandrasekaran et al. [16] investigated the ELSP with the time-varying lot size approach and sequence-independent/sequence-dependent setup times of parts, and applied GA, SA, and ant colony optimization. Raza and Akgunduz [17] examined the ELSP with time-varying lot size approach, and conducted a comparative study of heuristic methods, namely DH, HGA, neighborhood search heuristics (NS), tabu search (TS), and SA on Bomberger's [15], and Mallya's [18] problems. Their results showed that the SA outperformed DH, HGA, and NS. The SA algorithm also indicated faster convergence than the TS algorithm, but resulted in solutions of a similar quality. Sun et al. [19] solved the ELSP in a multiple identical machines environment applying GA under the common cycle policy.

Most studies investigating the different aspects of the ELSP assumed that each item is produced exactly once in the rotational production cycle. Goyal [20] and Viswanathan [21] implied that manufacturing of every item more than once per cycle may be more economical. Although this policy might result in a solution with a lower cost, it may bring about an infeasible schedule due to the overlapping production time of various items. Yan et al. [22] tackled the problem of schedule infeasibility when the production of each item more than one time in every cycle is permissible. They indicated that advancing or delaying the manufacturing start times of some items can lead to a feasible production plan using a two-stage heuristic algorithm. Initially, their model was simplified by omitting the schedule adjustment constraints and costs. Then, in the case of an infeasible schedule a modification procedure was employed using a greedy heuristic of sequentially selecting the activities, one every time, for either advancing or delaying the manufacturing start time, until a practicable schedule is achieved. However, the solution of the large scale proposed ELSP model seems to be out of reach using the suggested approach by Yan et al. [22] due to its complexity and computational effort. Furthermore, In Yan et al. [22] the items' production frequencies were restricted to three in order to make the problem practical, and limit the computational attempts. Thus, efficient heuristic methods are required to solve the proposed NP-hard model for large problems usually found in real-world situations.

So far, however, there has been no research on the ELSP with multiple products having unknown production frequencies, while considering the backordering and shelf-life constraints using metaheuristic methods. It this paper, the proposed model by Yan et al. [22] is investigated with minor modification in the cost function and constraints in order to obtain a feasible schedule, and minimize the long-run average cost using optimization engines, including the GA, particle swarm optimization (PSO), SA, and artificial bee colony (ABC) algorithms. Numerical examples found in the literature are solved and optimized to reveal the dominance and advantages of metaheuristic approaches among other suggested methods in the literature.

The remainder of this paper is organized as follows. In Section 2, the problem background, objective function, and problem constraints are discussed. In Section 3, the applied methods are explained. The details of the parameter tuning come in Section 4. Section 5 demonstrates numerical examples and reports the obtained results. Finally, conclusions are given in Section 6.