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Modeling and solving the constrained multi-items lot-sizing problem with time-varying setup cost

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ABSTRACT

The dynamic lot-sizing problem is highly complex and very important for the planning systems of manufacturing enterprises in time-varying environment, where production factors such as the production setup costs, unit storage costs, and production capacities may constantly rise or fall in different planning periods over the entire planning horizon. This paper proposed an extension model of the dynamic multi-product lot-sizing problem considering time-varying production setup cost and with dual constraints on dynamic capacities and resource limits, which carters for the actual situation of modern production and manufacturing systems in time-varying environments. Comparative experiments on synthesized problem instances were conducted by using the AMPL/CPLEX solver, which showed that the new model is efficiently on finding solutions with high qualities and the maximum size of test problems can be more than 500 products.

1. Introduction

Lot-sizing is an important issue for enterprise production and management [1–3]. It is the basic condition for achieving product producibility [4]. Research on batch problems has been going on for many years. Many planning systems, such as the Material Request Plan (MRP) and Master Production Schedule (MPS), rely heavily on basic mathematical models and methods to solve Lot-sizing problems. The Lot-sizing problem is a key issue in the MRP/MRPII system, and it is widely found in general production and manufacturing enterprises, which greatly affects the economic efficiency of the enterprise.

In the initial Lot-sizing problem model, when companies consider the total cost, we assume that the raw materials, processes, and sales prices for production are fixed, the production cost becomes a fixed value, and the total cost is the optimization between the production preparation cost and the inventory cost. Since there are production preparation costs in each production lot, if the corresponding production output is arranged according to the demand of the current period in all planning periods, although the inventory cost of the product is avoided, the production preparation cost will definitely increase; On the other hand, in order to reduce the cost of production preparation, companies hope that one production can meet the needs of multiple subsequent phases, which will inevitably lead to an increase in inventory cost. Therefore, the main research content of the lot-sizing problem is to decide when and how much production should be arranged within the scope of the entire plan, and to minimize the total cost in the case of ensuring product demand in each period.

Then, with the emergence of new problems, in the Lot-sizing problem, the capacity constraint is considered. Therefore, a Capacitated Lot-sizing Problem (CLSP) is derived. The problem is studied in the limited production schedule, given the production capacity constraints and the external demand of each production project, to determine the production quantity (i.e. production lot-sizing) of each production project in each time period, making the total cost minimum. Since the general arrangement of production must go through production setup and require the use of resources and capabilities, the total cost of general research should at least take into account the cost of production preparation and inventory. If the inventory constraints and capacity adjustments are taken into account, a more general CLSP model can be proposed.

All the time, multi-level Lot-sizing problems are still seen as an NP-hard problem. For small-scale problems, the following algorithms are solved. Arkin et al. [5] investigated the issue of computational complexity of the problem for all commonly studied product structures. Polynomial time algorithms are available for the single-item, serial and assembly systems. They proved that the remaining problems are NP-complete. Byktahtakn and Liu [6] provides a new idea for approximating the inventory cost function

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to be used in a truncated dynamic program for solving the capacitated lot-sizing problem. The proposed method combines dynamic programming with regression, data fitting, and approximation techniques to estimate the inventory cost function at each stage of the dynamic program. A dynamic programming algorithm, which aims to search for solutions that entail maximum production efficiency, was developed accordingly with the constraints of changeover costs and production deadlines (Kong et al. [7]). Akbalik et al. [8] identified various NP-hard cases, proposed a pseudo-polynomial time dynamic programming algorithm under arbitrary parameters, showed that the problem admits an FPTAS and give polynomial time algorithms for special cases. The branch-and-bound method proposed in many articles [9,10].

For multi-level problems in the Lot-sizing problem, the relationship between products is very complicated. When it comes to large-scale situations, it often cannot be planned within effective time. Therefore, many scholars have proposed large-scale cases using heuristic algorithms to solve multi-level Lot-sizing problems. Early work included the production sequence of the components of each product structure in the single-level Lot-sizing problem, and later extended to the study of multi-level Lot-sizing issues. Crowston et al. [11] discussed heuristics for the determination of lot-sizes in multi-stage systems, some based on current industrial practice, and gives computational times and solution values for the heuristic routines. Cheng et al. [12] provided a mathematical programming approach and two heuristic algorithms to analyse the total completion time minimisation problem when the ageing factor is less than one for even one batch. For the problem of joint management of pricing and inventory for perishable products, Li et al. [13] applied genetic algorithm (GA) to this problem and design a GA-based heuristic approach. To address multi-period planning problem, and also to provide guidance for heuristic design, Ahn et al. [14] derive performance bounds for two additional heuristics controls-(1) open-loop feedback control (OLFC), and (2) multipoint approximation control (MPAC). In an infinite horizon inventory and sales model, Vandenberg et al. [15] showed that an increase in batch size does not necessarily result in an increase in the optimal order time. Xiao et al. [16] improved the variable neighborhood search (VNS) algorithm for solving uncapacitated multilevel lot-sizing (MLLS) problems. For solving uncapacitated multilevel lot-sizing problems, Xiao et al. [17] have developed an iterated neighborhood search (INS) algorithm that is very simple but that demonstrates good performance.

In the research of heuristic algorithms, Li et al. [18] investigated the Problems with only one or two types of products, the proposed GA-based decomposition-coordination approach can be extended to problems with more than two types of products under any hierarchical structure. The extension necessitates a slight modification to the GA approach. The main difference is that a number of sub-problems, each corresponding to one type of product, must be solved to obtain the value of the dual function $Z(\lambda)$ when the fitness of an individual in the GA is to be updated. Jana and Das [19] presented a multi-item two-storage inventory model with nested discount policy with a resource constraint. The proposed model has been successfully solved by multi-objective genetic algorithm, multi-objective genetic algorithm with varying population and a new hybrid heuristic algorithm. For the blocking lot-streaming flow shop (BLSFS) scheduling problems, Han et al. [20] first proposed a multi-objective model of the above problem including robustness and stability criteria. Based on this model, an evolutionary multi-objective robust scheduling algorithm is suggested, in which solutions obtained by a variant of single-objective heuristic are incorporated into population initialization and two novel crossover operators are proposed to take advantage of non-dominated solutions. For an Advanced Resource Planning (ARP) problem that applies to stochastic supply chain management systems (SCMS) with multiple products and multiple resources, Lieckens and Vandaele [21] have shown that in search of the optimal lot sizes, the differential evolution method (DE) as a member of the genetic algorithms always outperforms the steepest descent algorithm, they have also shown that DE is able to detect lot size solutions near the global optimum.

With the globalization of the economy and the increasing competition between companies and manufacturing companies due to customer demand and fierce competition, today's market is increasingly showing the diversity of customer tastes and preferences, the rapid development of technology and the globalization of management and manufacturing. The original economic batch model has shown limitations in today's complex production environment. It is also increasingly difficult to provide satisfactory solutions. Based on this, we introduce the time factor, that is, consider the changes in product production preparation costs over time, taking into account the different planning periods with dynamic capacity constraints.

The following content of this paper is organized as follows. In the second section, a mixed integer linear programming model (MILP) is established for the TV-MPCLSP problem. The production cost interval over time is considered in the model, and the constraints are linearized by introducing variables, so that the proposed model can find the optimal solution through AMPL/CPLEX. In addition, analyze the newly generated mathematical properties in the model. In the third section, the proposed model is solved and compared with the results of other existing heuristic algorithms through calculation examples.

2. Linear modeling of TV-MPC LSP problem

2.1. Time-varying production environment

By analyzing and understanding the production characteristics of manufacturing companies, we found that the production preparation costs in the actual manufacturing process are time-varying. In general, in order to minimize the total cost during the limited planning period, the production schedule is discrete. Under the premise of meeting the above assumptions, we can see that the total cost is determined by the setup cost and the holding cost. For each batch of production, the former is fixed and the latter is related to production lots. Then, in many cases, if the time between production batches is longer, the production preparation is actually restarted, and the larger the amount of work such as cleaning, machine inspection, maintenance, and seating, the more resources and costs are consumed, and the greater the cost of preparation. Therefore, in this case, there is a positive correlation between production preparation costs and the length of production intervals. We assume that for every additional unit of time in the production interval, the cost of production preparation will increase by a fixed amount in one unit. Therefore, the traditional Lot-sizing model is no longer applicable to this situation, and it needs to incorporate the cost-time-varying characteristics of the production system in order to improve the traditional model.

To consider the time-varying nature of production preparation costs, this paper adds two factors: the production interval L_t and the production preparation cost growth factor $\alpha \in [0, \infty\}$.

Definition 1: Production interval L_t: indicates the number of unscheduled periods between the planning period t and the previous nearest adjacent planning period t' within a limited planning period n. The value of L_t is in the range of $L_t \in [0, t-2](t \geq 2)$, The formula is as follows:

$$L_t = t - 1 - max\left\{t' \cdot y_t \mid 1 \leq t' < t\right\}, \forall t \neq 1 \tag{1}$$

Among them, y_t is a 0–1 decision variable, which indicates whether to arrange production during t period. If production is