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Incorporating a database approach into the large-scale multi-level lot sizing problem

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ABSTRACT

Traditionally, optimization for large-scale multi-level lot sizing (MLLS) problems always encountered heavy computational burden. Scholars also indicated that "whatever the optimal method chosen to solve the MLLS problem, standard optimization packages were still faced with computer memory constraints and computational limits that prevented them from solving realistic size cases". Therefore, the main purpose of this paper is to propose an optimal method to reduce the computer memory while solving the large-scale MLLS problems. The optimal method is designed to implement on a database entirely because the demand for computer memory can be reduced significantly by means of the utilization of database storage. An example is given to illustrate the proposed method and computation capability is tested for the MLLS problems with up to 1000 levels and 12 periods.

1. Introduction

In a production-inventory system, practitioners always desire to make a set of production plans (PPs) for minimizing the sum of setup costs and inventory holding costs. By virtue of an optimal set of PPs, practitioners can decide how many quantities have to be produced in which periods at each level. However, this is a classical multi-level lot sizing (MLLS) problem.

Till now, the MLLS problems have received considerable attentions in the literature [1–3]. The two fundamental optimal methods for the MLLS problem with a *serial production structure* (each item has at most one direct predecessor and one immediate successor), one was Zangwill's [4] backward recursive algorithm and the other was introduced by Love [5]. Following that, various production structures were addressed and some optimal methods had also been proposed [1,6,7]. As a *general production structure* (each item has several direct predecessors and immediate successors) is considered, no optimal method is suitable for the MLLS problems over 50 items and exceeding 24 periods in size [8]. For example, one famous optimal methods, branch-and-bound-based algorithm, proposed by Afentakis and Gavish [1] handled the MLLS problem with up to 40 items and 12 periods for a general production structure and 106 items and 12 periods for a *assembly production structure* (each item has several direct predecessors but only one immediate successor). Dellaert and Jeunet [8,9] also pointed out that *"whatever the optimal method chosen to solve the MLLS problem, standard optimization packages were still faced with computer memory constraints and computational limits that prevented them from solving realistic size cases"*. However, if the MLLS problem is a large-scale size case, it will be one of the most difficult problems for decision making.

Because of the computational burden of optimization [3,10,11], scholars were usually toward creating the heuristic methods [8–17]. Simpson and Erenguc [3] found that many heuristic studies often neglected the use of the optimal solution

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as a benchmark by which to evaluate heuristics. Without an exact benchmark, scholars must evaluate heuristic techniques relative to other heuristic techniques [3]. From this argument, with respect to solving the large-scale MLLS problems, we are motivated to develop an optimal method rather than a heuristic method.

Some MLLS heuristic methods [12–14] typically adapted the single-level solution methods, i.e. Wagner–Whitin [18] and Silver–Meal [19] procedures. Blackburn and Millen [13] were the pioneers in introducing a heuristic method to solve the MLLS problems by "improving" the single-level solution methods. One significant result of Blackburn and Millen's [13] study is that *"deviation from the optimality by the heuristics is highly correlated with the 'depth' of the production structure"* namely the more the level, the larger the deviation from the optimality [12,13]. That is, even if a serial production structure is taken into account, as it is a large number of levels, how to explore an optimal solution exactly is still a significant issue.

In sum, if the MLLS problem was considered as a large-scale size case, the past research papers indicated that (1) using the optimal methods to deal with it would face the computer memory constraints [8,9]; and (2) adopting the heuristic methods to handle it will get a large deviation from the optimality [12,13]. Therefore, the main purpose of this study is to propose a solution method to reduce the computer memory for exploring an optimal solution (rather than a sub-optimal solution) while solving the large-scale MLLS problems.

2. Notation and statement of the problem

2.1. List of notations

In this paper, the following notations are adopted:

m	level index ($m = 1, 2, \ldots, M$);
t	period index ($t = 1, 2, \ldots, T$);
$s_{m,t}$	setup cost in period t at level m;
$h_{m,t}$	unit inventory holding cost from period t to period $t + 1$ at level m;
$d_{m,t}$	demands in period t at level m;
$q_{m,t}$,	the produced quantities in period t at level m;
$I_{m,t}$	the inventory level of level m at the end of period t;
$c_{m,m+1}$	c unit of demands have to be produced at level m in order to produce one unit of demands at level $m + 1$, namely "production ratio";
$\delta_{m,t}$	Boolean variable: $\delta_{m,t} = 1$ indicating a *production policy* adopted in period t at level m; $\delta_{m,t} = 0$ meaning an *inventory policy* adopted in period t at level m;
g	row index corresponding to the created Solving-Process data sheet ($g = 1, 2, \ldots, 2^{T-1}$);
$pp_{m,g}$	the gth feasible PP at level m (the feasible PP is made up of a series of production policies and inventory policies);
$c(pp_{m,g})$	total cost of $pp_{m,g}$;
$os_{m,g}$	an optimal set of PPs composed of various g, which denote $pp_{1,g}, pp_{2,g}, \ldots, pp_{m,g}$;
$R_{m,g}(v, j)$	(1) at the first round to implement the solution method: a set of g represent various $pp_{m-1,g}$ which can connect with a particular $pp_{m,g}$ (2) after the first round to implement the solution method: a set of g represent various $os_{m-1,g}$ which can connect with a particular $pp_{m,g}$;
$c(R_{m,g}(v, j))$	(1) at the first round to implement the solution method: the minimal value of various $pp_{m-1,g}$ included in $R_{m,g}(v, j)$ (2) after the first round to implement the solution method: the minimal value of various $os_{m-1,g}$ included in $R_{m,g}(v, j)$;
$c(os_{m,g})$	total cost of $os_{m,g}$;
c^*	the minimal total cost of the MLLS problem.

2.2. Problem description

In the past literature, in order to make the lot sizing problems fit the real-life circumstances more closely, several practical situations had been taken into account by scholars, i.e. quantity discount [20], capacity constraints [21], changes of setup cost [22–24], etc. In this study, the large-scale MLLS problem is discussed with a serial production structure without capacity constraints and lead times are zero, but bill-of-material (BOM) concept is taken into account. Even though to incorporate capacity constraints into the MLLS problems makes the lot-sizing problems fit a practical circumstance more closely, but it does not mean that the uncapacitated problem is an out-of-date problem [17]. Pitakaso et al. [25] indicate that, in practice, uncapacitated lot-sizing models continue to be largely used since the implementation of capacitated approaches requires much data which firms are often reluctant to collect or maintain. Han et al. [17] also conclude that *"the uncapacitated problem still has significance"*. In addition, Vickery and Markland [15] also claim that "*developing the solution methods to determine an optimal set of PPs in a serial production system is beneficial to process industry firms particularly since they are often characterized by serial-type production systems and batch-flow manufacturing processes*". Therefore, to develop an optimal method for solving the large-scale MLLS problem with a serial production structure is worth undertaking.

In a production-inventory system, each operation is assumed to take place in a given level, and only one operation takes place in a given level [4]. The demands at level $m + 1$ are always supplied immediately by the yields at level m [4,5], meaning that the demands at all levels cannot be complemented by external quantities except the first level. Without loss of