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Smoothing Procedures for an Integrated Approach for Multi-Level Lot Sizing and Detailed Scheduling

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1 Introduction

The integration of production planning and scheduling decisions represents an important challenge in production management. Typical Enterprise Resource Planning (ERP) systems, using Manufacturing Resource Planning (MRP-II) technique for capacity management, cannot guarantee feasible procurement and production plans at the operational level (short term planning horizon). Advanced Planning and Scheduling (APS) systems try to solve that inconsistency, by searching for an optimal solution, integrating procurement, production, distribution and sales decisions. However, since integrating all these decisions requires very high computing capabilities, subproblems are often solved separately, but some informations are shared. Some drawbacks are data losses and the use of not appropriate mathematical models, which do not allow capacity to be used efficiently.

In this paper we study the integrated multi-level lot-sizing and job-shop scheduling problem. We want to analyze various smoothing procedures that "repair" the relaxed capacity and Bill-Of-Materials (BOM) constraints in the Lagrangian heuristic of a recent approach [3].

2 Integrated approach

The solution strategy consists in decomposing the integrated problem into several multi-level lot-sizing problems with a different fixed sequence, which is generated by an iterative sequence improvement method. The multi-level lot-sizing problem with fixed sequence is solved through a Lagrangian heuristic, where detailed capacity and BOM constraints are relaxed (see [3]). This results in single-item uncapacitated lot-sizing problems (USILSP), which are solved in $O(T \log T)$ time, with T being the number of periods of the planning horizon, by using the algorithm of Wagelmans *et al.* [5]. We use a mathematical lot-sizing model for fixed sequence which is a generalization of the one used for the Multi-Level Capacitated Lot-Sizing Problem (MLCLSP) [1]. We replace inventory variables by echelon stock (quantity of material of a product at a given period, as finished product or as component) variables, using the formulation introduced in [2]. This allows reducing the number of decision variables, so that it is possible to use the Wagner-Whitin property. Detailed capacity constraints are modeled following a conjunctive graph, where nodes correspond to operations and arcs correspond to precedence constraints between operations of a same job, and between operations sharing the same resource. Each path of the graph is associated to a detailed capacity constraint. Then, since the number of paths is exponential, only the most violated constraints are relaxed.

The whole solving procedure is implemented through a Tabu Search metaheuristic. An initial version of this approach was presented in [3]. Here, we focus on the study of smoothing procedures for validating relaxed constraints, so that upper bounds corresponding to feasible solutions can be obtained.

3 Smoothing procedures

The smoothing procedure is a heuristic applied in some iterations of the Lagrangian heuristic to repair the relaxed constraints. The solution associated to the Lagrangian lower bound is transformed into an upper bound, which corresponds to the cost a feasible procurement and production plan. Lot sizes of finished products and components are modified, by moving production quantities from saturated periods to less busy periods. To satisfy capacity constraints, the algorithm presented in [4] for single-level problems is used, with additional restrictions to avoid violating BOM constraints. To satisfy BOM constraints, a new algorithm is applied. The principle consists in:

(i) Increasing the echelon stock value of a critical product (item whose available echelon stock is not enough to satisfy the internal demand).

(ii) Or reducing the echelon stock value of the critical product's successors.

We designed several heuristics for repairing both types of constraints. They differ in the following key decisions:

- Validation order of the constraints,
- Restricted or unrestricted moves,
- Partially or totally independent validation.

First of all, we have to decide which type of constraints has to be first validated: Capacity or BOM constraints. In fact, reducing the violation of one type of constraints frequently leads to a satisfaction margin reduction in constraints of the other type. On the one hand, to increase capacity, production has to be reduced in a given period thus reducing the available material at that period to satisfy internal demand in the next periods. On the other hand, to increase the inventory of some components, the production has to be increased, thus reducing the available capacity.

Obtaining the best compromise between the satisfaction of capacity and BOM constraints requires the application of moves with some flexibility. A strategy for validating constraints consists in forbidding moves that generate violation of constraints of the other type. This method can rapidly converge to a feasible solution. Nevertheless, it impedes a larger search space exploration, so solutions can be far from being optimal, and the heuristic may be stopped, because there are not enough possible moves. Other strategies can authorize moves that violate or reduce the margins of the other types of constraints, so that the search space increases and new solutions can be found. However, the convergence to a feasible solution may be slower.

Another important decision is when to start repairing the second kind of constraints. A total validation of the first type of constraints may be imposed or not, and a mix of moves for the two type of constraints can also be used.

4 Numerical results

Different smoothing procedures have been evaluated and compared, to find the best compromise between moves for validating the capacity constraints and moves for repairing the BOM constraints. Different experiments have been performed, using 7 bills of materials and 2 job-shop configurations (6 products, 6 operations per product and 6 resources, and 10 products, 10 operations per product and 10 resources). Planning horizons of 5, 10 and 20 periods have been considered, and instances have also been defined by varying the available capacity per period.

A first observation is that smoothing procedures starting by satisfying the BOM constraints lead to better results, when the execution time is rather short (around 5 minutes). The difficulty to find a feasible solution significantly increases when the number of periods increases. Job-shops with 10 products and 10 operations per

product and a planning horizon of 10 or 20 periods are particularly difficult to solve. The standard solver IBMG ILOG CPLEX 12.3 has been used to find optimal solutions and to measure the performance of our approach. As a result, job shops 6x6 can be solved in 300s, but job shops 10x10 often cannot be solved by the standard solver.

5 Conclusions

The principle of the smoothing procedure validating relaxed constraints in an integrated multi-level lot-sizing and scheduling approach has been presented. The need of evaluating different alternatives to find a compromise between capacity constraints and Bill-Of-Materials (BOM) constraints has been introduced. Numerical experiments, comparing results with solutions provided by the commercial solver IBM ILOG CPLEX, will be presented in the workshop. A good performance has been obtained with the integrated approach for relatively small instances, and feasible solutions are determined in all cases. Our current research aims at improving the approach for large size problems.

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