ELSEVIER

Int. J. Production Economics 84 (2003) 115–131

international journal of production economics

www.elsevier.com/locate/dsw

Optimization approximations for capacity constrained material requirements planning

Alistair R. Clark*

Faculty of Computing, Engineering and Mathematical Sciences, University of the West of England, Coldharbour Lane, Bristol BS16 1QY, UK

Received 22 January 2001; accepted 9 September 2002

Abstract

This paper develops three mixed integer programming (MIP) models and solution methods to assist in identifying a capacity feasible master production schedule (MPS) in material requirements planning (MRP) systems. The initial exact model takes into account sequence-dependent setup times of both end-items and components, but is optimally solvable only for small product structures. A first approximate model and solution method, to be used with larger product structures, suboptimally schedules setups and lots on a period-by-period basis, estimating the capacity usage of future setups through the use of linear rather than integer variables. A second model and method, developed from the first, greatly accelerates computing time by sequencing setups gradually within each period, but again suboptimally. The trade-offs between schedule quality and computing time are analyzed in computational tests. The second model is able to schedule setups of up to 100 products on 10 machines over 5 periods in reasonable computing time. The tests show that this complex production scheduling problem can be practicably and successfully simplified both in terms of modelling and of solution method.

Keywords: MRP; Sequencing; Rolling horizons; Heuristic; Setups

1. Introduction

In recent years, enterprise resource planning (ERP) systems have been implemented in many industrial firms (Wortmann, 1998; Kennerley and Neely, 2001). Several companies selling ERP software now include optimization facilities that make use of powerful Operational Research approaches, such as mixed integer programming (MIP), to help improve the quality of operations planning and scheduling (Robinson and Dilts, 1999). Prominent examples include SAP's Advanced Production Optimiser (SAP-APO, 2002) and i2's Trade Matrix software (Trade Matrix, 2000). Such advances stem from increased competitive pressures to improve supply chain and manufacturing performance, the development of high level mathematical modeling languages such as AMPL (Fourer et al., 1993) and OPL (Hentenryck, 1999), and the cheap availability of powerful computing technology. Indeed, so exciting are the possibilities that the term *advanced planning and scheduling* (APS) has become a new buzzword, as

*Tel.: +44-(0)-117-344-3144; fax: +44-(0)-117-344-3155.
E-mail address: alistair.clark@uwe.ac.uk (A.R. Clark).

0925-5273/03/$ - see front matter
PII: S0925-5273(02)00400-0

witnessed by several recent publications and seminars (Kruse, 2000; IOM, 2000a, b). Some companies have specialized in the provision of APS software, such as OPL Studio (ILOG, 2000) which incorporates powerful modelling and optimization tools.

The onus is, however, still on the user to *formulate* an optimizing model that suitably reflects the organization's planning objectives and constraints. The formulation of an appropriate model is by no means a simple task and if carried out naïvely can result in models that are inaccurate or impossible to optimize. In addition, even a well-formulated model, if too large, can still take an impossible amount of computing time to optimize and will need to be solved via a heuristic method (Kuik et al., 1993; Sait and Youssef, 1999). A related approach is to use approximate models that are simpler to solve, but still reflect the objectives and constraints.

As a case in point, this paper reports research into the approximate modelling and optimization of capacity utilization in material requirements planning (MRP) multi-level systems. A comprehensive mathematical model is formulated and then solved using two related approaches based on model approximation and sequential decomposition. Computational tests show that the second approach produces reasonable solutions in viable computing time for medium-to-large sized product structures.

2. Capacity planning and optimization in MRP systems

In MRP systems, the master production schedule (MPS) represents a plan for the production of all end-items over a given planning horizon. It specifies how much of each end-item will be produced in each planning period, so that future component production requirements and materials purchases can be calculated using MRP component-explosion logic. As such, the MPS has to be feasible so that components can be produced within the capacity available in each time period. It is clear that there is a role here for a planning tool that efficiently takes capacity and the MRP explosion into account at the same time, a point made by Shapiro (1993). This paper proposes just such a tool in the form of a very general mixed integer programming (MIP) model that allows for sequence-dependent setups, unlike the formulation in Shapiro (1993). As it stands, the model cannot be solved quickly so two approximate models are developed to permit faster specification of efficient MPS/MRP plans.

Proud (1999) argues that master schedulers must be "optimizers", balancing conflicting goals such as low inventories and efficient utilization of capacity. In this spirit, the MIP model aims to minimize the total cost of component & end-item inventory and backorders while keeping within available production capacity. The decision variables are primarily the MPS production quantities, but an MRP plan is also identified at the same time. The capacity requirements of the MPS depend upon the MRP component production plan which in turn depends on the lot-sizes used in the MRP explosion. These are all taken into account in the model.

The model developed represents setup times that are sequence-dependent and permits multiple setups within a planning period. This makes for a combined lot sequencing and sizing problem, a thorny topic on which there has been limited research (Potts and van Wassenhove, 1992; Meyr, 2000, 2002). The resulting huge number of binary (0/1) variables causes great computational intractability for non-trivial problems. Such complexity is overcome by substituting the vast majority of the binary variables and constraints with continuous variables and constraints, as explained below.

Substantial computing effort is needed to optimally solve complex lot-sizing models. Faced with sequence-dependent setup times and dynamic job arrivals, Ovacik and Uzsoy (1995) struck a compromise between the impractical computational effort needed by perfectly optimizing procedures and the poor solution quality of myopic methods. They achieved this by breaking a large problem into a number of smaller semi-myopic ones which were solved exactly by branch-&-bound. This paper takes a similar approach using a series of branch-&-bound solutions to