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Implementing a near-optimal solution for the multi-stage, multi-product capacitated lot-sizing problem by rolling out a cyclical production plan

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Abstract

This paper describes the implementation and operational results of a cyclical master production-scheduling model, steering the manufacturing process of a photographic film-producing company. The involved company has a number one or two selling position in the medical and graphical film market. In film production all items are produced within two stages. The first stage is process-oriented and produces a limited number of intermediate products. The second stage is flow-shop oriented and cuts and slices the intermediate products into a large number of end products. In its search for a global optimum, the company wanted to synchronise operations by establishing a common replenishment period as a co-ördination mechanism between the first and second production stage. The proposed cyclical model uses a level-by-level approach and solves the economic lot-scheduling problem (ELSP). The cyclical model proved to be very robust when aligning with dynamic demand, allowing a synchronisation of operations. Based on the resulting schedule stability management lowered the levels of safety stock, which resulted in significant savings. This paper compares the cyclical model with the mathematical optimum, generated by solving the corresponding capacitated lot-sizing problem (CLSP). The results prove the ability of the proposed method to achieve a near optimal solution. The cyclical model does not suffer from the NP hardness of the CLSP and is, therefore, able to solve large-scale models.
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1. Introduction

With a growing focus on supply chain management, firms realise that inventories across the entire supply chain can be more efficiently managed through greater co-öperation and better co-ördination. This certainly applies to the internal operations within multi-stage, multi-product production systems representing the manufacturing part of a supply chain.

This research model focuses on the semi-process industry with its typical X-type shape of product structure flow. The first, process-oriented, stage consumes a large number of components but

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produces only a limited number of intermediate products. Lot sizes are large, caused by expensive change-over costs. The second stage transforms the intermediate product into many distinct end products, different in size and packaging forms, as is the case for pharmaceuticals, photographic film, glass, steel, etc. The second stage process is fairly labour intensive. The production units are typically spread across the world. An example is the medical (X-ray) and graphical film production of Agfa, a company with a number one or two selling position in the mentioned product groups. The first stage coating lines, producing the intermediate products, are located in Antwerp. Set-up costs and lot sizes are high, mainly caused by liquid silver losses. The finishing departments are spread across the world. Within finishing set-up costs are low which leads to smaller lot-sizes. Because of the large process differences, both production stages used to be planned independently. The result was a set of two locally optimised processes separated by a large stock of intermediates acting as a decoupling point. In its search for a more global optimum, the company wanted to synchronise operations by establishing a common replenishment period as a co-ördination mechanism between the first and second production stage. This problem corresponds with the economic lot-scheduling problem (ELSP) within a multi-stage, multi-product environment. The company uses a level-by-level approach and first establishes a common repetitive production schedule for the coating process, typically the process with the highest set-up cost, and, therefore, the strongest driving factor within the inventory- and set-up cost function. The new model could be described as a cycle chain, where the involved products all have a distinct periodic review, fitting within one common cycle (production wheel).

The proposed cyclical MPS planning model is in operational use, since 2002, at Agfa's largest production site and includes the most important coating types corresponding with 83% of the total annual volume. Establishing this nominal cyclical production schedule is part of the annual 'Service Level Agreement Process' with the involved business groups. Based on the annual coating and finishing forecasts the model delivers a cyclical master production schedule. This cyclical volume plan is then used as leading plan in rolling forward the master production schedule, during the actual planning cycles.

Within the pragmatic level-by-level approach, the company limited the cyclical model to the set of fast-moving items. As in many companies the pareto rule, stating that 20% of items correspond with 80% or more of volume, is omni-present within Agfa's product portfolio. These fast-moving products have typically a quite stable demand pattern, which corresponds with the static demand assumption of the ELSP problem. The remaining spare capacity, within the cyclical model, is available for the production of slower moving items or to deal with demand fluctuations for the cyclical fast-moving products.

This paper describes briefly the operational use of the proposed cyclical model. The aim of this research was to prove the ability of a cyclical production plan to deliver a near-optimal solution for the multi-stage, multi-product capacitated lot-sizing problem (CLSP). The results of the cyclical model will be compared with the mathematical optimum, generated by solving the corresponding CLSP.

This paper has following structure. Section 2 reviews previous research on cyclical models. Section 3 describes the production process and relevant production data. The solution approach of both the ELSP- and CLSP-based planning models is described within Section 4. Section 5 describes both mathematical models. Section 6 lists the results of the ELSP- and CLSP-based solutions. Both solutions are compared in Section 7. Section 8 demonstrates the robustness of the ELSP-based solution and Section 9 concludes.

2. Cyclical planning models and previous research

Maes and Van Wassenhove (1988) and Salomon (1990) review different techniques for solving CLSPs. Two single-stage techniques, assuming static demand, are based on cyclic scheduling and solve the multi-product ELSP within a capacity constrained environment.

The 'common cycle approach' (CCSP) solves the model mathematically and determines the optimal length of a production cycle where each product is produced at the same common base frequency. A generalisation of this model towards a multi-stage environment is described by El-Najdawi and Kleindorfer (1993).

The cyclic scheduling approach is an extension of the common cycle model allowing schedules in which each product may be produced more than

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