Int. J. Production Economics 151 (2014) 206–213

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Simulation-based optimization methods for setting production planning parameters

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ARTICLE INFO

Article history:
Received 13 January 2013
Accepted 19 October 2013
Available online 25 October 2013

Keywords:
Production planning
Simulation
Optimization
Hierarchical planning
Planning parameters

ABSTRACT

This paper refers to a hierarchical production planning system in a make-to-order environment. A challenging task in this context is to determine good production parameter settings in order to benefit from established planning methods. We present a framework for hierarchical production planning which we use to identify good settings for three planning parameters, namely planned leadtimes, safety stock, and lotsizes. Within a discrete-event simulation which mimics the production system we use a mathematical optimization model for replicating the decision problem. This mathematical model is solved to optimality using a standard optimization engine. We use data referring to four different demand market situations in order to derive general statements concerning the quality and sensitivity of the three analyzed planning parameters.

For exploring the parameter space we follow the concept of simulation-based optimization. We compare the performance of six different optimization methods to a kind of systematic enumeration of parameter combinations. We show that among these a search procedure based on the idea of Variable Neighborhood Search (VNS) leads to the best results in this context.

1. Introduction

Manufacturing companies are often faced with challenging market situations concerning product complexity and changing demand situations. Their customers frequently emphasize on logistics performance (e.g. service levels, delivery leadtimes, average lateness) in addition to product quality. In order to remain competitive various decisions, which are strongly influencing each other although referring to different planning levels, have to be made carefully. Tasks like capacity planning, order release, lotsizing, and scheduling are often mentioned to be typical challenges in this context (see Stadtler and Kilger, 2005; Schuh, 2006). Different decision levels usually refer to different time horizons and aggregation degrees. This is mainly induced by an increasing level of uncertainty involved in longer planning horizons. Coordination between decisions taken on different levels can be approached by implementing a hierarchical planning system (cf. Hax and Meal, 1975; Sitompul and Aghezzaf, 2011; Hopp and Spearman, 2000; Schneeweiss, 2003). We present such a system in the context of make-to-order production. Our experimental framework has been implemented based on data from the automotive supplier industry. However, it is not restricted to this business area, but could also be used to model make-to-order manufacturing environments from other industries.

The main driver in make-to-order manufacturing systems are customer orders, which means that production processes are always triggered by the given demand. Important components of hierarchical planning system for make-to-order production systems are aggregate planning, Master Production Scheduling (MPS) and Material Requirements Planning (MRP). Within our framework for aggregate planning we use a linear model, solve it to optimality and derive the master plan.

The performance of such a planning framework of course is highly influenced by the setting chosen for the inherent parameters. Thus, parameter tuning is a crucial issue in this context. Since MPS is already solved exactly, we have to take care about MRP related parameters that have to be optimized in order to ensure a well performing system. In this study we consider planned leadtimes, safety stock, and lotsizes as most relevant for our investigations.

In this study we use the term *planned leadtimes* for the number of time periods to insert between the due date and the start date of a production order in addition to known processing times. Thus, the release date of a production order i with planned leadtime plt_i and estimated processing time t_i is $(plt_i + t_i)$ periods ahead of its due date. Of course both customer orders and production replenishment orders are triggered by this parameter. The arising trade-off refers to short planned leadtimes with more variable workload

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http://dx.doi.org/10.1016/j.ijpe.2013.10.016

on the shopfloor, and long ones leading to an increased level of work-in-process (cf. Teo et al., 2011).

Since we are investigating a setting with stochastic influences we also use safety stocks to increase service levels. Safety stocks used within the MRP concept have a somehow similar impact as planned leadtimes since both of them are intended to reduce the risk of stock-out situations. Clearly, here we observe a trade-off between increased service level and high inventory levels.

Increased lotsizes also lead to higher inventories but reduce the number of set-ups. In our framework the settings specified during the planning steps are used for execution on the simulated shopfloor where we are able to measure a number of performance indicators. The impact of parameter settings is examined on a combined objective function consisting of service- and inventory level.

For this purpose we have to find a method able to search the parameter space efficiently. Of course using the stand-alone simulation for some trial-and-error experiments would be insufficient to find satisfying results. An analytical model on the other hand covering all stochastic and non-linear dependencies of the given problem would be far too complex to be solved in acceptable amount of time (see Almeder et al., 2009). The concept of simulation-based optimization, where the simulation is embedded into a superordinate search procedure seems to be most appropriate here (cf. Köchel and Nieländer, 2005). This leads us to a further contribution of this work which is the identification of methods for searching the parameter space efficiently. Different simulation-based optimization methods, where the output of the simulation triggers a superordinate search procedure, are compared. Also a commercial software add-on is subject to our evaluations. The performance of these methods is evaluated based on results from a systematic enumeration of parameter combinations.

This paper is organized as follows. The upcoming section is dedicated to related literature. Section 3 describes the experimental framework used as input for the parameter optimization procedures. The latter are described in Section 4. Results are provided in Section 5. Conclusions and further research are summed up in Section 6.

2. Related work

Hierarchical production planning which has initially been presented by Hax and Meal (1975) is still discussed in recent literature (see Aghezzaf, 2011; Torabi et al., 2010). In the context of hierarchical production planning MRP and its parameterization are of course part of the key issues in this context (e.g. Buzacott and Shanthikumar, 1994; Enns, 2001; Inderfurth, 2009).

Research on offsetting under uncertainties for MRP, as it is called in common literature, mainly focusses on safety stocks (e.g. Persona et al., 2007; Osman and Demirli, 2012; Hung and Chang, 1999) while for example planned leadtimes are addressed rarely. Buzacott and Shanthikumar (1994) compare the influence of safety stock and safety time. The latter is defined as the amount the deterministic planning leadtime assumed for MRP exceeds the expected time a lot will take to be completed by the manufacturing process. Molinder (1997) tackled the problem of protection against uncertainties in lead time and demand, but he concentrated on the situation where one has to decide whether to use safety stocks or leadtimes. Also, e.g., Whybark and Williams (1976) weigh up safety time versus safety stock. Louly and Dolgui (2011) presented an analytic model for finding optimal planned leadtimes in MRP systems, but as for stochastic influences they solely assumed unknown leadtimes. In contrast to the existing analytical models we provide the possibility to find good parameter settings in situations where the problem complexity precludes the use of analytical approaches.

Optimal parameterization of lotsizing methods in this context is not covered sufficiently so far (cf. Louly and Dolgui, 2011). However, a simultaneous optimization of planning parameters has been explicitly recommended by Molinder (1997).

An analytical model for simultaneous optimization of capacity and planned lead time in a two-stage production system with different customer due dates has been presented by Altendorfer and Minner (2011). Planned leadtimes in a disassembly remanufacturing system have been investigated by Tanga and Grubbstro (2007). A method derived with Lagrange's method of indeterminate coefficients used for setting planned leadtimes in capacity requirements planning has been proposed by Matsuura and Tsubone (1993). Teo et al. (2011) investigated on planned lead times for a make-to-order production system. They embedded their model into a non-linear optimization program to find the optimal values of the planning parameters but state that including the dynamics of MPS would have been a valuable extension here.

Liberopoulos and Koukoumialos (2005) explored the trade-offs between base stock levels, numbers of kanbans, and planned supply lead times in production/inventory systems with advanced demand information numerically. They used an approach of simulation-based optimization in a make-to-stock environment.

Simulation-based optimization of inventory systems has been discussed by Köchel and Nieländer (2005). Arakawa et al. (2003) solved the operational planning problem of job shop scheduling using an optimization-oriented method in combination with simulation. A production-inventory system with multiple items has been considered for the application of simulation-based optimization of sequencing and lotsizing by Kämpf and Köchel (2006). Since that problem is too complex for an analytical solution they restrict their search to simple structured policies, which can be described by a few parameters. They used a simulator which has been combined with a genetic algorithm as an optimizer.

Also Li et al. (2009) used genetic algorithms as component within their hybrid simulation optimization method. They applied this approach to optimize the production planning and control policies for remanufacturing scenarios. Almeder et al. (2009) combined discrete-event simulation with optimization in order to support the operational decisions for supply chain networks. Ehrenberg and Zimmermann (2012) propose a simulation-based optimization approach that relies on coupling simulation and optimization through a relaxation-based schedule generation procedure. They use this approach for determining schedules for make-to-order production of companies that manufacture special purpose glasses. A simulation optimization-based decision support tool for steel manufacturing is introduced by Melouk et al. (2013). For optimization they link their simulation model with an optimization module developed using OptQuest™. In addition to single factor experiments, they use their tool to conduct tests where the impact of changing two system factors simultaneously are examined.

There are a number of further studies to be found in the literature where simulation models are connected with an optimization algorithm leading to improvements in given objective functions. However, to our knowledge the solution space in these studies is practically unknown. Thus, improvements can be observed but it is, for example, not clear whether the algorithms are trapped in local minima or not. In contrast to that, we reproduce the whole solution surface using an equidistant grid. Based on this, we compare 6 different optimization methods and are able to make valid statements on their performance.

Both a simultaneous optimization of planned leadtimes, safety stocks, and lotsizes, and investigations concerning methods to