PERGAMON

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Automatica 39 (2003) 793–805

automatica

www.elsevier.com/locate/automatica

A bimodal scheme for multi-stage production and inventory control☆

Jean-Claude Hennet*

LAAS - CNRS, 7, Avenue du Colonel Roche, 31077 Toulouse, Cédex 4, France

Received 26 October 2001; received in revised form 29 May 2002; accepted 13 January 2003

Abstract

This study considers a multi-stage multi-item production plant with its supply chain and customer environment. The production, supply and inventory plan is optimized on a dual-mode basis, under two different information patterns. The short-term plan relies on firm orders received from customers. On the contrary, the long-term plan is based on predicted demands represented by random sequences. In this study, the role of the long-term plan is mainly to impose a final condition set to the short-term plan.
© 2003 Elsevier Science Ltd. All rights reserved.

Keywords: Production planning; Multi-stage production; Linear programming; State feedback; Model predictive control

1. Introduction

A major difficulty in production planning relates to the choice of the time horizon. As a medium-range tactical tool for a company, a production plan should provide reference production values over time not only to satisfy the current order list from customers, but also to anticipate future orders which have not yet been placed. Accordingly, the planning time horizon is generally selected longer than the horizon for which the data are considered frozen. Future demands which are expected or imperfectly known at the time of computation are replaced by their forecasts (see e.g. Thomas & McClain, 1993 and the references therein).

Due to the heterogeneity of its input data, the planning problem may then be decomposed into two subproblems: one which is deterministic over a short-range horizon and one which is stochastic and covers a longer time horizon. However, such a decomposition generates an additional problem: when and how to link up and sequence the solutions of the two problems? In agreement with this observation, this paper proposes to solve the infinite horizon planning problem in two parts:

(i) Resolution of a finite horizon production planning problem under deterministic demand and a terminal constraint. For the considered product structures, this problem can be formulated and solved as a Linear Program.

(ii) Construction of a stationary production and supply policy to optimally react to bounded random variations of demand for end products, through a robust closed-loop inventory control policy.

Under a rolling horizon implementation of the plan, only the finite horizon solution is applied, but the terminal constraint, associated with feasibility of the closed-loop policy, guarantees system stability and optimality with respect to the infinite horizon problem. Such a stability condition combined with a finite-horizon rolling policy is somewhat similar to the one encountered in model predictive control (MPC) schemes (Mayne, Rawlings, Rao, & Scockaert, 2000).

The closed-loop control approach used in this paper recovers most of the classical results on optimal inventory policies for multi-echelon systems (Clarke & Scarf, 1960; Federgruen & Zipkin, 1984; Porteus, 1991). It is based on similar assumptions in terms of production costs, assumed proportional to quantities, and in terms of lead times, supposed fixed or random, but independent of the quantities produced or ordered. In this respect, the main originality of the approach proposed is that it considers general multi-product structures directly, through vector and matrix representations, rather than as an extension of the single period single item model.

☆ This paper was not presented at any IFAC meeting. This paper was recommended for publication in revised form by Associate Editor Pirooz Vakili under the direction of Editor Alain Haurie.

* Tel.: +33-5-61-33-63-13; fax: +33-5-61-33-69-36.
E-mail address: hennet@laas.fr (J.-C. Hennet).

0005-1098/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0005-1098(03)00026-8

The remainder of the paper is organized as follows. Section 2 presents the equations and constraints defining the model. Then, Section 3 describes the optimization problem and focuses on the resolution of the infinite horizon planning problem. It is proposed to construct an invariant domain in which the system trajectory can be maintained under any admissible demand vector trajectory. This invariant domain is then used as a target domain in the short-range planning problem studied in Section 4. Section 5 presents an example to illustrate the approach, and the final section contains some concluding remarks.

2. The production and supply model

Most of the literature on inventory theory under stochastic demand and fixed lead times (Porteus, 1991) first solves the single-stage case, extends the classical base stock policy result to series multi-echelon structures, using the decomposition proposed in Clarke and Scarf (1960), and then to assembly systems, by constructing an equivalent series system (Rosling, 1989). In particular, this approach allows to determine conditions on initial stocks under which an assembly system can be transformed into an equivalent series system (Federgruen, 1993). More complex multi-stage product structures can be represented by acyclic graphs which are neither trees nor anti-trees. The purpose of this study is to construct a dynamic model for such systems and to design a production and inventory control policy directly from this model. Typically, the considered product structure involves primary products, ordered to suppliers, intermediate products internally produced and consumed, and final products delivered to customers.

The production planning problem is considered at the aggregate level where products are aggregated into product types and time periods are much longer than setup times. Under such assumptions, demand, production and inventory quantities at each period take large integer values which can be accurately approximated by real numbers (see e.g. Bitran & Tirupati, 1993). Practical implementation of results of the aggregate plan then require a disaggregation process, not studied in this paper.

2.1. The bill of materials

According to a given manufacturing recipe, the production of one unit of product i requires the combination of components $j = 1,\dots,n$ in quantities π_{ji}, for $j = 1,\dots,n$. In the considered production structure, each production activity has several input products but only one output product. The bill of materials can thus described by

- the input matrix $\Pi = ((\pi_{il})) \in \mathfrak{R}^{n\times n}$,
- the output matrix, which is the identity matrix $I \in \mathfrak{R}^{n\times n}$.

Such product structures typically characterize the field of application of MRP techniques. Classically, it is assumed that the product structure has no cycle. It can then be decomposed into levels: level 1 products are the p end products, numbered from 1 to p. Then, intermediate and primary products are numbered in the increasing order of their level. The level of product i, for $i = p+1,\dots,n$ is the maximal number of stages to transform product i into a final product. Matrix Π is lower triangular under such a level-consistent ordering of products.

Let d be the nonnegative vector of external demands over a given time period. The gross production/supply vector, u, necessary to satisfy this demand is related to d through the following Leontief-type equation (Veinott, 1969):

$$(I - \Pi)u = d. \quad (1)$$

The structure of the net production matrix $(I - \Pi)$ implies that its inverse exists and is nonnegative. Thus, vector u is uniquely defined by

$$u = (I - \Pi)^{-1}d. \quad (2)$$

Note that matrix $(I - \Pi)^{-1}$ is the sum of the powers of matrix Π. If all the terms of Π are nonnegative integer, as it is generally the case, then $(I - \Pi)^{-1}$ is also a matrix of nonnegative integers. And thus, since the entries of d are nonnegative integers, the entries of vector u are also nonnegative integers.

The bill of materials defined by (2) provides a static view of the system material requirements over a given time horizon. In the following section, a dynamic model will be constructed to formulate the aggregate planning problem, taking into account product lead times, inventory levels and capacity constraints.

2.2. The dynamic model

In addition to the quantitative description of the process by its bill of materials, the model of the system must include the logical aspects of inputs availability. There are two basic methods to guarantee the availability of inputs as a pre-condition to production: inventories and synchronization of orders. In practice, few processes run on a pure make-to-stock or make-to-order basis. On the one hand, the need for stocks appears very clearly to limit delays or lost sales when considering the random aspects of demands for final products and lead times. But reactivity and low costs also impose to adjust orders to demands in time and quantity.

This is a reason why nowadays, most practical production control systems, including Kanban and MRP, use a combination of the two basic methods.

A long-term time horizon, denoted T_L is considered. Time is discretized into periods of equal lengths. The planning time horizon is divided into elementary time periods k, with $k = 0,1,\dots,T_L$. From the demand prediction viewpoint, the horizon is decomposed into two parts. Demands are supposed perfectly known from time period 0 to a short-range date, denoted T_S, with $T_S \ll T_L$ and predicted after this date,

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات