International Journal of Production Economics 190 (2017) 31–36

Contents lists available at ScienceDirect

Int. J. Production Economics

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

A flexible production planning for rolling-horizons

Raimundo J.B. de Sampaio*, Rafael R.G. Wollmann, Paula F.G. Vieira

Pontifical Catholic University of Parana (PPGEPS – PUCPR), Curitiba, Paraná 80215-901, Brazil

ARTICLE INFO

Keywords:
Production planning
Clearing function
Rolling-planning

ABSTRACT

Previous studies on production planning indicated that keeping updated information on estimates of demand, estimates of production capacity, estimates of available resources, etc., during the planning horizon, is particularly important to maintain the current production planning. Hence, the planner has to change the production planning from time to time to accommodate these updating, and therefore, there is a huge waste of resource planning, since the production planning is carried out for the entire planning horizon, but only run for a few periods, or just one period. Another drawback of the existing arrangements to implement a rule of rolling-planning with the production planning is that they do not work well under capacity constraints and thus all the rolling-planning models that result from linear programming models coupled with clearing function are clearly outside the scope of these current schemes, since all of them incorporate capacity constraints. This paper comes providing a new scheme (Algorithm) to solve the pointed drawbacks, analyzes the scheme, prove a theorem which guarantees the result provided by the algorithm is correct, and finally illustrates the result using a numerical example.

1. The problem

Linear programming models are widely used to address production planning problems, which have been studied for several decades (Kefeli et al., 2011; Karmarkar, 1989; Graves, 1986; Chu, 1991; Asmundsson et al., 2009; Kempf et al., 2011; Srinivassan et al., 1988; Hopp and Spearman, 2001; Kacar and Uzsoy, 2014), although their recommendations are inconsistent with the queuing behavior observed in most production facilities (Kefeli et al., 2011; de Sampaio et al., 2009, 2011). The vast majority of insights show that the performance of productive systems is affected by the loading of the system well before capacity is fully utilized, and average lead-time increases nonlinearly with capacity utilization (Karmarkar, 1989; Graves, 1986; Hopp and Spearman, 2001), i.e., with the workload of system. Hence, the workload of the system determines lead-time, impacting the feasibility of production plans. This creates difficulties for linear programming formulations of production planning problems that assume constant lead-time. These models, assuming constant lead-time, determines the levels of resource utilization in the system, which in turn, may result in realized lead-times that are different from those initially assumed. This circularity has been approached by several iterative schemes (Asmundsson et al., 2009), nevertheless, to the best of our knowledge, their convergence is not yet understood (Fatih et al., 2010). In this paper we address this circularity through the use of clearing functions, first introduced by Graves (1986), Karmarkar (1989), and Srinivassan et al. (1988), and more recently by Asmundsson et al. (2009), Kefeli et al. (2011), Fatih et al., (2010), and de Sampaio et al. (2009, 2011, 2012, 2013a, 2013b), etc. For a detailed review of the state-of-art in production planning using clearing function, see Missbauer and Uzsoy (2010).

It is assumed that clearing function is a two variable indefinite function that expresses the expected production throughput of a capacitated resource over a planning period as a function of the average work-in-process level over that period and the throughput time in the system, thus giving realistic information on the capacity of the resources. Introduction of clearing function into a linear programming production planning model destroys its linear structure, which we usually want to preserve, however, the convex structure of the resulting nonlinear model allows it to be easily approximated to any degree of accuracy by a large linear programming model (Kefeli et al., 2011), which may require decomposition techniques to solve (de Sampaio et al., 2011, 2012, 2014; Wollmann, 2012). The classical schemes used to decompose this resulting problem (Chu, 1991; de Sampaio et al., 2009), does not work properly in the presence of nominal capacity constraints, and since clearing functions are a form of capacity constraint, the classical decomposition scheme does not work properly in this context either, as seen in (de Sampaio et al., 2011). Hence, a new decomposition approach is required to decompose the planning horizon (de Sampaio et al., 2014). Nevertheless, a new decomposition would be of limited value if it does not allow rolling-planning programming, which is the issue we address here.

* Corresponding author.
E-mail address: raimundo.sampaio@pucpr.br (R.J.B. de Sampaio).

http://dx.doi.org/10.1016/j.ijpe.2017.01.003
Received 30 January 2016; Received in revised form 7 July 2016; Accepted 4 January 2017
Available online 11 January 2017
0925-5273/

The implementation of production planning using rolling-planning approach is common practice in a dynamic environment (Chand et al., 2002; Naphade et al., 2001) and is extensively studied and applied in both academia and industry. Concerning production planning, rolling-planning problems can be found in many different areas, such as, Material Requirement Planning (Blackburn and Millen, 1982; Simpson, 1999), aggregate planning (Chung and Krajewski, 1987; Nedaei and Mahlooji, 2014), lot sizing (Stadtler, 2000; Tiacci and Saetta, 2012; Bardhan et al., 2012), production planning and scheduling integration (Li and Ierapetritou, 2010; Bredström et al., 2013), Master Production Scheduling (Campbell, 1992; As'ad and Demirli, 2010; Vargas and Metters, 2011) and hierarchical production planning (Mehra et al., 1996; Wu and Ierapetritou, 2007) just to quote a few. These problems can be solved using many different techniques, such as, Linear Programming (Albey et al., 2015; Galasso et al., 2008), Dynamic Programming (Bitran and Leong, 1992; Sung and Lee, 1994), Simulation (Nedaei and Mahlooji, 2014; Vargas and Metters, 2011), Mixed and Integer Programming (Erdirik-Dogan and Grossmann, 2007; Herrera et al., 2015) and Heuristics (Mercé and Fontan, 2003; Toy and Berk, 2013) to cite a few.

Considering a multi-period problem, the planning horizon is divided into T time periods (for example 12 periods) and the production planning model is solved. Once the model is solved, decisions for the current period (Tiacci and Saetta, 2012) or for the next few periods (Vargas and Metters, 2011) are implemented. Towards the end of the period, information are updated and a new model is solved which now covers the planning horizon for the next T periods (12 months) or the remaining months of the year *T-1*, *T-2* and so on. The latter situation would be the case of, for example, in annual budget planning (Bredström et al., 2013). At the beginning of any period, a set of decisions are made considering new information and future estimations available, usually, under the supervision of a decision support system based on the mathematical programming model.

Rolling-planning is considered more efficient than the methodology that restricts implementation to the immediate period for which demand information is least subject to error (As'ad and Demirli, 2010). In general, in industrial engineering works, rolling-planning in production planning is extensively studied for the case where the planning horizon has its size of T at each iteration (Blackburn and Millen, 1982; Simpson, 1999; Chung and Krajewski, 1987; Nedaei and Mahlooji, 2014; Stadtler, 2000; Tiacci and Saetta, 2012; Bardhan et al., 2012; Campbell, 1992; As'ad and Demirli, 2010; Vargas and Metters, 2011; Mehra et al., 1996; Albey et al., 2015; Galasso et al., 2008; Bitran and Leong, 1992; Sung and Lee, 1994; Herrera et al., 2015; Mercé and Fontan, 2003; Toy and Berk, 2013). The case where T is fixed and the planning horizon gets shorter and shorter at each iteration (Li and Ierapetritou, 2010; Wu and Ierapetritou, 2007; Erdirik-Dogan and Grossmann, 2007) is not well explored yet. In this last case chemical engineering works deal with problems in a continuous production environment where the last batch finishes at a certain period, but this way of modelling can be expanded and used in other applications, in order to cover not only the chemical engineering field but also industrial engineering as a whole, as for instance in the case of public service concessions.

The rolling-planning scheme provided here uses linear programming model whose information about capacity comes from an externally estimated clearing function. Explicitly the rolling-planning scheme is the following: The planning horizon is fixed as a fix number of periods ahead; the first production planning is formulated covering all the periods of the planning horizon; only the decisions to the first period are executed; repeat the procedure until the set of periods is void. Therefore, each production planning is one period shorter than the previous, until it finishes, and in this sense the presented scheme is a decomposition process.

The remainder of this paper is organized as follows. In Section 2, the structure of the problem is presented, an algorithm is defined, and a theorem on the algorithm is presented and proved. In Section 3, a numerical illustration is presented to show why the existing scheme of decomposition (de Sampaio et al., 2014) fails, as well as the way the new rolling-planning scheme overcomes the failure, and finally the conclusions are presented.

2. Structure of the problem

Motivated by the schemes proposed by Chu (1991), de Sampaio et al. (2009, 2011, 2012), and Wollmann (2012), which describe cumulatively the resources whose leftovers can be transferred from one period to the next, and period to period, the resources whose leftovers cannot, we consider the following production planning problem: Lets x_{ij} be the production level of product i in period j, and c_{ij} the unit cost to produce one unit of product i in period j. Let b_{ki} be the number of components k used to produce one unit of product i, and h_i the standard time required to produce one unit of product i. Suppose that R_j is the amount of labor resource (in units of standard time) available during period j, and that any unused labor resource from period j cannot be carried out to period $j+1$. Let S_{kj} be the supply of components k available for consumption in period j, and let D_i be the maximum demand for product i until the end of the planning horizon, and suppose that γ_{ij} is the available production capacity for each product i in period j, prescribed by external clearing functions. Hence, the simplest model of production planning coupled with clearing function that can be proposed to present our approach to the used rolling-planning scheme may be formulated as,

$$
\begin{aligned}
&Maximize \quad \sum_{j=1}^{T}\sum_{i=1}^{N} c_{ij}x_{ij}\\
&s.\,t. \quad \sum_{j=1}^{t}\sum_{i=1}^{N} b_{ki}x_{ij} \le \sum_{j=1}^{t} S_{kj}\,, k=1,\ldots,K,\quad t=1,\ldots,T,\\
&\sum_{j=1}^{T} x_{ij} \le D_i,\quad i=1,2,\ldots,N\\
&\sum_{i=1}^{N} h_i x_{ij} \le R_j,\quad j=1,2,\ldots,T,\\
&x_{ij}-\gamma_{ij} \le 0,\quad i=1,2,\ldots,N,\quad j=1,2,\ldots,T\\
&x_{ij} \ge 0,\quad i=1,2,\ldots,N,\quad j=1,2,\ldots,T.
\end{aligned}
\tag{1}
$$

$\forall\, i, \forall\, j, \gamma_{ij}=\rho_{ij}\varphi_j(W_j, T_j), \rho_{ij}\ge 0$ and $\sum_{i=1}^{N}\rho_{ij}=1$. γ_{ij} is the shared capacity of the production system for each product i in the period j. Let W_j be the total workload of the system, and T_j its corresponding lead time, then the value $\varphi_j(W_j, T_j)$ is the estimated capacity provided by external clearing functions. The objective function of the problem (1) can be modified to incorporate costs associated with inventory, work-in-process, releases etc., provided it is maintained as a linear function, and the corresponding constraints are written period to period or in a cumulatively way for those resources whose leftovers can be carried from one period to the next. Without any loss of generality, the model (1) was chosen the simplest possible to emphasize the idea of decomposition to solve the rolling-planning scheme, but it can incorporate any others decision variables, without major difficulties.

Model (1) couples a linear programming model with an external clearing function to represent the nonlinear variability of production throughput with the workload and lead times of the system, following the approach introduced in (Kefeli et al., 2011; de Sampaio et al., 2011, 2012, 2013a, 2013b). Since the clearing function is defined for each resource at each period of the planning horizon, then it can simply be combined with the decomposition scheme throughout the rolling-planning scheme. Nevertheless, clearing function will not be discussed here any further.

The existing decomposition schemes for model (1) have good performance, but they do not work well in general when applied to the model combined with rolling-planning, see for instance (de Sampaio et al., 2014) for a counterexample that shows they may fail, and that this failure mainly occurs because of the difficulties of propagating the current information from a period to subsequent periods. To overcome this shortcoming, the sub-problems foreseen in