Information Sciences 278 (2014) 841–861

Contents lists available at ScienceDirect

Information Sciences

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

Integrated production planning and preventive maintenance in deteriorating production systems

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ARTICLE INFO

Article history:
Received 15 August 2010
Received in revised form 18 March 2014
Accepted 23 March 2014
Available online 1 April 2014

Keywords:
Production planning
Preventive maintenance
Lot sizing
Failure-prone

ABSTRACT

The traditional production planning model based upon the famous linear programming formulation has been well documented. However, the integration of preventive maintenance planning in the same model is a recent problem. This paper proposes an extended linear programming model as a hybrid approach for computing the optimum production plan with minimum total cost. The dual objective problem of production planning and maintenance is treated into a mixed integer linear program. This program is not only considering cases of multi-lines, multi-periods and multi-items but also taking into account the deterioration of the lines. This deterioration is represented in the model as a reduction of production lines capacities in function of the time evolution. Maintenance operations are supposed to provide lines in an operational state as good as new, i.e. with a maximum capacity. Through the study of the models limits, it is shown that the proposed approach can deal with a broader range of problems than that of Aghezzaf and Najid (2008) [3]. An optimal relaxation technique based on the polyhedral theory is developed to improve the computational time and expand the limits of the proposed model. Also, a "Fix and Relax heuristic" is developed for complex problems. Their computation time and their difference are computed referring to the same lower bound and the same considerations as those presented by Aghezzaf and Najid. It is proved through more than 880 several simulations for each model with different capacities and different setup costs, that this approach can solve large size problems with moderate computational time and gap.

1. Introduction

Within the field of production planning, the main goal is to meet the satisfaction of the demand for a few specific products. The most commonly used technique to solve these issues are based on a sound knowledge of the problem's parameters, such as production cost, production order, etc. In fact, these parameters are subject to a number of uncertainties and rates of fluctuation during the production planning process. Therefore, some of these production plans are inexact or even irrelevent. In this case, the initial plan needs to be updated continually to consider the fluctuation of the quoted parameters. Then, this update becomes more and more crucial for a reactive planification [14].

The first authors to introduce how important is to consider the machines "reliability" as a parameter to elaborate a production plan are Older and Suri [11]. At first, the problem was treated and formulated as a stochastic process in which the failure moments as well as repairing ones were considered as a homogeneous Markov chain. Then, non-homogeneous Mar-

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http://dx.doi.org/10.1016/j.ins.2014.03.097
0020-0255/

Nomenclature

Parameters

L	set of production lines
P	set of product's types
N	number of periods of fixed length τ
κ_j	nominal capacity of the line $j \in L$
$f_j(t),\ F_j(t)$	probability density function and distribution function respectively, of time's failures of line $j \in L$ during period $t \in H$
$r_j(t)$	failure rate of line $j \in L$ during period $t \in H$
C_j^p	cost of preventive maintenance operation on line $j \in L$
C_j^r	cost of corrective maintenance operation on line $j \in L$
$T^j = n_j\tau$	length of maintenance cycles of line $j \in L$
d_{it}	demand of product $i \in P$ during period $t \in H$
f_{it}^j	setup cost related to launching item $i \in P$ during period $t \in H$ on production line $j \in L$
p_{it}^j	manufacturing item cost $i \in P$ during period $t \in H$ on production line $j \in L$
h_{it}	inventory holding cost of item $i \in P$ during period $t \in H$
d_{tN}^i	quantity of product $i \in P$ remaining to be produced over periods ranging from $t$to $N\tau$
ρ_{ij}	operating time needed to produce one unit of product $i \in P$ on line $j \in L$
θ_p^j	capacity reduction as a result of a preventive maintenance operation on production line $j \in L$
θ_r^j	capacity reduction as a result of a corrective maintenance operation on production line $j \in L$
$\Phi^j(n_j)$	maintenance cost of line $j \in L$ with a maintenance period of $T^j = n_j\tau$
$\Phi_s^j(t)$	maintenance cost of line $j \in L$ during periods $t \in H$ if the maintenance period is $s \in H$
$\kappa_j(t)$	available capacity of line $j \in L$ during period $t \in H$
$\kappa_j^s(t)$	available capacity of line $j \in L$ in period $t \in H$ if the maintenance period is $s \in H$
x_{it}^j	quantity of product $i \in P$ to produce on the line $j \in L$ during period $t \in H$
y_{it}^j	binary variable equal to 1 if product $i \in P$ is produced on line $j \in L$ during period $t \in H$
I_{it}	quantity of product $i \in P$ remaining in stock at the end of period $t \in H$
z_s^j	binary variable equal to 1 if the period of maintenance of the line $j \in L$ is $s \in H$

Notations

PCPMAN	model proposed by Aghezzaf and Najid in [3] for the problem of Production and Cyclic Preventive Maintenance
PCPMCYY	reformulation of model *PCPMAN*
PCPMCYY $-$ *R*	second restatement of the *PCPMAN* model (production variable relaxed x_{it}^j and I_{it})
PCPMFR	heuristic fix and relax for the problem of Production and Cyclic Preventive Maintenance
PCPMLR	Lagrangian relaxation to the problem of Production and Cyclic Preventive Maintenance

kov processes were elaborated in order to consider the machines capacities: Boukas [5] and Gharbi [7]. These papers are assuming that failure rate as well as control policy depends on machines life time. Thus it has been proved that machines tend to have more availability when a preventive maintenance plan is adopted. A number of studies had been done in these last two areas. Shapiro [15] and Pinedo [12] are overviewing all the relevent publications regarding the production planning issues. In the same context Sherif and Smith [16] and Dekker [6] came up with several studies on the subject of maintenance optimization models. However, almost all the previous published studies treat separately the two problems of production and maintenance scheduling. The two subjects were never integrated in the same model even if they were in direct correlation. Recently very few studies point the leverage of combining the two problems in a communal formulation. In this perspective, Graves and Lee [8] presented a scheduling model combining the two approaches and considering the case of only one machine and one maintenance operation on a time scale. The aim was to minimize weighted completion time of jobs. Lee and Chen [9] have extended the problem to multi machines. Our initiative belongs to this general context that justifies formulating an approach combining the production and the maintenance planning for a parallel machines system. This article comes in addition to and capitalises on the two previous publications of Aghezzaf and Najid [3,2], in which the objective function is to minimize the total cost of the two core subjects combined. Through their work not only the maintenance policy has been considered as periodical but also any machine failure would inherently cause a capacity fall. bf In extension to previous works, Najid et al. [10] have proposed a mixed-integer linear program in which the demand shortage and the