Information Sciences 178 (2008) 3382–3392

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 20 March 2007
Received in revised form 8 March 2008
Accepted 4 May 2008

Keywords:
Production planning
Preventive maintenance
Failure-prone manufacturing systems

ABSTRACT

This paper discusses the issue of integrating production planning and preventive maintenance in manufacturing production systems. In particular, it tackles the problem of integrating production and preventive maintenance in a system composed of parallel failure-prone production lines. It is assumed that when a production line fails, a minimal repair is carried out to restore it to an 'as-bad-as-old' status. Preventive maintenance is carried out, periodically at the discretion of the decision maker, to restore the production line to an 'as-good-as-new' status. It is also assumed that any maintenance action, performed on a production line in a given period, reduces the available production capacity on the line during that period. The resulting integrated production and maintenance planning problem is modeled as a nonlinear mixed-integer program when each production line implements a cyclic preventive maintenance policy. When noncyclical preventive maintenance policies are allowed, the problem is modeled as a linear mixed-integer program. A Lagrangian-based heuristic procedure for the solution of the first planning model is proposed and discussed. Computational experiments are carried out to analyze the performance of the method for different failure rate distributions, and the obtained results are discussed in detail.

1. Introduction

To cope with the current tough competition many manufacturing companies have invested in highly automated production systems with sophisticated equipments. To be economically sustainable, these costly equipments should be exploited to the last instant of their maximum possible productive time. When an unplanned downtime, caused by a production line failure, occurs it often trims down the system's productivity and renders the current production plan obsolete. Revising the production plan in an emergency situation is usually very expensive and often causes increased variability in product quality and in service level. It is, therefore, essential that production planning and preventive maintenance activities be carried out in an integrated way to hedge against these often avoidable failures and re-planning occurrences. This paper proposes and discusses models to generate such integrated production and maintenance plans which aim at achieving an optimal trade-off between the various production and maintenance costs.

The issue of integrating production planning and preventive maintenance, in failure-prone manufacturing systems, is becoming an active area of research due to its importance in the current highly competitive environment. However, it is frequently tackled at the operational (the scheduling) level. In particular, scheduling problems on unreliable machines have received a considerable attention in the literature [1,6,11,12,17,18]. A large number of these scheduling problems assume that

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0020-0255/$ - see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.ins.2008.05.007

maintenance periods are known in advance, and thus reduce to scheduling problems with machine availability constraints [1,15,19]. A recent survey on scheduling problems with limited machine availability can be found in [20]. A general result is that these scheduling problems, with availability constraints, under different machine configurations and various objective functions are NP-hard [13,16]. Various heuristics as well as exact methods for their solution are proposed [3,8].

At the tactical level, there are only few papers discussing this issue. Wienstein and Chung [23] presented a three-part model to resolve the conflicting objectives of system reliability and profit maximization. An aggregate production plan is first generated, and then a master production schedule is developed to minimize the weighted deviations from the specified aggregate production goals. Finally, work center loading requirements, determined through rough cut capacity planning, are used to simulate equipment failures during the aggregate planning horizon. Several experiments are used to test the significance of various factors for maintenance policy selection. These factors include the category of maintenance activity, maintenance activity frequency, failure significance, maintenance activity cost, and aggregate production policy. Aghezzaf et al. [4] presented an integrated production and preventive maintenance planning model for a single-line production systems which can be minimal repaired at failure. They assumed that maintenance actions carried out on the production line reduce its capacity, and proposed a mathematical programming model to establish an optimal integrated production and maintenance plan for the single-line production systems.

In Section 2, a mathematical programming model for the integrated production and maintenance problem in production systems implementing cyclic preventive maintenance policies is proposed. In Section 3, a heuristic solution algorithm for the solution of the proposed model is proposed and discussed. Section 4 presents an integrated production and maintenance planning model for systems implementing general preventive maintenance policies. The last section presents some computational experiment to analyze the performances of the proposed models and their algorithms. Finally, some concluding remarks are presented in Section 6.

2. Integrated production planning and cyclic preventive maintenance

Consider a planning horizon H of length $T = N\tau$ covering N periods of fixed length τ, and a set of items $i \in P$ to be produced on a set of capacitated parallel production lines $j \in L$ during this planning horizon. Each production line $j \in L$ of the system produces each item $i \in P$ at a known production rate, expressed in product units per unit of time. During each period $t \in H$, a demand d_{it} of item $i \in P$ should be satisfied. It is assumed that each production line $j \in L$ has a known nominal capacity (given in time units) and is denoted by κ_j. Each preventive or corrective maintenance action performed on the production line consumes a certain percentage of this capacity. Thus, each preventive maintenance action and each corrective maintenance action on production line $j \in L$ consume, respectively $\theta_j^p = \alpha\kappa_j$ and $\theta_j^r = \beta\kappa_j$ capacity units (where $0 \leqslant \alpha \leqslant 1$ and $0 \leqslant \beta \leqslant 1$). It is also assumed that the failure distribution of each production line $j \in L$ is known. Let $f_j(t)$ and $F_j(t)$ denote its corresponding probability density and cumulative distribution functions, respectively. Let $r_j(t)$ denotes the failure rate function of the production line $j \in L$ at time t. It is well known that $r_j(t)$ is given by

$$r_j(t) = \frac{f_j(t)}{1 - F_j(t)}.$$

Finally, assume that preventive maintenance tasks are performed periodically on each production line $j \in L$, in the beginning of periods $t = 1, (n_j + 1), (2n_j + 1), (3n_j + 1), \ldots, N$, that corrective maintenance tasks are carried out on the production line when a failure occurs, and that any maintenance action is completed within the period in which it started. Fig. 1 shows an example of an integrated production and cyclic preventive maintenance plan and also the preventive maintenance cycle

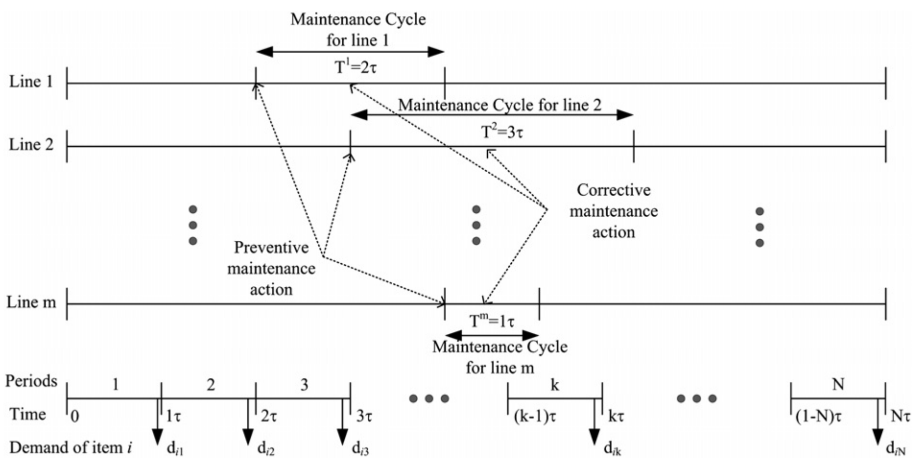

Fig. 1. An integrated production and cyclic preventive maintenance plan.