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Integrating noncyclical preventive maintenance scheduling and production planning for multi-state systems

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ABSTRACT

This paper integrates noncyclical preventive maintenance with tactical production planning in multi-state systems. The maintenance policy suggests noncyclical preventive replacements of components, and minimal repair on failed components. The model gives simultaneously the appropriate instants for preventive maintenance, and production planning decisions. It determines an integrated lot-sizing and preventive maintenance strategy of the system that will minimize the sum of preventive and corrective maintenance costs, setup costs, holding costs, backorder costs, and production costs, while satisfying the demand for all products over the entire horizon. The model is first solved by comparing the results of several multi-products capacitated lot-sizing problems. Then, for large-size problems, a simulated annealing algorithm is developed and illustrated through numerical experiments.

1. Introduction

Maintenance scheduling and production planning are two important activities which can significantly contribute to better business management in industry. These activities directly operate on the same resources and equipment. Due to the difference between maintenance and production purposes, their relationship has been considered as mutually in conflict, especially if the production and maintenance planning are done separately. According to Berrichi et al. [7], the conflicts may result in an unsatisfied demand in production, due to equipment unavailability if the production service does not respect the time needed for maintenance activities. Integration of maintenance and planning activities can avoid conflicts. In Aghezzaf et al. [2] and Chung et al. [13], the authors have shown the benefits of integrating maintenance and production planning. Communication and collaboration between the two departments are the main keys to doing successful planning in production systems.

Much research related to integrated production and maintenance planning can be found in the literature, especially during the last few years. In these integrated models, it is considered that the beginning times of preventive maintenance (PM) tasks are decision variables, as well as production jobs, and both (maintenance and production) are jointly scheduled [7]. Budai et al. [10] classified these problems into four categories: high level models, the economic manufacturing quantity models, models of production systems with buffers, and production/maintenance optimization models. In the last category, where our work is situated, many problems have been presented in the literature. Most of these models aim to optimize a combination of maintenance and/or production costs, production makespan or system availability (or unavailability). Berrichi et al. [7] suggested a model minimizing, simultaneously, the makespan for production and the system unavailability for systems with parallel machines. The model was solved by genetic algorithms. Berrichi et al. [8] improved the obtained results by using an ant colony algorithm. Ben Ali et al. [5] studied a job-shop scheduling problem under periodic unavailability periods for maintenance tasks. The problem was solved by developing an elitist multi-objective genetic algorithm minimizing makespan and total maintenance cost. Chung et al. [13] presented a model also optimizing the production makespan, with a reliability option based on the acceptability function for multi-factory networks. The maintenance strategy is suggested for both perfect and imperfect maintenance policies. A bi-objective optimization model minimizing simultaneously the production makespan and the system unavailability is considered by Moradi et al. [26], where production decisions assign the appropriate n jobs to m machines and maintenance decisions determine the instants of PM activities.

Pan et al. [31] suggested an integrated scheduling model incorporating both production scheduling and preventive maintenance planning for a single machine in order to minimize the maximum weighted tardiness. Cassady and Kutangolu [11] and

Abbreviations: PM, preventive maintenance; SA, simulated annealing; GA, genetic algorithm; TS, tabu search; MSS, multi-state system; PR, preventive replacement; MR, minimal repair; UGF, universal generating function; ES, exhaustive search

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Nomenclature

ΔE loss of energy of the simulated annealing algorithm
δ_j the reduction factor for the component j ($j=1,\dots,n$) when PM actions are performed at the beginning of production planning periods
AG $n \times TS$ age matrix representing the effective age of each component j at the beginning of each maintenance planning period
A $n \times T$ matrix representing the availability of each component j during each production planning period t ($t=1,\dots,T$)
CMR $n \times n$ minimal repair cost diagonal matrix, where CMR_{jj} ($j=1,\dots,n$) is the minimal repair cost for the component j
CPR $n \times n$ preventive replacement cost diagonal matrix, where CPR_{jj} ($j=1,\dots,n$) is the preventive replacement cost for the component j
M $n \times TS$ matrix representing the expected number of failures of each component j during each maintenance planning period
$\mathbf{p_j^t}$ the probability distribution of the component j during the planning period t ($j=1,\dots,n$ and $t=1,\dots,T$)
Q $TS \times T$ bloc diagonal scale reduction matrix
R $n \times n$ diagonal matrix of cost reduction if PM actions are performed at the beginning of the production planning period
TMR $n \times n$ minimal repair time diagonal matrix, where TMR_{jj} ($j=1,\dots,n$) is the minimal repair time for the component j
TPR $n \times n$ preventive replacement time diagonal matrix, where TPR_{jj} ($j=1,\dots,n$) is the preventive replacement time for the component j
π_{pt} cost of producing one unit of product p in period t
τ length of the maintenance planning period
τ^{ts} the s^{th} maintenance planning period of the production planning period t ($t=1,\dots,T$ and $s=1,\dots,S$)
A_j^{ts} availability of the component j during the maintenance planning period τ^{ts} ($j=1,\dots,n$, $t=1,\dots,T$, $s=1,\dots,S$)
a_j^{ts} age function of the component j at the end of the maintenance planning period τ^{ts} ($j=1,\dots,n$, $t=1,\dots,T$, $s=1,\dots,S$)
b_{pt} backorder cost (lost opportunity and goodwill) per unit of product p by the end of period t
C cooling constant of the simulated annealing algorithm
CM total maintenance cost
CT total maintenance and production costs
d_{pt} demand of the product p to be satisfied at the end of period t
E energy objective function of the simulated annealing algorithm
$f_j(\cdot)$ the lifetime function of the component j ($j=1,\dots,n$)
G_j nominal production rate of component j
g_k production rate for the state k, ($1 \le k \le K$)
G_{MSS}^t MSS available production capacity during the period t
H planning horizon
h_{pt} inventory holding cost per unit of product p by the end of period t
j component index ($1 \le j \le n$)
K finite number of production rates
k system state ($1 \le k \le K$)
L length of production planning periods t
$M_j(t)$ expected number of failures/repairs of the component j, in the time interval $[0,t]$
M_j^{ts} the expected number of failures of the component j during the maintenance planning period τ^{ts} ($j=1,\dots,n$, $t=1,\dots,T$, $s=1,\dots,S$)
N the number of possible combinations of the maintenance policy matrix **Z**
n number of components
P set of products
p product, $p \in P$
$prob_k$ the steady-state probability of the state k, ($1 \le k \le K$)
q_{ts}^i binary variable equal to 1 if $t=i$ and 0 otherwise ($t=1,\dots,T$, $s=1,\dots,S$ and $i=1,\dots,T$)
$r_j(\cdot)$ the hazard function of the component j ($j=1,\dots,n$)
S number of equal sub-periods of the interval L
s maintenance planning period index ($1 \le s \le S$)
Set_{pt} fixed set-up cost of producing product p in period t
T number of production planning periods
t production planning period, ($1 \le t \le T$)
T_e temperature of the simulated annealing cooling process
T_{max} maximal temperature of the simulated annealing algorithm
T_{min} minimal temperature of the simulated annealing algorithm
w random value from the interval [0, 1]
z_j^{ts} binary variable equal to 1 if a PR is carried out on the component j at the beginning of the maintenance planning period τ^{ts}, and 0 otherwise

Decision variables

Z binary matrix representing system preventive replacement policy
B_{pt} backorder level of product p at the end of period t
I_{pt} inventory level of product p at the end of period t
x_{pt} quantity of product p to be produced in period t
y_{pt} binary variable, which is equal to 1 if the set-up of product p occurs at the end of period t, and 0 otherwise

Sortrakul et al. [36] proposed an integrated maintenance planning and production scheduling model for a single machine minimizing the total weighted expected completion time to find the optimal PM actions and job sequence. Yu-Lan et al. [43] extended these researches where PM actions can be performed under flexible intervals (instead of equal intervals) which leads to more efficient solutions. Jin et al. [18] presented a model determining the optimal number of preventive maintenance activities in order to maximize the average profit under uncertain demand by using the financial "option" approach.

A mathematical model for a single unit determining simultaneously the optimal value of lot size and the optimal preventive replacement interval with non-conformity constraints is suggested by Chelbi et al. [12]. Hajej et al. [17] investigated stochastic production planning and the maintenance scheduling problem for a single product and a single machine production system with subcontracting constraints. Ashayeri et al. [4] proposed a model optimizing total maintenance and production costs in discrete multi-machine environment with deterministic demand. Weinstein and Chung [42] worked on an integrated production