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A new effective heuristic for the intelligent management of the preventive maintenance tasks of the distributed systems

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Abstract

We consider a class of scheduling problems of n weighted tasks on M identical, and parallel processors with an objective of minimizing the sum of the tasks weighted flow-times. A priority rule for total weighted flow-time (PRTWF), is then proposed for locally optimal scheduling of tasks with unequal release dates and processing times. Then, an algorithm based on a heuristic and the PRTWF, is worked out to minimize the total weighted flow-time of the given set of tasks on a single server. This algorithm is designed for implementation in a dynamic process of real-time decision-making. It is next extended to tasks scheduling (with unequal release dates and processing times) on parallel servers, while minimizing their total weighted flow-time. A lower bound of solutions is also proposed to evaluate the algorithm, with a complexity in $O(n^3)$ in the off-line scheduling process. The rule is then used in an algorithm of on-line planning and scheduling of maintenance tasks in a large size distributed system with weighted Equipments.

Keywords: Tasks scheduling; Weight; Flow-time; Release date; Real-time; Maintenance; Decision making

1. Introduction

In several areas of activity as in maintenance, delays in starting tasks engender, for the user, extra costs due to the degradations of Equipments, raw materials and products' quality, and disorganization of the production process. Such cost may be very high in some cases, particularly in maintenance tasks management for several reasons: the considered tasks are not always available from the initial time t_0 before the decision-making times t; in some cases, tasks cannot be started before a given date which marks the beginning of inescapable degradations, etc. As a result, the processing of many tasks may be delayed in relation to their release dates. Under these conditions, the costs include additional costs due to delayed completion of tasks. It is then necessary, in this case, to set up a real-time decision making strategy to manage tasks.

Obviously, these costs increase with the flow-times of worsening operation conditions. A way to reduce these costs is to schedule tasks so as to minimize their flow-times in penalizing situations. When the additive cost increases uniformly and in an identical way for all the tasks, the problem consists in minimizing, through optimal scheduling, the sum of the flow-times of all the tasks in penalizing situations.

Works addressing the typical problem of maintaining optimal task scheduling and processors allocation are rare in the existing literature. We mention Weinstein and Chung [27] who proposed a mixed-integer linear model which incorporates preventive maintenance into the production policies. This method aims at minimizing the cost and the deviation of production tasks in contrast to maintenance free production policies. In regards to preventive maintenance, we also mention the heuristic method of Qi et al. [17] based on the Shortest Processing Time (SPT) priority rule to minimize the makespan in a production policy. They studied the parallel-machines scheduling problem where preventive maintenance tasks are performed on each machine, just as in Lee and Chen [15] and Graves and Lee [13]. Lee and Chen [15], Qi et al. [17] proposed a branch and bound method to

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minimize weighted completion time of tasks based on the partition formulation of the problem.

In Ref. [1], we proposed an on-line algorithm for real-time maintenance planning and scheduling methods on a given horizon. In the given algorithm, tasks are scheduled in real-time, and the precedence constraints linking the different tasks on the same Equipment have been dealt with. But the existing methods in production are quite limited where the maintenance assets' sensitivity (importance) and tasks' set-up time are concerned. In this paper, we propose a priority rule for the total weighted flow-time. This rule, which considers task pairs, has very good properties. It can be used as well in production as in maintenance activities planning and scheduling. On this basis, we propose an algorithm for maintenance tasks real-time scheduling and resources allocation.

In the continuation of this paper, we state in Section 2 the real-time maintenance decision making problem and the link to a scheduling problem of weighted tasks with unequal release dates. In order to solve it, Section 3 is devoted to a static (off-line) approach to the scheduling problem. A local optimality priority rule ((Priority Rule for Total Weighted Flow-time, PRTWF) is proposed, proved and compared to existing rules in the literature in this section. In Section 4, we adapted the approach to the real-time maintenance decision making process. Experimentations are provided in Section 5 and finally Section 6 concludes and proposes future extensions to this work.

2. From maintenance activities management to scheduling problem

This paper deals with the problem of maintenance process modelling with cost minimization through tasks scheduling on the one hand and repairmen (processors) assignment to tasks on the other hand. In the remainder of this paper, we will use the term 'processor' to signify the principal maintenance resource or repairman assigned to the tasks. Let us consider a distributed system composed of N sites working independently and in parallel, and sharing M repairmen for the preventive maintenance activities on the different Equipments of the system. On a given site, Equipments operate in series. Obviously, the number of repairmen is less than the total number of Equipments in the system $\left(M \ll \sum_{k=1}^{N} N_k\right)$ and the repairmen are shared by the overall system, N_k being the number of Equipments on a site k. An Equipment may be a production machine or a simple equipment. It generally requires important logistic times to move a repairman from a site to another, but in the approach proposed in this paper, we assume that the logistic time are small enough to be included in the maintenance tasks' processing times. The main problem is then to dynamically evaluate the processor needs at sites levels so as to establish priorities. The available processors must be assigned to the Equipments so as to ensure a minimum required availability to the sites while minimizing the involved cost on a working horizon.

To model this problem, we consider a planning horizon H on which each site's unavailability and maintenance cost must be minimal. We assume that the maintenance tasks are processed without pre-emption. So, once begun, each maintenance task is processed to its completion without interruption. We also consider them to be perfect maintenance tasks, which mean that an Equipment is supposed to be renewed after a preventive maintenance. The different Equipments in the system are weighted according to their sensitivity and their importance in the system. The maintenance tasks processors are supposed to have equivalent performance and can be used in parallel. In the approach the Equipments' availabilities are assumed to follow the exponential law. But this assumption is not restrictive. The model can still be used when the Equipment behaves according to other laws such as Weibull's law. The failure and repair rates (λ_{ik} and μ_{ik}) of an Equipment E_{ik} (equipment i of site k) are then assumed to be constant on the planning horizon H. The exponential availability A_{ik} of an Equipment E_{ik} is renewed at the end of a maintenance task at time T (considered also to be a start-up date of the Equipment) as

$$A_{ik}(t) = \frac{\mu_{ik}}{\lambda_{ik} + \mu_{ik}} + \exp[-(\lambda_{ik} + \mu_{ik})(t - T)] \tag{2.1}$$

In order to guarantee the minimum required availability of each site, a threshold α_{ik} given in]0,1[is imposed on the availability A_{ik} of each Equipment E_{ik}. An Equipment E_{ik}, which works for a time without failure reaches that threshold and should be submitted to a preventive maintenance task. An Equipment working under its threshold is supposed to be in a critical state with a high probability of failure. The time spent from the occurrence of such a critical state on the Equipment E_{ik} to the completion date of the maintenance task on that Equipment (which is considered to be also the start-up of the Equipment), involves a time-unit cost w_{ik} which is the weight of E_{ik} in the system. From the expression of the availability function of the Equipment E_{ik} in Eq. (2.1) and the threshold α_{ik}, the duration from a start-up of the Equipment to the critical date is derived from the inequality $A_{ik} \geq \alpha_{ik}$. By taking the start up date T to be the initial date 0, this duration for the Equipment E_{ik} is then τ_{ik} expressed as below:

$$\tau_{ik} = \frac{-1}{\lambda_{ik} + \mu_{ik}} \ln\left[\alpha_{ik}\left(1 + \frac{\mu_{ik}}{\lambda_{ik}}\right) - \frac{\mu_{ik}}{\lambda_{ik}}\right] \tag{2.2}$$

Each Equipment has as many start ups on the planning horizon as there are completions of maintenance tasks following a critical state. Let us note $r_{m,ik}$ the mth occurrence date of a critical event on the Equipment E_{ik} and $c_{m,ik}$ the completion date of the corresponding maintenance intervention. Then the critical states cost on