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Genetic algorithms for integrated preventive maintenance planning and production scheduling for a single machine

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Abstract

Despite the inter-dependent relationship between them, production scheduling and preventive maintenance planning decisions are generally analyzed and executed independently in real manufacturing systems. This practice is also found in the majority of the studies found in the relevant literature. In this paper, heuristics based on genetic algorithms are developed to solve an integrated optimization model for production scheduling and preventive maintenance planning. The numerical results on several problem sizes indicate that the proposed genetic algorithms are very efficient for optimizing the integrated problem.

Keywords: Genetic algorithms; Preventive maintenance; Production scheduling; Optimization

1. Introduction

Production scheduling and preventive maintenance (PM) planning are among the most common and significant problems faced by the manufacturing industry. Production schedules are often interrupted by equipment failures, which could be prevented by proper preventive maintenance. However, recommended PM intervals are often delayed in order to expedite production. Despite the trade-offs between the two activities, they are typically planned and executed independently in real manufacturing settings even if manufacturing productivity can be improved by optimizing both production scheduling and PM planning decisions simultaneously.

Numerous studies have been conducted in these two areas in the past decades. Shapiro [1] and Pinedo [2] reviewed various papers in production scheduling. Similarly, Sherif and Smith [3] and Dekker [4] reviewed several studies using maintenance optimization models. However, almost all relevant studies considered production scheduling and PM planning as two independent problems and therefore solve them separately.

Only a few studies have tried to combine and solve both problems simultaneously. Graves and Lee [5] presented a single-machine scheduling problem with the objective to minimize the total weighted

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completion time of jobs. However, only one maintenance activity can be performed during the planning horizon. Lee and Chen [6] extended Graves and Lee's research to parallel machines, but still permitting only one maintenance action. Qi et al. [7] considered a similar single-machine problem with the possibility for multiple maintenance actions, but the risk of not performing maintenance is not explicitly included in the model. Cassady and Kutanoglu [8] developed an integrated mathematical model for a single-machine problem with total weighted expected completion time as the objective function. Their model allows multiple maintenance activities and explicitly captures the risk of not performing maintenance.

In this paper, we develop genetic algorithm heuristics to solve the integrated production scheduling and preventive maintenance planning problem for a single machine introduced in Cassady and Kutanoglu [8]. The following section, Section 2, contains an overview of the integrated production scheduling and PM planning problem. Section 3 briefly describes the proposed genetic algorithm procedures. The experimental results of multiple problem sizes appear in Section 4. The conclusions are summarized in Section 5.

2. Integrated production scheduling and PM planning problem

This section describes the integrated model and proposed solution procedures for a single-machine production scheduling and PM planning problem presented by Cassady and Kutanoglu [8].

2.1. Production scheduling problem

The deterministic single-machine scheduling problem with the objective to minimize the total weighted completion time is considered. Assuming that every job is ready at the beginning of production period and the preemption of one job for another is prohibited, the optimal solution for this problem can simply be obtained from the WSPT (weighted shortest processing time) rule. As mentioned in Pinedo [2], jobs are scheduled under this rule in descending order of the ratio of weight to processing time.

2.2. Preventive maintenance planning problem

Suppose the time to failure of a machine is governed by a Weibull probability distribution having scale parameter η and shape parameter β greater than 1. When a machine fails, minimal repair is performed to restore the machine back to its operating condition without altering its effective age. Since $\beta > 1$, the machine failure rate increases over time. Therefore, PM may be used to stop the increasing risk of machine failure by restoring it back to a "good as new" condition.

Since PM restores the machine to a "good as new" condition, machine performance can be modeled using a renewal process, where the renewal points correspond to the completion of a PM activity. Since repair is minimal, failures occur during each "cycle" of the renewal process according to a non-homogeneous Poisson process (NHPP) having intensity function $z(t)$ where $z(t)$ corresponds to the hazard function of a new machine. As a result, the expected value of the number of failures that occur during a single cycle of the renewal process is

$$m(\tau) = \int_0^{\tau} z(t)\,\mathrm{d}t = \int_0^{\tau} \frac{\beta}{\eta^{\beta}} t^{\beta-1}\,\mathrm{d}t = \left(\frac{\tau}{\eta}\right)^{\beta} \quad (1)$$

Therefore, an "average" cycle of the renewal process includes τ time units of operation, $m(\tau)$ machine repairs of length t_r, and a single PM action of length t_p. The resulting steady-state machine availability is

$$A(\tau) = \frac{\tau}{\tau + m(\tau)t_r + t_p} \quad (2)$$

Differentiation and algebraic analysis reveal the optimal PM interval, which maximizes machine availability, to be

$$\tau^* = \eta\left[\frac{t_p}{t_r(\beta-1)}\right]^{1/\beta} \quad (3)$$

2.3. Integrated problem

In the integrated problem, a machine possesses all production requirements defined in Sections 2.1 and 2.2. In addition, jobs cannot be preempted for PM. Also, jobs interrupted by machine failure can be resumed after machine repair without any additional time penalty. For this problem, there are two major tasks that must be considered simultaneously. The first