Optimizing Series Repairable Systems with Imperfect Repair

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ABSTRACT

Repairable systems are either repaired perfectly to a state of as good as new or imperfectly. In this work, a system which undergoes imperfect repair is investigated. A nonlinear mathematical model is formulated for a system with the objective of finding the optimum failure and repair rate with the minimum costs subject to attaining a pre-specified performance level. Two imperfect repair models are examined. In the first model, the system is replaced by a new one after several failures. In the second model, the system is either replaced with a specific probability \((1-p)\) or is imperfectly repaired after each failure with probability \(p\). The optimal solution is presented in a closed form expression.

Keywords: Imperfect Repair, Nonlinear, Optimization, Performance, Repairable

INTRODUCTION

Maintenance optimization models aim at finding an optimum balance between the cost of running a system with maintenance and the benefits obtained from it. Generally, maintenance optimization models cover four categories: (1) a description of the technical system, (2) a modelling of the system deterioration and its consequences, (3) a description of the available information of the system, and (4) an objective function and an optimization technique for finding best alternative or balance.

The interest in developing and implementing of maintenance optimization started in the early 1960s. A basic reference was presented by Barlow and Hunter (1960). Extensive literature survey on models for optimization is given by McCall (1965), Sherif and Smith (1981), Valdez and Feldman (1989), Cho and Parlar (1991), and Sandve (1996). Yun and Bai (1987) studied a system where upon its failure, the repair cost can be estimated by inspection. The system is replaced if the repair cost is below a pre-specified value, otherwise, it is repaired. The failed system is repaired to a state of as good as new with probability \((1-p)\), or is minimally repaired with \(p\). An optimization model was formulated with the objective of minimizing the expected cost rate. The time to failure was modeled using the Weibull distribution, while the repair time was assumed to be exponentially distributed. Stadje and Zuckerman (1990) examined optimal strategies in a repair replacement model. The assumptions were that costs and rewards to be proportional to the duration of the operational and repair times. Dekker (1996) reviewed recent papers on the optimization of maintained sys-

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tem, and presented an overview of the different applications of maintenance models. While analysing the role of these models in maintenance, he discussed the structure of different models, their limitations and shortcomings, and listed the factors hindering their applications. He also indicated the existence of a gap between the theory and practice attributing this primarily to the stochastic nature of many maintenance optimization models and to the difficulty in obtaining exact solutions using these models.

Vaurio (1997) studied periodically ageing components under various testing and repair policies. He considered the time dependent unavailability for the different categories of unscheduled maintenance. In this paper, it was assumed that: (1) the state of the system to be only known through the tests conducted periodically, (2) repair and replacement were performed only for failed components, and (3) correct repair and replacement were always at test points. The main costs considered were the costs of testing, maintenance, repairs and accidents. Equations and criteria for optimizing both periodic testing and scheduled maintenance were developed. Zeng and Zang (1997) analysed a system consisting of a single workstation, a repair station, and several parallel and identical servers. The system consisted of several standby components (buffer) serving the workstation. The objective was to determine the capacity of the inventory buffer, the number of repairmen, and the mean repair rate minimizing the total operational cost when failures and repairs followed exponential distribution.

Kumar and Knezevic (1998) developed mathematical models to find the optimum number of spares required to achieve a specific level of availability when the distributions for time to failure of components followed exponential, gamma, normal, and Weibull. Moreover, they presented models for maximizing the availability of a series system having a general distribution for time to failure with constraints on cost and weight. Billinton and Pan (1998) developed a system of equations to evaluate the failure rate and frequency of failure of a parallel system with two identical components. They found the optimum maintenance intervals that minimized the total failure frequency of the system. Vaurio (1999) studied a system whose components failed randomly, but were only detected by inspection. In this model, a component failing between consecutive inspections remained in the failed state until the next scheduled inspection. Furthermore, components were renewed by preventive maintenance, repair, or replacement whichever occurred first. The total cost of testing, repair, maintenance, loss of production, and accident were considered and the best replacement and inspection intervals that minimized the total cost rate were determined.

Barata et al. (2002) used Monte Carlo simulation in modeling a deteriorating system which is continuously monitored. The simulation model firstly examined a system with single non-repairable component followed by a multi-component repairable system. A cost optimization procedure was developed with the objective of finding the optimal degradation thresholds of maintenance. In their paper, Marquez and Heguedas (2002) stated that most of the maintenance models in the literature do not have actual contributions in solving to real life industrial problems, especially when considering realistic time frames and specifically for repairable systems. Using Semi-Markovian probabilistic allowing a maintenance policy optimization using dynamic programming has been and a usual approach for patterning systems under finite time duration. These models although flexible, never the less are very tedious to handle especially as the number of the states increases. In their paper, they explored the trade-off between flexibility and complexity of these models. They also compared these models in terms of data requirements versus potential benefits obtained. Elegbede and Adjallah (2003) presented an optimization model with the objective of maximizing availability and minimizing cost for repairable parallel-series systems. The weighting techniques were used in order to transform the problem from NP-hard with continuous discrete variables, which very hard to solve, to a single objective optimization
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