Metaheuristic-based inspection policy for a one-shot system with two types of units†

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Abstract

In this paper, we address an inspection policy problem for a one-shot system with two types of units, namely, Type 1 units that fail at random times and Type 2 units that degrade with time. Interval availability and life cycle cost are used as optimization criteria and estimated by simulation. We determine inspection intervals, preventive replacement ages of Type 1 units, and preventive maintenance thresholds of Type 2 units that have minimal life cycle cost and satisfy the target interval availability during inspection periods. A simulation-based optimization procedure using a hybrid genetic algorithm is proposed to find near-optimal solutions. Numerical examples are studied to investigate the effects of model parameters on optimal solutions and compare the hybrid genetic algorithm with the general genetic algorithm.

Keywords: One-shot system; Inspection interval; Gamma process; Simulation; Hybrid genetic algorithm

1. Introduction

One-shot systems, such as missile systems, fire extinguishers, and airbags, are usually stored for a long period of time and are operational at most once during their life cycle. The maintenance of high reliability of these one-shot systems in storage is important to successfully perform their objectives. However, the reliability of one-shot systems in storage deteriorates with time, and failure is only revealed when they are required. Thus, inspection must be carried out periodically to immediately detect system failure. However, determining the most suitable inspection intervals that will balance inspection frequency and maintenance costs is difficult. Thus, determining inspection intervals is an optimization problem in the formulation of inspection and maintenance policies for complex repairable systems. Several researchers had proposed various inspection policies for a one-shot system. Hariga [5] considered two possible scenarios: the determination of a good state of repair upon inspection and the detection of a system failure upon inspection. A procedure that will determine optimal inspection interval \( T^* \) was proposed to maximize the expected profit per unit of time.

Ito and Nakagawa [6] addressed the periodic inspection policy problem for a storage system with two types of units, namely, Type 1 unit that is maintained upon inspection and Type 2 unit that is degraded over time. An inspection policy was also proposed in which the system is replaced if its reliability becomes lower than a pre-determined level. Optimal inspection time \( T^* \), which minimizes the average cost until overhaul, was determined. Ito and Nakagawa [7] proposed another inspection policy in which the storage system is replaced either upon the detection of failure or at a pre-determined time \((N + 1)T\), depending on which occurs first. Optimal inspection time \( T^* \), which minimizes the total expected cost until replacement, was determined. Under the previously mentioned inspection policy, Ito and Nakagawa [8] determined optimal inspection times, with which the total expected cost, including the testing and lost costs, is minimized until system failure is detected. Ito and Nakagawa [9] then considered the testing and overhaul costs and determined optimal inspection times with which the mean time to overhaul is maximized and the average cost until overhaul is minimized. Ito et al. [10] likewise proposed an extended inspection model for a storage system consisting of three types of units, namely, Type 1 that is maintained at time interval \( T \), Type 2 that is replaced at time interval \( NT \), and Type 3 that is neither maintained nor replaced. The optimal inspection time \( T^* \) and optimal inspection number \( N^* \), which minimize the average cost until overhaul, were analytically determined. Kaio et al. [11] considered an inspection policy problem for a single-unit system and assumed that the system will fail in the inspection process. Optimal inspection intervals were determined to minimize the expected cost until system failure is detected. Hariga [5] studied a periodic inspection policy for a single-unit system and proposed a heuristic method to determine optimal inspection intervals that will maximize the ex-
pected profit per unit of time for cases of exponential distribution and Weibull distribution of the time to failure. Nakagawa and Mizutani [13] considered three inspection policies, namely, periodic, sequential, and asymptotic inspection policies for a single-unit system over a finite time span. Nakagawa et al. [14] proposed periodic, random, and sequential inspection policies for a deteriorating system with random working times and determined optimal inspection intervals that will minimize the total expected cost. Taghipour and Banjevic [16] proposed an inspection optimization model for a multi-unit system over both finite and infinite time horizons. They proposed an inspection policy in which the failed units are either minimally repaired or replaced at pre-determined times as a function of their age. The optimal inspection interval $T^*$ was indicated as a means of minimizing the expected cost, with a penalty cost being incurred for the time interval between failure and detection.

To date, some researchers have considered the periodic inspection policy for a storage system but regular inspection intervals may not always be profitable. Inspection intervals often need to be reduced as the age of the system increases. Thus, the non-periodic inspection policy for a storage system has been proposed for a storage system. Golmakani and Moakedi [4] addressed a non-periodic inspection policy problem for a multi-unit system over a finite horizon. A search algorithm was suggested to determine optimal inspection intervals with which the expected total cost is minimized. The non-periodic inspection policy was also compared with the periodic inspection policy. Yun et al. [17] considered a one-shot system consisting of two types of units, namely, Type 1 units that fail at random times and Type 2 units that are replaced by new ones at pre-determined times. Interval availability was used as an optimization criterion to maintain high system availability between inspection times. Given the replacement times of Type 2 units, optimal inspection points were determined to minimize the life cycle cost and satisfy the target interval availability during inspection periods using a genetic algorithm.

Meanwhile, the units in a one-shot system can be classified into two types, namely, Type 1 units that fail at random times and Type 2 units that degrade with time. For example, in the case of a missile system, the guidance and control units are Type 1 units, whereas the ignition unit of the rocket motor is a Type 2 unit. In general, the inspection process only involves checking whether the system normally operates or not, thus the formulation of a preventive maintenance policy for the units in the one-shot system is necessary to improve the reliability of the units. Li and Pham [12] proposed a condition-based maintenance model for a storage system and two randomized degradation functions to describe the degradation of the units in the system. Inspection intervals and preventive maintenance thresholds of the units were both determined to minimize the expected total maintenance cost. Markov processes, such as the Brownian motion with drift, compound Poisson process, and gamma process, have also been used to describe the degradation of Type 2 units. Grall et al. [2] attempted to solve a condition-based maintenance policy problem for a single-deteriorating system and considered a gamma process for the degradation of system. Optimal inspection times and preventive maintenance thresholds were determined, and a periodic inspection scheme was compared with a dynamic inspection scheme. Noortwijk [15] reviewed the applications of gamma processes in time-based and condition-based maintenance optimization problems. Yun et al. [18] studied an inspection policy for a one-shot system and used the compound Poisson process to describe the degradation of Type 2 units. Inspection intervals and preventive maintenance thresholds of Type 2 units, which minimize the life cycle cost and satisfy the target interval availability, were determined.

In the present paper, we aim to address a non-periodic inspection policy problem for a one-shot system with two types of units: Type 1 units that fail at random times and Type 2 units that degrade with time. The preventive maintenance policies for Type 1 and 2 units are considered to improve reliability. We aim to optimally determine inspection intervals, preventive replacement ages of Type 1 units, and preventive maintenance thresholds of Type 2 units.

This paper is organized as follows. The inspection interval model for a one-shot system with two types of units is explained in Sec. 2. A simulation-based optimization procedure using a hybrid genetic algorithm is proposed in Sec. 3. Numerical examples are studied to investigate the effects of model parameters and compare the hybrid genetic algorithm with the general genetic algorithm in Sec. 4. Finally, the conclusions of the study are presented in Sec. 5.

2. Inspection interval model for a one-shot system with two types of units

In this section, we introduce the inspection interval model for a one-shot system consisting of two types of units. The preventive maintenance policies for Type 1 and 2 units are explained to improve the storage system reliability. The appropriate performance measures in the evaluation of the one-shot system are also detailed in terms of interval availability and life cycle cost. Table 1 shows the notation for the model.

A one-shot system usually consists of several units, and the units can be classified into two types: Type 1 units that fail at random times and Type 2 units that degrade with time and require stringent storage environments to prevent their degradation in storage. Therefore, system failure is only revealed when the system is operational, but the one-shot system performs its objective at most once during its life cycle.

Keeping high system reliability in storage is important, and inspection must be carried out periodically to immediately detect system failure. However, finding appropriate inspection intervals is difficult because inspection frequency and maintenance costs must be balanced. While frequent inspection can keep high system reliability in storage, the high frequency of inspection leads to high maintenance costs and in some cases,