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Determining the inspection intervals for one-shot systems with support equipment

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ABSTRACT

This paper considers systems that comprise one-shot devices and support equipment. One-shot devices are stored for long periods of time, and failures are detected only upon inspection. The support equipment needed to operate one-shot devices is maintained immediately upon failure. This paper addresses the inspection schedule problem for such systems with limited maintenance resources. The interval availability and life cycle cost are used as optimization criteria. The aim is to determine near-optimal inspection intervals for one-shot systems to minimize the expected life cycle cost and satisfy the target interval availability between inspection periods. An estimation of distribution algorithm (EDA) and a heuristic method are proposed to find the near-optimal solutions, and numerical examples are given to demonstrate the effects of the various model parameters to the near-optimal inspection intervals.

1. Introduction

One-shot systems such as the man-portable air-defense system (MANPADS) are complex and involve one-shot devices and support equipment. The one-shot devices in MANPADS are missiles, which are kept in storage for long periods of time. The support equipment is the launchers, which are including a battery coolant unit (BCU), grip stock, and launch tube. This equipment does not need a specific environment for storage, and their failures can be known immediately without inspection. Furthermore, one launcher can be used with several missiles.

One-shot devices carry out their functions only once at most during their life span, and usually need high reliability to ensure successful operation. The reliability of one-shot devices deteriorates over time during storage, and the exact failure times of a system cannot be predicted accurately in most instances. The conditions of such systems may only be determined upon operation. Thus, inspections are carried out periodically to detect system failures and maintain high system reliability. However, it is difficult to determine suitable inspection intervals for most one-shot systems due to the trade-off between inspection frequency and maintenance costs. More frequent inspections reduce the mean down time of systems or the time between failure and detection, but they incur higher maintenance costs. Additionally, the process of testing may degrade specific units of the system. Appropriate inspection intervals for one-shot systems are therefore needed.

Many researchers have proposed various inspection policies for such systems. Nakagawa and Mizutani [1] reviewed three inspection models over a finite time span: periodic inspection, sequential inspection, and asymptotic inspection. Nakagawa et al. [2] proposed periodic and sequential inspection policies that involve inspecting a system periodically. They determined the optimal inspection numbers to minimize the expected total cost. Hariga [3] developed a mathematical model for a single-unit system to determine inspection intervals that would maximize the expected profit per unit time. Chelbi and Ait-Kadi [4] also developed a mathematical model to obtain optimal inspection intervals for a system. They assumed that the system would be replaced with a new one if the inspection revealed a failure. Alternatively, a preventive replacement would be scheduled if the system does not fail but the measured values of the control parameter exceed predetermined threshold levels. The optimal inspection intervals were determined to minimize the expected total cost per unit time over an infinite time span.

Huynh et al. [5] considered periodic inspection/replacement ($P-I/R$) and block replacement ($B-R$) policies for a single-unit system. Under $P-I/R$ policy, the system is inspected with period T, and is restored to as-good-as new after repair. When degradation reaches a preventive maintenance threshold M, the system is replaced. They determined optimal inspection interval and a preventive maintenance threshold that minimize the expected maintenance cost per unit over an infinite time span. The system is always replaced at interval T, and corrective replacement cost is considered higher than preventive replacement cost in the ($B-R$) policy, they also found the optimal values of regular time interval T which minimized the cost criterion. Van der Weide and Pandey [6] presented a stochastic alternating renewal process model for a single-unit system. Failures are detected only by periodic inspection, the system is renewed at each inspection time point. It can also be renewed by preventive maintenance (*PM*) once it reaches a

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predetermined age. Renewal function, point unavailability and time average unavailability, and the effect of age based on *PM* policy were evaluated. They concluded that the point unavailability can be reduced by *PM*. Cui et al. [7] obtained the instantaneous availability and the limiting average availability under periodic inspections for a single-unit storage system. The instantaneous availability is obtained by using the virtual age concept, and they assumed that the virtual age during the failure time is the same as at the moment before the system fails. Inspection is assumed to be perfect, and if failure is detected, there are two possible maintenance actions: minimal repair for regular failures and perfect repair at *N*th inspection time point.

Ito and Nakagawa [8] considered optimal inspection policies for a system with two units in storage, one of which is maintained upon inspection and the other degrading over time. To maintain a higher degree of system reliability, the system is inspected and maintained periodically, and it is overhauled if the reliability becomes less than or equal to a specific value. The optimal inspection times were determined to minimize the average cost, including inspection and overhaul costs. In a later study, Ito and Nakagawa [9] assumed that the system would be replaced upon the detection of failure or when its reliability decreases beyond a specific value. Ito and Nakagawa [10] also considered a system that contains a component that degrades over time, and they determined the optimal inspection intervals that minimize the expected total cost, including inspection and loss costs. They later determined the optimal inspection times that would minimize the mean down time and average cost until overhaul [11]. They also considered three types of units: Unit 1 is inspected and maintained at time interval *T*, Unit 2 is partially replaced at time interval *NT*, and Unit 3 is only overhauled if the reliability is less than or equal to a specific value. The optimal inspection and replacement times were determined to minimize the expected total cost until overhaul [12].

Badia et al. [13] proposed an inspection policy for a single-unit system that is renewed upon the observation of failure through periodic inspection. They assumed that the inspection might not be perfect, and the optimal inspection intervals were determined to minimize the average cost per unit of time over an infinite time span. Wolde and Ghobbar [14] considered reliability, availability, and cost as optimization criteria. Availability and reliability were used to evaluate the system performance. They showed how these optimization criteria are related to each other and that improved reliability can impact availability. They suggested a mathematical model to determine the optimal inspection intervals to improve reliability and availability while reducing cost.

Periodic inspection is the most commonly used inspection policy. However, the information gathered during inspection is used to decide when the next inspection will take place. Hence, non-periodic inspection might be more appropriate, especially when the aging rate of a unit is unknown and must be estimated with information gathered by inspection. Zhao et al. [15] developed a mathematical model to evaluate the reliability of a single-unit system and optimize the inspection schedule. If a defect is detected by non-periodic inspection, the system is repaired immediately but minimally. They assumed that a defect can be detected by inspection with a specific probability. The probability of defect detection had a significant effect on reliability. The optimal inspection intervals were determined by maximizing the reliability of the unit rather than merely meeting the required reliability within a given period [0, *t*].

Yun et al. [16,17] considered optimization problems to determine inspection intervals for a one-shot device with two types of units. Type 1 units fail at random times and are maintained at inspection times, while Type 2 units do not fail and are replaced at pre-determined times. Yun et al. [18] assumed that Type 2 units in a one-shot system degrade over time, and they described the degradation using a compound Poisson process. Simulation was used to determine the optimal inspection intervals and the preventive maintenance thresholds of Type 2 units based on a genetic algorithm. Age-based preventive maintenance policing was considered for Type 1 units, and the optimal preventive replacement age was obtained by minimizing the life cycle cost [19].

To maintain one-shot systems, a certain amount of resources is required at the maintenance site. Therefore, the maintenance can be delayed when the number of resources is not enough to maintain a great number of one-shot devices at the same time. Hence, an efficient inspection schedule for one-shot systems should be established to reduce maintenance delay. Yun et al. [20] studied inspection schedules for many one-shot devices. They used simulation and a genetic algorithm to determine the inspection intervals and first inspection points of each one-shot device, as well as the preventive maintenance threshold of Type 2 units. An inspection schedule problem was also considered for multiple one-shot devices with limited maintenance resources [21]. Gamma processes were simulated using the gamma bridge sampling method and applied to the degradation of Type 2 units [21]. Some one-shot devices require support equipment to ensure successful operation, which previous studies have not considered. This paper deals with the inspection schedule problem for such systems with limited maintenance resources. Section 2 describes the inspection schedule model for one-shot systems with support equipment, and Section 3 explains a simulation-based optimization procedure using a hybrid EDA-based algorithm. Numerical examples are presented in Section 4, and conclusions are presented in Section 5.

2. Inspection schedule of one-shot systems

This section introduces an inspection policy and proposes an inspection schedule model for one-shot systems with support equipment. We also explain the performance measures of interval availability and the expected life cycle cost which are used as optimization criteria in this paper. The following notation is used for modeling the inspection schedule:

f	Index of periods ($f = 1, 2, 3, \ldots, F$)
R	Number of one-shot devices handled by one support equipment
TA	Target interval availability
C_{FI}	Fixed inspection cost
C_{VI}	Variable inspection cost
${C_R}^p$	Repair cost of Type 1 unit p of one-shot device
${C_R}^q$	Repair cost of unit q in support equipment
$E[LC]$	Expected life cycle cost
TI	Total number of inspections
TI_i	Total number of inspections of one-shot device i
AI_f	Interval availability in the fth period
$N_o(t)$	Number of functioning one-shot devices at time t
$N_s(t)$	Number of functioning support equipment at time t
$E[{NR_i}^p]$	Expected number of repairs of unit p in one-shot device i
$E[{NR_j}^q]$	Expected number of repairs of unit q in support equipment j
N_{tot}	Total number of one-shot devices

The following assumptions are made:

1) The life cycle of the one-shot devices and support equipment is finite and given.
2) Inspection is performed perfectly and any failure of one-shot devices can be identified.
3) Failures of support equipment are detected immediately.
4) Replacement times of Type 2 units in the one-shot device are given.
5) Inspection is also performed at the times of replacement for Type 2 units.
6) The number of inspection equipment is limited.
7) Repair is perfect and the state of units after repair is same as new ones.