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Failure replacement and preventive maintenance spare parts ordering policy

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Abstract

This paper addresses inventory policy for spare parts, when demand for the spare parts arises due to regularly scheduled preventive maintenance, as well as random failure of units in service. A stochastic dynamic programming model is used to characterize an ordering policy which addresses both sources of demand in a unified manner. The optimal policy has the form $(s(k), S(k))$, where k is the number of periods until the next scheduled preventive maintenance operation. The nature of the $(s(k), S(k))$ policy is characterized through numeric evaluation. The efficiency of the optimal policy is evaluated, relative to a simpler policy which addresses the failure replacement and preventive maintenance demands with separate ordering policies.

Keywords: Inventory; Failure replacement; Preventive maintenance; Dynamic programming

1. Introduction

The problem of providing an adequate yet efficient supply of spare parts, in support of maintenance and repair of plant and equipment, is an especially vexing inventory management scenario. Spare parts for plant and equipment may be very expensive, and thus costly to keep in inventory. Nonetheless, spares must be on hand when needed, in order to avoid costly plant shutdown or equipment unavailability. In the face of this combination of high cost and high criticality, random failure of units in service typically generates a low-volume, intermittent demand process.

In addition to random failure replacement, demand for spare parts may also arise under a policy of regularly scheduled shutdown and preventive maintenance for the larger system in which the parts are used. In contrast to the low volume failure replacement demand, preventive maintenance may present a "lumpy demand" scenario in which a larger number of units are required at a known point in time.

This paper is directed toward an efficient ordering policy recognizing both preventive maintenance requirements, and requirements due to random failure of units in service. The premise is that greater efficiency will be realized by

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addressing these two sources of demand in a unified manner, relative to the use of separate ordering policies for the two demand streams.

This scenario is closely related to a system of "age replacement" and associated inventory ordering policies. Under age replacement, a randomly failing item is replaced upon reaching some specified age T, or upon failure, whichever occurs first. Barlow and Proschan (1965) originally studied the problem in terms of finding the best replacement age T. Subsequently, Kaio and Osaki (1978, 1981) examined the situation where spares' inventory ordering policy and replacement age are jointly optimized. Park and Park (1986) extended this model to the case of random lead time. Kabir and Al-Olayan (1994, 1996) further extended the analysis to the case of multiple units in service, and the possibility of holding more than a single unit of inventory.

Whereas the age replacement literature assumes units are replaced upon reaching a certain number of periods in service, the current paper is addressed toward a scenario where the system in question is shut down for preventive maintenance or overhaul at regularly scheduled intervals. The timing of the preventive replacement is not necessarily dictated by the age of any specific unit, but rather, on the requirements of the larger system in which the unit is used. As such, we treat the time between preventive maintenance operations as a given parameter, the determination of which is beyond the scope of the present investigation.

We assume a system having n identical parts in service (see Walker, 1997). Random failure of units in service generates intermittent, single-unit demands between preventive maintenance periods. At preventive maintenance, all units in service are inspected, and a decision is made as to which ones should be proactively replaced. Providing sufficient inventory in support of preventive maintenance is of paramount importance, so as not to delay a schedule of inter-related preventive maintenance activities.

We should note that the present investigation is directed toward the case of spare parts in support of plant maintenance and equipment, rather than spare parts in support of equipment at a number of geographically dispersed customer sites, or in support of product service or warranty repair. This paper is also directed toward the case where the parts in question are not repairable. Kennedy et al. (2002) provide a recent survey of literature on spare parts inventories.

The remainder of the paper is organized as follows. In Section 2 a stochastic dynamic programming model is formulated, implicitly defining the optimal policy for the scenario at hand. The characteristics of the optimal policy, examined through numeric evaluation of the dynamic programming model, are discussed in Section 3. Section 4 presents a comparison between the cost of the optimal policy vs. a that of a simpler policy which treats the two sources of demand separately. Summary and possible extensions are discussed in Section 5.

2. Model development

Assume a system containing n identical components. Each component fails according to a constant failure rate λ, such that the time to failure for each component is exponentially distributed with mean $1/\lambda$ periods, independent of the remaining $n-1$ units. The total number of part failures during any given period then has Poisson distribution with mean λn. Failed units must be replaced from existing inventory, or expedited.

Scheduled preventive maintenance occurs every T periods, during which the n units in service are inspected, and some or all are replaced in a proactive manner. We assume the number of units replaced is binomial with parameters n and p. As with the failure replacement, demands due to preventive maintenance must be satisfied through existing inventory or expedited.

We desire an optimal ordering policy which accounts for both sources of demand as the preventive maintenance period approaches. Toward this end, we will develop a stochastic dynamic programming characterization of the optimal ordering policy.

For the derivations to follow it will be convenient to adopt a common notation to represent both the random failures and preventive maintenance demands. Define $D(t)$ as the number of units required during period t. Without loss of general-