

Simulation-based Decision Making for Maintenance Policy Selection for Complex Systems

Zhaojun Li, Haitao Liao

Department of Industrial and Manufacturing Engineering, College of Engineering

Abstract. This paper investigates the performance of deteriorating systems maintained under structural constraints using a simulation approach. Three maintenance policies are investigated, and the performance of the system is measured by the steady-state system availability. The best maintenance policy is chosen with the highest steady-state availability. Unlike those widely used methods that treat such systems as continuous-time Markov processes, the proposed simulation model is able to deal with more general failure time and repair time distributions. Moreover, since desirable performance indices can be easily obtained using this method, it will be an effective tool to assist in selecting the optimal maintenance policy for a complex system.

1. Introduction

A machine degrades over time due to gradual wear-out of its components and damage caused by random shocks. To maintain the machine's performance at a certain level, preventive maintenance and replacement are usually conducted. In the literature, Markov processes have been widely used to describe the state transition of such systems, and a large number of maintenance models have been developed. However, most existing models assume exponential time distributions [1, 2], which may not be realistic in practice. Furthermore, the problem regarding the maintenance optimization for complex systems under structural constraints is rarely discussed.

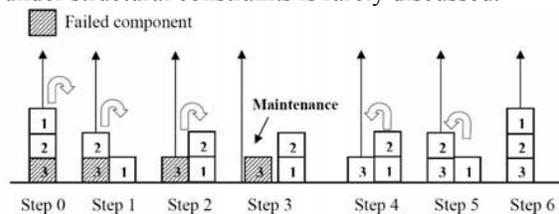


Fig. 1. Maintenance of a three-module system

This paper relaxes the exponential distribution assumption and investigates the performance of a complex system maintained under structural

constraints using a simulation approach. More specifically, for the system in Fig.1, in order to maintain module #3, modules #1 and #2 have to be taken off first. In practice, such structural constraints impose a set of rules on the sequence of maintenance activities, thus making the maintenance decision more complex.

In the proposed simulation method, the performance index, i.e. steady-state system availability, can be easily obtained. More importantly, the simulation models can deal with more general time distributions involved.

2. Experiment, Results, Discussion, and Significance

2.1 Assumptions

The following assumptions are made first:

- 1 The system consists of two failure-independent modules connected in series. The second module is structurally constrained by the first one.
- 2 The system is under continuous monitoring such that the modules' states are known during operation.
- 3 Each module can experience two phases of failure rates, and time to transit from the low failure rate to high failure rate is exponentially distributed.
- 4 Time between failures and time to repair of each module follow the Weibull distributions, and the distribution parameters depend on degradation severity.
- 5 For a specific module, the time to take off and the time to reinstall follow the lognormal distributions.

The system state is represented by a triplet (i.e. higher vs. lower failure rate, functioning vs. failure, and on vs. off machine, see Table 1).

Table 1: System state description in three indices

S (failure rate)	0	Lower failure rate
	1	Higher failure rate
F (functioning/failure)	0	Functioning
	1	Fails

For instance, $v = [0,1,0,1,0,0]$ means that module 1 is currently at the lower failure rate stage, failed and on the machine; module 2 is at the high failure rate stage, functioning and still on the machine.

2.2 Maintenance policies

Performing simultaneous maintenance action is usually less expensive than one maintenance action at a time [3]. In this paper, three different maintenance policies are investigated. The simplest one is minimum repair (MR) policy, i.e. the system is as bad as old after each repair without replacement. The second maintenance policy, failure replacement (FR), considers replacement when a module fails at severely degraded states. The third policy is preventive maintenance (PM), which preventively replaces a module even it is still functioning but at higher failure rate states. Each maintenance policy has a specific performance index under given budgetary constraints. The maintenance policy with the highest performance index will be chosen for implementation.

To build the associated simulation models, the state transaction diagrams for the three maintenance policies are first constructed [4]. For simplicity, only the state transaction diagram of the MR maintenance policy is depicted (Fig. 2). Due to the structural constraints, the number of system states is 32, while the possible total system states are $2^6 = 64$.

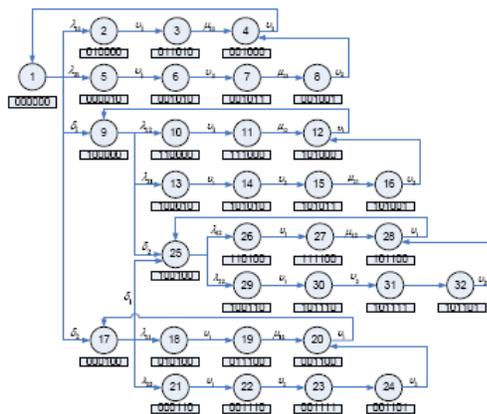


Fig. 2. Transition diagram of MR maintenance policy

2.3 Simulation model

Based on the state transaction diagram in Fig. 2, the simulation models are constructed using Area simulation software. The *Statistic advanced*

process and the *Route advanced transfer* are used in building the simulation models. For given sets of system characteristic parameters, the performance index (i.e. availability) for the three maintenance policies are calculated based on a 7,200 hours simulation for each of the ten replications. The simulation process ends within several seconds.

Table 2: Simulation results (system availability)

	MR	FR	PM
Availability	0.43944	0.69872*	0.40262

From Table 2, the FR maintenance policy achieves the highest system availability of 0.69872. Therefore, the FR maintenance policy should be implemented for the system with the given system parameters.

2. 4 Model validation

To validate the simulation model, the analytical solution of the steady state system availability for the FR policy is compared with the simulation results under exponential time distribution assumption. The analytical availability is the sum of working state probabilities, which depend on the given system parameters:

$$A_{sys} = p_1 + p_9 + p_{17} + p_{25}(1)$$

The closed-form solution of Eq. (1) is 0.92481 under Markovian formulation, while the simulation result is 0.92529, which is very close to the analytical result with only 0.048% difference. That validates the simulation models.

3. Conclusions

This paper proposes to apply a simulation method to facilitate decision making in selecting maintenance polices among multiple choices. The simulation model achieves satisfactory results and can deal with more practical time distributions involved in complex engineering systems.

4. Acknowledgement

We are grateful to the Research Grant Council, Hong Kong.

5. References

- [1] G.K. Chan and S. Asgarpoor, Preventive maintenance with Markov processes, Proceedings of the 2001 North American Power Symposium, 510515, 2001.
- [2] M.S. Moustafa, E.Y. Abdel-Maksoud and S. Sadek, Optimal major and minimal maintenance policies for deteriorating systems, Reliability Engineering and System Safety, 83, 363-368, 2004.
- [3] E. Borgonovo, M. Marseguerra and E. Zio, A Monte Carlo methodological approach to plant availability modeling with maintenance, aging and obsolescence, Reliability Engineering and System Safety, 67, 61-73, 1999.
- [4] Z. Li and H. Liao, Maintenance optimization of a degrading system under installation constraints, The proceedings of the 13th ISSAT conference on reliability and quality in design, 285-289, 2007.