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Reliability Measurement for Multistate Manufacturing Systems with Failure Interaction

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Abstract

Reliability is one of the important factors for manufacturing system. Most researches assume that the failure is independent and the components only have two states, which will lead to inaccurate results. In this paper, a reliability model is proposed considering both failure interaction and multi-state property of the manufacturing system. Starting with a two-component system, a function of state probability under the impact of failure interaction is established after the analysis of failure interaction. Then the multi-component system is decomposed into several subsystems and the failure interaction coefficient is estimated in each subsystem with a Copula function and the Grey model method. Finally, the reliability model is realized with the performance generating function which is derived with the UGF technique and failure interaction coefficients. An example of a cylinder engine manufacturing system is studied, and the result is closer to the practical data.

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Keywords: multistate manufacturing system; reliability measure; failure interaction; universal generating function; grey model

1. Introduction

Reliability describes the probability of a system completing its expected function during an interval of time, which gives an assessment of the overall performance of a system. An accurate reliability measure for a system guarantees its functionality, efficiency and safety. With the development of its scale and complexity, manufacturing system puts forward higher requirements for reliability analysis.

Most of the reliability analyses are based on two simplified assumptions: First, consider the subsystems and the whole system as a binary system, which means the system has a fully operational state and a completely failed state. Second, no failure interaction exists between the components. Failure interaction here refers to a prevailing phenomenon that one subsystem`s failure or degradation will affect the failure process of other related subsystems.

The study of multistate systems (MSS) started in the mid-1970s[2], since then lots of research have been carried out in this area. Methods adopted to reliability analysis of MSS mainly include: Monte Carlo Simulation[3,4], Stochastic Process Analysis[5], Universal Generating Function(UGF)[6] and so on. Other methods were also developed. Ding et al.[7] developed the fuzzy universal generating function considering a multistate system where performance rates and corresponding state probabilities are presented as fuzzy values. Lisnianski[8] extended the classical reliability block diagram method to a repairable multistate system based on the combined random processes and the universal generating function technique. Taboada et al.[9] developed a custom genetic algorithm to solve multiple objective multistate reliability optimization design problems. Qian et al.[10] proposed a new discretized modeling process on Bayesian belief networks basis for the reliability of multi-state mechanical systems. The study mentioned above focus on the multistate property of MSS to extend the study on reliability

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analyses. However, reliability can be influenced by various factors. Ping et al.[11] considered joint buffer station in a multi-state manufacturing network. Infinite and finite buffer volume was discussed and the study indicated that the assumption of infinite buffer volume will overestimate the system reliability.

Failure interaction commonly exists in multistate systems, which may also influence the performance of the system. During the operation of a manufacturing system, failures of a unit caused by corrosion, ageing, wearing or shock damages like improper maintenance or overwork may increase the load of other units, then affects the failure characteristics of the other units and eventually leads to the failure of the units. Attention has been paid to the failure mechanism and failure interaction in the systems` reliability as well.

Nakagawa and Murthy[12] divided failure interaction into three types, which is widely used in this area. According to this category, researchers expanded failure interaction into many aspects. Lai and Chen[13] developed an optimal periodical replacement policy for a multi-unit system subject to failure rate interaction between units. Sun et al.[14,15] introduced the concepts of interactive failure, developed an analytical model and presents five approaches to estimate the interactive failures. Gao et al. [16] established a reliability model of system and a quasi-periodic dynamic Preventive Replacement to research the coexists of type I and II failure interaction. Qi et al.[17] presented two periodical maintenance cost models for a two-state series system and a three-state series system respectively based on the three types of failure interactions.

Considering the failure interaction gives rise to the analysis of the system, however the result always yields the practical data. The studies mentioned above focusing on the failure interaction studied issue on reliability and maintenance either in a multistate two-component system or a binary multi-component system. Study focusing on multistate multi-component system with failure interaction is still in infancy.

This paper for the first time considers failure interaction in a multi-component multistate manufacturing system(MSMS) to derive the reliability. Moreover, based on a previous study on the influence of the degeneration[18]. The reliability is given with two failure mechanisms, namely failure interaction and the degeneration. To define the failure interaction, the copula function and Grey model is used to find the parameters as a new approach. The rest of the paper is organized as follows. The next section gives an analysis of a two components multistate manufacturing system with failure interaction. Markov chain is used to represent all the states and their transitions. Section 3 proposes a decomposition method of the system based on fault correlation of the components and figures out the failure interaction coefficient using Copula function and grey model method. Then the reliability model is constructed after giving the performance generating function of one component and the whole system by using the UGF technique and mapping relationship. Section 4 dedicates to a case study on a three processes engine cylinder manufacturing system. The paper concludes that considering failure interaction in multistate system will give a lower reliability.

2. Failure Transition in A Two-component MSMS

2.1. Definition and Assumption

Consider a system with two machines. Any machine can have $l+1$ different states in its lifecycle, represented by the set $L=\{l,l-1,\cdots,0\}$, where l denotes the new state and 0 denotes the completely failure state. Very mild assumptions are required for the sequential study. These are follows:

- All general faults are maintained immediately after it occurs and no maintenance time is considered.
- Whenever a system failure occurs, it is detected immediately and only one unit fails naturally.
- All failed units are correctively maintained but cannot be repaired as good as new.
- All performance analyses are done only when the system is at a steady state.
- The state transition caused by failure interaction is instantaneous.

2.2. Failure transition representation

According to the failure interaction category [12], the failure transition for two machines is illustrated in Figure.1.

When a machine fails due to the fault of itself, such as corrosion, ageing and so on, it can induce the failure of the related component refer to Machine II in Figure.1 with a probability of *p*; or it increases the failure rate of machine II with a probability *1-p* and gives rise to the failure of machine II with the accumulation of the damage. While the failure of machine II will induce an instantaneous failure to machine I with a probability of q.

When machine I fails due to an external shock damage, the following two situation should be considered: The shock damage is quite small that only a general failure occurs on machine I. The hazard will increase the failure rate of machine II with a probability of p` and lead to failure when the total damage exceeds a specified level. While the failure of machine II caused by the damage will induce instantaneous damage to machine I with a probability of $q$` and lead to the failure of machine I. Otherwise, if the shock damage gives rise to a 'dramatic destroy' on machine I it will lead to instantaneous failure. The hazard will induce an instantaneous failure of machine II with a probability of *1-p*` and result in failure of the system eventually.

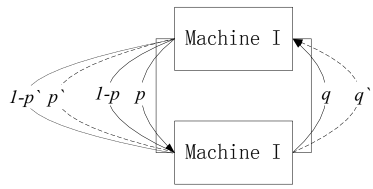

Fig.1 Failure transition between two components

2.3. Markov model for state transition

In its lifecycle [0, t), all machines will degrade from state l to its completely failure state *0*. The machine can transfer to