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Failure analysis of engineering systems with preventive maintenance and failure interactions

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Abstract

Optimal operation and maintenance of engineering systems heavily rely on the accurate prediction of their failures. Most engineering systems, especially mechanical systems, are susceptible to failure interactions. These failure interactions can be estimated for repairable engineering systems when determining optimal maintenance strategies for these systems. An extended Split System Approach is developed in this paper. The technique is based on the Split System Approach and a model for interactive failures. The approach was applied to simulated data. The results indicate that failure interactions will increase the hazard of newly repaired components. The intervals of preventive maintenance actions of a system with failure interactions, will become shorter compared with scenarios where failure interactions do not exist.

Keywords: Interactive failure; Reliability prediction; Dependent failure; Repairable systems; Preventive Maintenance; Interactive hazard

1. Introduction

Repairable engineering systems are commonplace in industries. A repairable engineering system (from hereon refereed to as 'repairable system') indicates that the functionality of this system after each failure can be recovered through repairs. It is normally a complex system composed of a number of components. In this paper, the term "components" usually includes subsystems and the term "repair" includes "replace or replacement" unless specified. Failure prediction of repairable systems is an important topic in reliability engineering (Blischke, et al., 2000; Ebeling, 1997; Elsayed, 1996; Hoyland, et al., 1994). Accurately predicting the failures of repairable systems is essential to the optimal operation and maintenance of these systems.

The failures of a repairable system can be classified into two categories in reference to the failure relationships of the components of the system: (1) Independent failure - the failures of the components in a system do not affect each other; and (2) Dependent failure - failure in one or more of the components in a system will interact with or cause failures of the other components in the system. Interactive Failure (IntF) is one type of dependent failure and is defined as mutually dependent failures, that is, the failures of some components

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(termed as influencing components) will affect the failures of other components (termed as affected components) and vice versa (Sun, Ma, Mathew, & Zhang, 2006b) - IntF is an accelerated failure due to failure interactions between components in a system. The failure interactions among components will increase the probabilities of failures of the components. As a result, the failure rates of the components and the system increase. This increased failure rate is defined as Interactive Hazard (IntH). Correspondingly the failure rates of components without failure interaction are termed as Independent Hazard (IndH). Failure interactions can be either stable or unstable (Sun, Ma, & Mathew, 2003). When a failure interaction is stable, the failure rates of affected components will be greater than their independent failure rates (IndH) but remain at a certain level, whereas unstable failure interaction indicates that the failure rates of the affected components will increase dramatically in a very short time. Stable failure interactions normally result in gradual degradation interactive failures (Sun et al., 2006b). This type of failure is the focus of the study in this paper.

Interactive failure occurs commonly in engineering assets, especially in mechanical systems. One needs to consider IntF when repairing a system with failure interactions, or otherwise the repair maybe incomplete. An example to support this argument has previously been provided by the authors (Sun, Ma, Mathew, & Zhang, 2004). In this example, two bearings on a shaft in a machine were damaged and caused the shaft to vibrate intensively. However, only the lower bearing was replaced during the repair of this machine. As a result, the damaged upper bearing still caused the shaft to vibrate. This vibration accelerated the failure of the new lower bearing so that the repair was ineffective. This accelerated failure is an interactive failure. The case demonstrated in this example is relatively commonplace in maintenance engineering. The effect of IntF on repairable systems needs to be analysed quantitatively in order to repair a system effectively and efficiently.

In reference (Sun et al., 2006b), an Analytic Model for Interactive Failure (AMIF) was developed to calculate the IntF of systems without considering the effects of repairs on the reliability prediction of the systems. On the other hand, Sun, Ma and Mathew (Sun, Ma, & Mathew, 2007) previously developed a Split System Approach (SSA) to predict the reliability of repairable systems without interactive failures. However, the research on the reliability predictions of repairable systems with IntF is still in its infancy. Despite an exhaustive literature review, the authors were unable to find related research reports to date.

In this paper, an approach to predict the reliability of repairable systems with IntF is developed. This approach consolidates both SSA and AMIF, and hence is termed as the Extended Split System Approach (ESSA).

Currently, Preventive Maintenance is usually conducted on repairable systems to improve the overall reliability of these systems. Different PM strategies have been developed. One of them is the Reliability Based Preventive Maintenance (RBPM) strategy (Malk, 1979). In this strategy, a reliability level (termed as control limit of reliability) is predefined for a system. Whenever the reliability of the system falls to this control level, a PM action is carried out on the system. RBPM strategy is usually more effective in risk management compared with other PM strategies such as time based PM strategy. This paper investigates the reliability prediction of systems with the RBPM strategy and considers the scenario where always the same single component is repaired in all PM actions. The repaired component is connected with the remaining system (termed as subsystem) in series. This scenario is commonplace in the real world (Sun et al., 2007).

The rest of the paper is organised as follows. In Section 2, the methodology for ESSA is presented. Reliability prediction formulae based on this methodology are derived in Section 3. In Section 4, the newly developed method is validated using an example and numerical simulations. Section 5 presents the conclusions.

2. Methodology

The reliability of a system is expected to increase after a repair because the hazard of the system is reduced (Wang, 2002) (the scenario where repairs degrades assets is not considered in this paper). Repairs can improve the reliability of a system in two aspects: (1) decreasing the Independent Hazards (IndH) of repaired components, and (2) reducing the Interactive Hazard (IntH) of unrepaired components due to the conditions of repaired components being improved. This characteristic has been observed in experiments conducted by the authors (Sun et al., 2004). In the following sections, a methodology is developed to analyse the changes of hazards and reliability of systems with interactive failures and multiple PM intervals quantitatively based on the AMIF and SSA.