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A corrective maintenance scheme for engineering equipment

Yuanhang Wang [a], Chao Deng [a], Jun Wu [b,*], Yingchun Wang [c], Yao Xiong [d]

[a] National Engineering Center of Digital Manufacturing Equipment, Huazhong University of Science and Technology, Wuhan, Hubei Province 430074, China
[b] School of Naval Architecture & Ocean Engineering, Huazhong University of Science & Technology, Wuhan 430074, China
[c] China Chang Jiang Energy Corporation, Wuhan, Hubei Province 430074, China
[d] Wuhan Second Ship Design and Research Institute, Wuhan 430064, China

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ABSTRACT

Corrective maintenance is a maintenance task performed to identify and rectify the cause failures for a failed system. The engineering equipment gets many components and failure modes, and its failure mechanism is very complicated. Failure of system-level might occur due to failure(s) of any subsystem/component. Thus, the symptom failure of equipment may be caused by multilevel causality of latent failures.

This paper proposes a complete corrective maintenance scheme for engineering equipment. Firstly, the FMECA is extended to organize the numerous failure modes. Secondly, the failure propagation model (FPM) is presented to depict the cause-effect relationship between failures. Multiple FPMs will make up the failure propagation graph (FPG). For a specific symptom failure, the FPG is built by iteratively searching the cause failures with FPM. Moreover, when some failure in the FPG is newly ascertained to occur (or not), the FPG needs to be adjusted. The FPG updating process is proposed to accomplish the adjustment of FPG under newly ascertained failure. Then, the probability of the cause failures is calculated by the fault diagnosis process. Thirdly, the conventional corrective maintenance recommends that the failure with the largest probability should be ascertained firstly. However, the proposed approach considers not only the probability but also the failure detectability and severity. The term REN is introduced to measure the risk of the failure. Then, a binary decision tree is trained based on REN reduction to determine the failure ascertainment order. Finally, a case is presented to implement the proposed approach on the ram feed subsystem of a boring machine tool. The result proves the validity and practicability of the proposed method for corrective maintenance of engineering equipment.

1. Introduction

In reliability engineering, failure describes the state or condition of not meeting the intended objective. To repair or prevent failures, many maintenance strategies have been gradually proposed, such as corrective maintenance (CM) [1–4], condition based maintenance (CBM) [5] and reliability centered maintenance (RCM) [6]. Herein, CBM is currently a hot issue in maintenance engineering [7]. However, the preventive maintenance is not able to completely eliminate failures. It is a fact that corrective maintenance is still widely adopted in engineering practice.

Corrective maintenance focuses on the identification of cause failures from the failure phenomenon. The failure phenomenon contains one or more symptom failures. In order to fulfill the corrective maintenance, various models have been built to represent the failure mechanisms. Iyoob et al. [1] discussed the impact of five corrective maintenance models to equipment

* Corresponding author. Tel.: +86 027 87543258; fax: +86 027 87542146.
E-mail address: wuj@mail.hust.edu.cn (J. Wu).

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Nomenclature

FMECA	failure mode, effects and criticality analysis
FPM	failure propagation model
FPG	failure propagation graph
CNC	computer numerical control
REN	risk metric of the failure
RR	REN reduction
$\Pr(Y)$	probability of failure Y
Oc	fuzzy occurrence of failure
Se	fuzzy severity of failure
De	fuzzy detectability of failure
n	the number of failure nodes in FPG
m	the number of concurrent nodes in FPG
A	direct matrix, $A = (a_{ij})_{n*n}$
B	linked matrix, $B = (b_{ij})_{n*m}$
C	concurrent matrix, $C = (c_{ij})_{m*n}$
S	symptom vector, $S = [S_1, S_2, \ldots, S_n]$
W	$W = \begin{bmatrix} A & B \\ C & 0 \end{bmatrix}$
D	depth vector, $D = [D_1, D_2, \ldots, D_n]$
Pr	probability vector, $\Pr = [\Pr(1), \Pr(2), \ldots, \Pr(n)]$
$(\text{new\_}W, \text{new\_}S) = \text{UPD}(W, S, S_p)$	FPG updating process with ascertained failure p
$D = \text{DEP}(W, S)$	node depth calculation process
$\Pr = \text{DIG}(W, S)$	fault diagnosis process
Binary decision tree = $\text{DTT}(W, S)$	training process of the binary decision tree
UFp	the p-th unascertained failure with the lowest detectability
1E−4	1.0×10^{-4}

availability: renewal, minimal, Kijima I, Kijima II, and quasi renewal. Carlo et al. [2] proposed a Bayesian model to solve the problem: what corrective measure is the best suited to delay the occurrence of the failure when aging is confirmed. Besides, there are plenty of methodologies of fault diagnosis for specific objects, for example [3,4]. However, few generic technologies for corrective maintenance have been proposed. FTA is the most commonly used technique for causal analysis in risk and reliability studies. Recent FTA applications cover three aspects: root cause analysis [8–10], risk assessment [11]and design safety assessment [12,13]. FMECA is an essential first step in understanding the system. The recent researches of FMEA focus on the risk assessment [14]. On the other hand, the graph models have proved to be useful for modeling and analyzing various kinds of systems [15,16]. Iri et al. initially applied the graph theory in fault diagnosis in [17]. Venkata Rao and Gandhi [18] presented a methodology to analyze the failure causes of a machine tool using causality digraph and matrix methods. In addition, Bayesian network is another graphical representation of failure relationships [19].

This paper proposes a complete corrective maintenance scheme for engineering equipment. The framework of the proposed scheme is shown in Fig. 1. Firstly, the conventional FMECA is extended to organize the numerous failure modes and also their causality. Then, failure propagation model (FPM) is presented to depict the causal relationships between failures. Multiple FPMs will make up the failure propagation graph (FPG). FPG is able to represent the complicated failure mechanism of engineering equipment. For a specific symptom failure, the FPG is constructed by iteratively searching the cause failures with FPM. Moreover, when some failure in the FPG is ascertained to occur (or not), the FPG needs to be adjusted. The FPG updating process is proposed to accomplish the adjustment of FPG when some failure in FPG is newly ascertained. Then, the probabilities of the cause failures can be derived by the fault diagnosis process. According to the probability derived by fault diagnosis and failure detectability/severity information in the extended FMECA, a term “REN” is introduced to measure the failure risk. Then, a binary decision tree is trained based on the REN reduction. The training

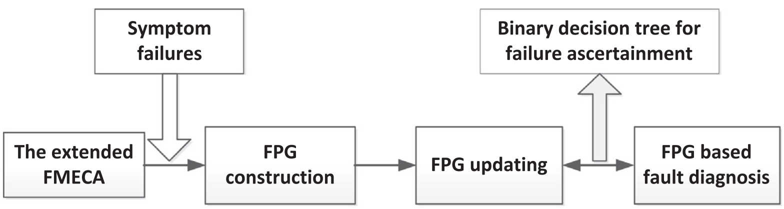

Fig. 1. The framework of the proposed corrective maintenance scheme.