Reliability Centered Maintenance Methodology for Product in Design Improvement Phase: A Case Study on Dough Presser

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LIST OF ABBREVIATIONS

PM	Preventive Maintenance
OEM	Original Equipment Manufacturer
RCM	Reliability Centered Maintenance
RCA	Root Cause Analysis
MSG	Maintenance Steering Group
FTA	Fault Tree Analysis
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
SII	Significant Impact Item
PDF	Probability Density Function
MTBF	Mean Time Between Failure
RPN	Risk Priority Number

LIST OF SYMBOLS

λ(t)	Hazard rate
$F\ (t)$	Failure rate
$R\ (t)$	Reliability rate
K_{fm}	Criticality number
λ	Failure rate
F	Probability of failure effect / severity of consequences
θ	Failure mode ratio
t	Operational time expressed in hour
S	Severity
O	Occurrence
D	Detection

Struktur Kaedah Penyelenggaran Berdasarkan Keboleharapan Pada Produk Dalam Fasa Penambahbaikan Rekaan: Kajian Kes Pada Alat Penekan Doh

ABSTRAK

Strategi penyelenggaraan melalui analisa berasaskan keboleharapan semakin penting terhadap kos keseluruhan operasi dengan mengurangkan rutin penyelenggaraan yang tidak mustahak. Keperluan strategi penyelenggaraan kini bukan hanya untuk rutin penyelenggaraan tetapi juga untuk penambahbaikan rekaan. Bagaimanapun, masih belum ada kaedah analisa untuk sistem dalam fasa penambahbaikan rekaan. Kaedah analisis penyelenggaraan berasaskan keboleharapan tidak selalunya sesuai untuk semua fasa peralatan. Salah satu penyelesaian ialah menggunakan kaedah analisis penyelenggaraan berasaskan keboleharapan khas untuk fasa penambahbaikkan rekaan. Kaedah analisis direka untuk mengurangkan risiko kegagalan yang gagal dikesan. Objektif pengesahan kajian kaedah analisis tersebut dilaksanakan melalui objektif khas iaitu mengkaji kesan penukaran alat analisa punca kegagalan dari FMEA kepada FTA, mengkaji perbezaan antara hasil analisis melalui gambarajah blok dan FTA and akhirnya mengkaji kelebihan integrasi di antara RPN dan index kritikal. Kaedah analisis melibatkan empat fasa iaitu pengelasan komponen, analisis punca kegagalan sistem, analisis risiko kegagalan dan penentuan strategi penyelenggaraan. Perubahan alat analisa punca kegagalan memberi ruang untuk mengesan kaitan antara punca-punca kegagalan. Pengesahan hasil Gambarajah blok dan FTA memberikan perbezaan kebolehan antara alatan. Perbandingan antara RPN dan index kritikal menunjukkan situasi di mana keduanya perlu digabungkan. Didapati kaedah analisis penyelenggaraan berasaskan keboleharapan memberi peluang mengurangkan risiko ketika fasa penambahbaikkan rekaan.

Reliability Centered Maintenance Methodology for Product in Design Improvement Phase: a case study on Dough Presser

ABSTRACT

Maintenance strategy through the RCM had become increasingly important to the overall operation profit by reducing unnecessary maintenance routine. Maintenance strategy needs have become not just for the maintenance routine but also the design improvement. However, there was no RCM methodology available for the system in design improvement phase. The RCM methodology is not always fits all equipment phase. One of the solutions is using RCM methodology specific for the design improvement phase. The methodology designed to reduce unseen failure risk. The objectives of the research is to validate the methodology through the specific objectives which are to study the effect of the root cause analysis tool change from FMEA to FTA, to examine the finding different between Block diagram and FTA tools and eventually to investigate the benefit of RPN and criticality results integration. The methodology involves four mains phases which are the component classification, root cause analysis, failure risk and criticality analysis and finally the maintenance strategy determination. The change in root cause tool provides the detection towards the relation between the root causes. The qualitative result verification between Block diagram and FTA shows the gap between the tools. Investigation of the RPN and criticality present the situation where the quantitative result has to be integrated. Observed the proposed RCM methodology has provided the opportunity to minimize the risk in design improvement stage.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Maintenance strategy plays important to minimize the adverse effect of the equipment breakdown, reach the production performance and achieve cost effective operation (Barafshan & Hajjari, 2012). Equipment breakdown causes an issue such as production loss, delay in schedule, materials shortage, overtime works demand and insufficient manpower (Vishnu & Regikumar, 2016). An optimum maintenance strategy required the best combination of predictive maintenance, PM, CM and proactive maintenance as the fundamental (Jasiulewicz, 2015).

RCM contributes towards an effective maintenance strategy by identifying the potential causes of interruption in performance, hence preventing failures and a providing proactive approach to operations and maintenance (Igba et al., 2013). The benefit of maintenance strategy through RCM practices has helped to reduce the number of routine maintenance works in between 40-70% (Moubray, 1997).

A part from the benefit, RCM has its limitation which has been emphasized by Rausand (2008) that RCM is just to sustain system reliability not to improve it but the improvement can be realized through design modification. It shows that reliability cannot be enhanced through RCM alone, but it has to integrate with a design modification. In order to link the main RCM and the design improvement aspect, a feedback loop throughout the equipment lifecycle phases required (Igba et al.,2013).

Conventional RCM methodology focal point is the function failures of a system based on the probability statistics and consequences but does not engage failure mechanism and the actual causes of the failures (Li & Gao, 2010).

1.2 Problem Statement

Recently, maintenance strategy has become increasing important as the impact contributes 15-70% of the overall profit (Salonen & Deleryd, 2011). It is impossible to totally eliminate the maintenance cost, thus a cost effective maintenance strategy is needed (Ding & Kamaruddin, 2015). Since industries attempt to use maintenance to increase profit, maintenance is no longer just the repairs, PM or prediction activities but also beneficial towards improvement (Ding & Kamaruddin, 2015). Due to the high contribution on the profit, the system performance required optimum reliability and availability at the lowest cost. Therefore, the maintenance decisions have to be supported by sound technical analysis called RCM.

However, there was no research being carried out on the development of RCM methodology for the system in design improvement phase in the past 10 years. Researches on the RCM were focusing on the RCM improvement during the operation phase. The problem arises when the existing RCM methodology is not always suitable for all types of equipment phase. Thus, there is a need arise to develop the methodology for the equipment or system which is in design improvement phase. A modified RCM methodology had appeared to be an ideal solution to serve the reliability analysis during the design improvement phase.

1.3 Research Objective

The main goal of this research is to propose the RCM methodology specifically for the equipment in design improvement phase and validate through the objectives which consist of:

i. To study the effect of the root cause analysis tool replacement from FMEA (Failure Mode and Effect Analysis) to Fault Tree Analysis (FTA)

ii. To examine the difference in FMEA result with respect to the data sources (block diagram versus FTA)

iii. To investigate the benefit of the integration between Risk Priority Number (RPN) and the criticality analysis.

1.4 Scope of Research

The scope of the research is the validation of the proposed RCM analysis methodology which includes the impact of analysis tool replacement, root cause verification and the priority measurement verification. The analysis subject is the functional failure, which is detected through defect occurrence. The aspect of the comparison is the capability to minimize undetected failure during the root cause analysis. The scope of the RCM analysis is limited to the systems where the condition monitoring is available. Research is not intended to perform an age exploration study on the components involved as the approach is fully based on the functional condition.

1.5 Thesis Structure

There are total five chapters covered in this dissertation. The Introduction in Chapter 1, consist of the research background, problem statement, objective, scope of research and thesis structure.

Chapter 2 presents the literature review on the RCM related theory, benefit, principle, standard, framework development and their application.

Chapter 3 provides the RCM analysis using the proposed methodology. The process carries out using three main tools which are Block Diagram, Fault Tree Analysis (FTA), failure mode effect and criticality analysis (FMECA). The methodology contains 4 main phases which are component classification, root cause analysis, failure prioritization and maintenance task selection.

Chapter 4 discusses the results and findings gained from the reliability analysis of the case study. The first Section covers the result of data collection on the working mechanism and the functional expectation. Next, the discussion proceeds to the root cause analysis and the benefit of the method change. Third Section presents the quantitative analysis on each of the failure modes and the comparison of two analysis result. The fourth Section is the maintenance task and design improvement plan.

Finally, Chapter 5 summarizes the findings made in the Chapter 4 and provides the recommendations for future RCM research. Recommendations for future studies are presented based on their potential with the current research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section presents the literature review on the evolution of reliability-based maintenance, the bathtub curve theory for maintenance and its limitation, the introduction to the RCM concept and the development of RCM frameworks. Finally the literature findings state the focus area on RCM methodology improvement.

2.2 Evolution of Maintenance

Generally there are three major maintenance approaches which are corrective maintenance (CM), preventive maintenance (PM) and condition-based maintenance (CBM) (Zhang et al., 2017). Each type progressively developed since after the World War II in 1940s. At the earlier generation of the maintenance before the World War II, the approach taken was the solely corrective maintenance. The corrective maintenance is the actions performed after the failure took place (Niu et al., 2010). In fact, it was a sufficient maintenance strategy for the robust equipment which inherent high reliability and the repair time is short (Smith, 2003).

After World War II, the concept of Preventive Maintenance (PM) practice has been introduced due to the increased in automation accompanied by higher levels of equipment complexity. The basis of the PM strategy is to conduct the maintenance activity before the failure occurs. According to the maintenance terminology, Preventive maintenance is the activities carried out at predetermined intervals to reduce the probability of failure or the degradation of the functionality of an item (Bengtsson, 2004).

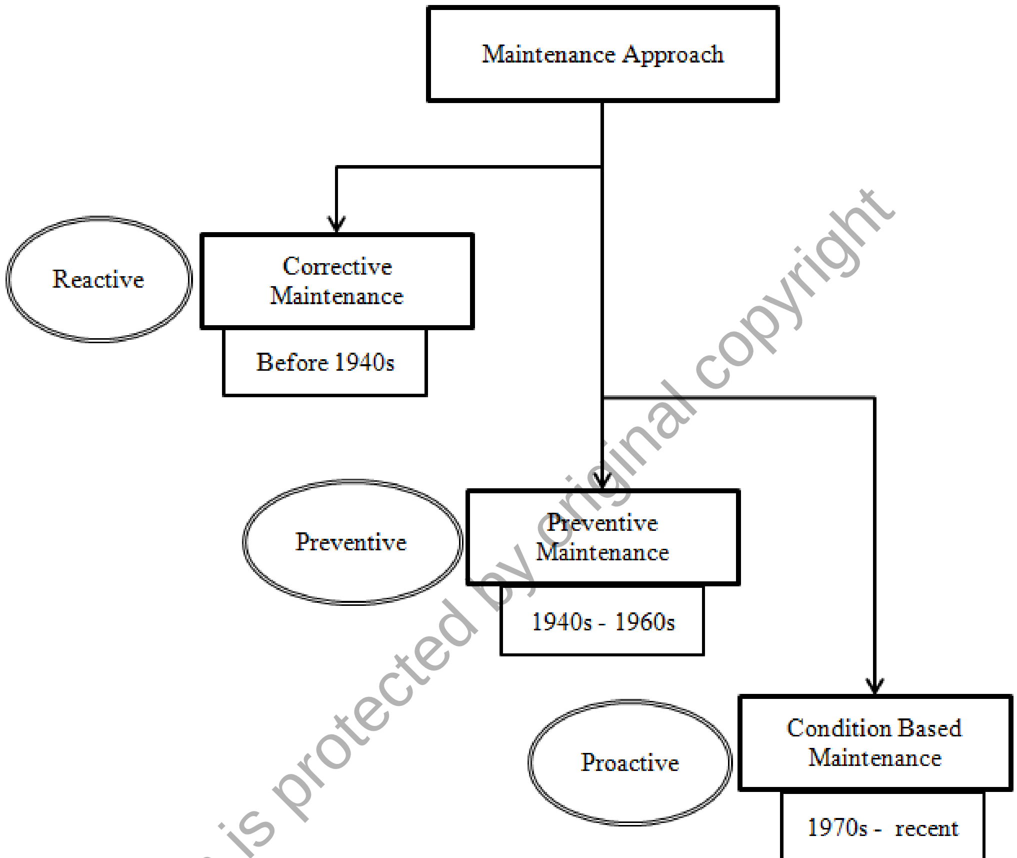

Figure 2.1: Maintenance revolution (Zhang et al., 2017)

Initially, the problem solving PM was the equipment overhauls over fixed time intervals which is classified as predetermined maintenance (Niu, 2009). In 1970s the development led to the more maintenance option variation in PM, known as Condition Based Maintenance (CBM). The development progress of the maintenance approach has been simplified in Fig. 2.1. In contrast CBM does not use predetermined intervals but the preventive maintenance plan is based on the component monitoring result (Campos et al., 2010). CBM has been identified as worthwhile PM over scheduled repairs as it increased efficiency due to the reduction of idle time and the optimal use of materials and other resources (Campos et al., 2010). However, the technique is not suitable for the system where the condition monitoring is not feasible. The strategy classification is simplified in Fig. 2.1. There is still a challenge in the maintenance found in early 2000 by Smith and Hinchcliffe (2003) which had emphasized the maintenance strategies at the era were focusing only on maintaining equipment operational, but neglect functional requirements.

2.3 Evolution of the Reliability

Other than the functional requirement Smith and Hinchcliffe (2003) further present the needs for systematic communication in managing maintenance. The maintenance was related to the equipment complexity. During the first maintenance generation, there is an effective experience based preventive maintenance (PM) system in place where the design, maintenance, and operation expertise is the same person (Smith & Hinchcliffe, 2003). When a single person handling it provide the advantage of centered knowledge where the experiences were synchronized across the design, maintenance and operation aspect. However, as the equipment complexity and volume expanding the responsibility division started to be initiated. As a part of the consequences, the responsibility division had introduced a challenge to get a synchronized experience inputs.

Thus the reliability engineering helps to deal with the challenge by a systematic communication between experts for maintenance tasks derivation (Smith & Hinchcliffe, 2003). Reliability engineering begins within electronic industries in the 1940s (Smith& Hinchcliffe, 2003). The term reliability is defined by military standard as a chance that a part will execute its planned function for a specific duration over predetermined condition

(Stapelberg, 2009). The reliability assessment resolved the reliability and criticality action precedence for a system or equipment at the component level. Reliability $R(t)$ is time dependent, where it decreases as the time increase. As the equipment getting older, the reliability decreased. The better system has been built up, the longer success period of operation it has. The failure probability is known as unreliability and the value obtained from Equation (2.1) (Arno, et al., 2016) which mean when a complete functional failure or unreliability does occur the reliability value is zero.

$$F(t) = 1 - R(t) \tag{2.1}$$

Three frequently applied methods for reliability evaluation contain the statistical modeling (Smith & Hinchcliffe, 2003);

i. Hazard rate function. For characterizing the failure rate pattern by weighing the ratio between failure probability and the reliability function. Result from the assessment projected the failure rates and the failure rate patterns by components, which can be the random functional failures or the wear-out failures (Arno, et al., 2016)
ii. Exponential failure distribution. For identifying the probability of failure and the reliability function for the circumstance of random functional failures interval.
iii. Weibull failure distribution. For measuring the criticality of the wear-out related failure.

Hazard analysis is frequently applied model to identify the reliability based on failure scenario due to the flexibility of the model to analyze at both random and wear out phase, the hazard rate function applied. Hazard refers the origin of loss or break (Arunraj & Maiti, 2007).

2.4 Reliability Analysis

In maintenance, the hazard is the loss of reliability. Risk is the probability that the hazard will occur (Arunraj & Maiti, 2007). Therefore the risk represents the probability of reliability loss. Probability Density Function (PDF) is an equation that relates the probability of the hazard occurrence with respect to time. The output is known as failure rate. Normally the plot of PDF versus time produces a graph with a bell curve shape (Arno, et al., 2016).

The failure rate λ is representing the rate that a failure per unit time within the time interval, assuming the failure prior to the beginning of the interval is zero. Mean time between failures (MTBF) shown in Fig. 2.2, is the mean (average) time the equipment performed its intended function before it failed.

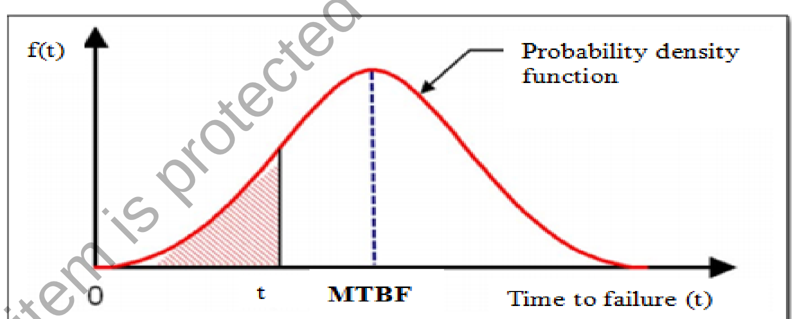

Figure 2.2: Probability of failure, *F(t)* (Arno, et al., 2016)

The failure scenarios are developed based on the physical condition and characteristic of the system during operation (Arunraj & Maiti, 2007). For continuous random variables, the cumulative distribution function (CDF) is defined by Equation (2.2)(Stapelberg, 2009),

$$F = \int_{-\infty}^{t} f(x)dx \tag{2.2}$$

$f(x)$ = probability density function of the distribution of value x within the $-\infty$ to t interval. The probability density function is derived from the cumulative distribution function, as shown in Equation (2.3) (Stapelberg, 2009). The probability of failure or known as unreliability is $F(t)$. The reliability functions over a period of time t showed by Equation (2.4) is the subtraction of the CDF of failure over a period of time t. The hazard rate function represented in the hazard rate curve as $\lambda(t)$. Equation (2.5) depicted the relationship between the hazard rate, failure rate, and reliability (Stapelberg, 2009).

$$\frac{dF(t)}{dt} = \frac{d}{dt}\left[\int_{-\infty}^{t} f(x)dx\right] \tag{2.3}$$

$$R(t) = 1 - F(t) \tag{2.4}$$

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1 - F(t)} \tag{2.5}$$

A hazard rate pattern is used to illustrate the equipment failure rate characteristic (Stapelberg, 2009). The hazard rate curve was divided into three time frames consisting of the decreasing, constant, and increasing trend. The pattern is also known as bathtub curve. The bathtub curve is important in reliability practice, especially in constructing the strategy to reduce the loss during the infant mortality time frame.

2.4.1 Bathtub Curve

The hazard rate curve basic idea is originally from the human deterioration nature and presumed similar to the equipment deterioration nature (Smith & Hinchcliffe, 2003). The bath tub curve can be simplified into three phases (Klutke et al., 2003) which is:

i. Early failure (infant mortality)

ii. Constant (random) failure

iii. Wear out failure

The trend of the bathtub curve is shown in Fig. 2.3. At the beginning, the decreasing trend is known as a burn-in period, or infant mortality period. The burn-in period failure is the indication of the early failures which is the outcome of the design, weakness or set up defects in new equipment.

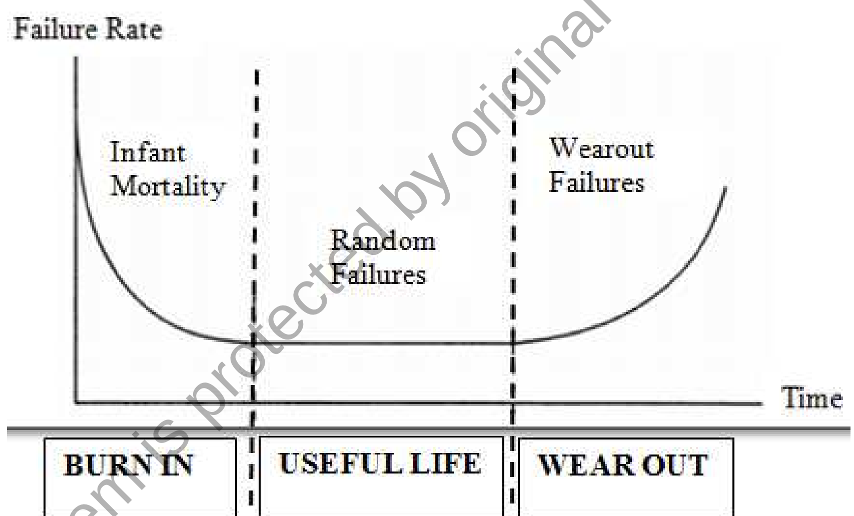

Figure 2.3: Bathtub curve (Klutke, et al., 2003)

As the time in burn-in period increases, the failures growth drop and start become consistent. During the second time frame, the constant failure rate is called as the useful life period of the equipment. The second time frame involves the failures occur in the useful life period called as random failures due to the failure happen unpredictably.

The third time frame of the curve which shows the increasing trend is known as the wear-out phase of the equipment. The wear out phase begins star once useful life phase end. The failure rate begins to increase exponentially and it is known as wear-out failures. Once the