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LIST OF ABBREVIATIONS

CAM	Computer-aided Manufacturing
CDF	Cumulative Density Function
CFR	Constant Failure Rate
DFR	Decreasing Failure Rate
FF	Functional Failure
FMECA	Failure Mode Effect and Criticality Analysis
IFR	Increasing Failure Rate
MTTF	Mean Time to Failure
NC	Numerical Control
PA	Pareto Analysis
PF	Physical Failure
TTF	Time to Failure

LIST OF SYMBOLS

β	Shape parameter
θ	Scale parameter
α_{kp}	Failure mode ratio
λ_p	Parts of failure rate
$R(t)$	Reliability
$F(t)$	Cumulative density function
$f(t)$	Probability density function
$\lambda(t)$	Failure rate function
Γ	Gamma
C_r	Criticality index
C_m	Criticality matrix
λ_m	The modal failure rate
β_k	Probability conditions
t	Time of operation
y_i	Vertical scale
x_i	Horizontal scale
r	Coefficient index of fit
e	Exponents

Analisa Keboleharapan Berdasarkan Taburan Weibull dan Analisa Kritikal dan Ragam Kegagalan.

ABSTRAK

Dalam industri pengeluaran kegagalan disebabkan oleh kegagalan mesin memberi kesan kepada kualiti produk, kepuasan pelanggan dan prestasi pengeluaran. Disebabkan itu, adalah penting untuk memastikan keboleharapan mesin sentiasa berada pada tahap yang berkesan.Walaubagaimanapun, adalah penting malahan sukar untuk mengawal dan mengurangkan kegagalan yang terjadi secara tidak dirancang. Situasi sebegini memberi kesan besar yang mana membawa kepada kecacatan produk, penurunan kualiti pestasi dan peningkatan kos penyenggaraan. Salah satu strategi ialah dengan menggunakan analisis keboleharapan sebagai medium untuk membangunkan polisi penyenggaran yang sesuai. Analisis keboleharapan ini mengenalpasti ciri-ciri kegagalan dan mesin keboleharapan. Untuk penyelidikan ini, dua kaedah analisis keboleharapan iaitu analisis Taburan Weibull dan analisis kritikal dan ragam kegagalan digunakan. Untuk taburan Weibull data kuantitian masa untuk kegagalan diaplikasikan. Dimana, data kuantitian masa ini menunjukkan, masa diantara kegagalan pertama sehingga kegagalan seterusnya berlaku. Manakala dalam analisis kritikal dan ragam kegagalan, data ragam kegagalan, kesan dan akibat kegagalan dengan kebarangkalian digunakan.. Data ini berdasarkan data kegagalan yang diperolehi dari tiga mesin yang kritikal pada lini "Camshaft" bagi industri permotoran di Malaysia. Bagi analisis keboleharapan ini, analisis taburan Weibull menghasilkan jawapan kepada keadaan ciri-ciri dan sifat kegagalan mesin. Keadaan ciri-ciri dan sifat kegagalan ini boleh digunakan sebagai panduan pembangunan jenis-jenis pennyenggaraan bagi analisis seterusnya. Selain itu, nilai parameter keadaan ciri-ciri dan kegagalan membawa kepada anggaran purata masa antara kegagalan. Manakala, dari analisis kritikal dan ragam kegagalan keputusan menunjukkan pengenalpastian, pengelasan dan penjelasan kepada ragam kegagalan dan susunatur kegentingan. Darjah kegentingan kepada kegagalan kritikal boleh ditentukan dengan lebih jelas pada matrik kegentingan. Matrik kegentingan membawa kepada penentuan tindakan pembetulan yang perlu diambil dengan mengambilkira faktor keselamatan dan kekerapan kegagalan. Dengan itu, ini menunjukkan gabungan analisis keboleharapan dan analisis kritikal dan ragam kegagalan menunjukkan keputusan yang lebih spesifik dan jelas kepada kegagalan mesin.

Reliability Analysis Based on Weibull Distribution and Failure Mode Effect and Criticality Analysis

ABSTRACT

In manufacturing industry breakdown due to machine failure affect the product quality, customer satisfaction and product performance. However it is important more over difficult to control and decreasing failure due to unplanned failure. This situation gives a big impact since it leads to product defect, decreasing of performance and increasing of maintenance cost. One of the strategies is using the reliability analysis as the medium to develop a proper maintenance. This reliability analysis identified the characteristics of the failure and the reliability of the machine. For this research two method of reliability analysis used are Weibull distribution and failure mode effect and criticality analysis. For Weibull distribution the quantitative data of the time to failure is applied. Time to failure data is the range of time from the first failure to the next failure to happen. Where in failure mode effect and criticality analysis the data used are the failure mode, failure cause and effects and its probability. These data based on failure data provided from three critical machines on the Camshaft line of automotive manufacturing industry in Malaysia. For this reliability analysis, Weibull distribution analysis ends up the results with the state of characteristics and behaviour of the machine failure. State of the failure characteristics are able to use as the guideline for future analysis of proper maintenance development. Moreover, the value of parameter on the characteristics and behaviour of the failure state leads to estimation of mean time to failure. Meanwhile, from the failure mode and failure cause and effects results leads to identification, classification and clarification of the failure mode and its criticality ranks. In the criticality matrix the degree of seriousness for the critical failure mode is more clearly viable. The criticality matrix leads to decision of corrective action taken with the consideration of safety factor and occurrence of failure. Therefore, the combination of reliability analysis and failure mode and failure cause and effects on machine failure presents more clear and specifics results.

CHAPTER 1

INTRODUCTION

This section divided into four sections where it started with an overview of the research background and secondly explanation of the problem statement. Then, the objectives of the research are given in third section. Finally, the focus and limitation of the research are stated on the fourth section.

1.1 Background

Breakdowns or unplanned maintenance happened when the machine unable or fail to perform it intended function. Failure of the machine leads to a stoppage time of a machine and discontinued of production operation. .According to Ebeling (1997) failure of a machine can be defined relatives to the function ability being performed by the system. Increasing failures is effected the reliability on the machine or production line. Furthermore based on Stephens (2004, reliability is the ability of a system to perform its intended function during its expected life period.

Identifying the reliability on the machine are important on producing quality products as being mentioned by Ebeling (1997) a high quality product will have high quality reliability. Consistency and validity of reliability analysis can be determined using the statistical method. For this project the reliability analysis are based on Weibull distribution analysis and failure mode effect, and critically analysis (FMECA). Weibull distribution analysis used industrial failure time data and failure mode effect, and critically analysis (FMECA), using the combination of quantitative and qualitative industrial failure data. Consequently, the results will show characteristics patterns of the failure.

1.2 Problem statement

Machine failure will bring the impact on the operation of the production line. Once a machine breakdown the time consume will affect the cost of the production and delivery time of a product. In manufacturing time consume is money, considering the situation, the reliability analysis need to be develop for enhance the useful life of machine and reliability interrelations between different systems consequently increasing the quality of the operational performance.

In this research, the reliability analysis based on the Weibull distribution analysis is to identify the failure characteristics pattern where else for the failure mode effect, and criticality analysis (FMECA) is used to identify the degree of seriousness criticality on each failure mode. With two method on this reliability analysis a detail and more complete reliability can be determined and use for development of proper maintenance policy to decrease the failure existence on each machine.

1.3 Objective

The objectives of this project remain in three aspects below:

1. To identify the characteristics patterns of the failure based on Weibull distribution method.
2. To identify the criticality of the machine failure based on failure mode effect and criticality mode (FMECA) analysis.
3. To validate the reliability analysis for the above objectives based on real industry data.

1.4 Scope

This project is based on reliability analysis using the quantitative data of time to failure (TTF) based on Weibull distribution. For the failure mode effect, and criticality analysis (FMECA) it used combination of quantitative and qualitative industrial data. The results on Weibull distribution analysis are the two parameter of shape parameter and scale parameter and mean time to failure (MTTF). Where from the FMECA are the criticality index and location of failure mode on criticality matrix identified.

CHAPTER 2

LITERATURE REVIEW

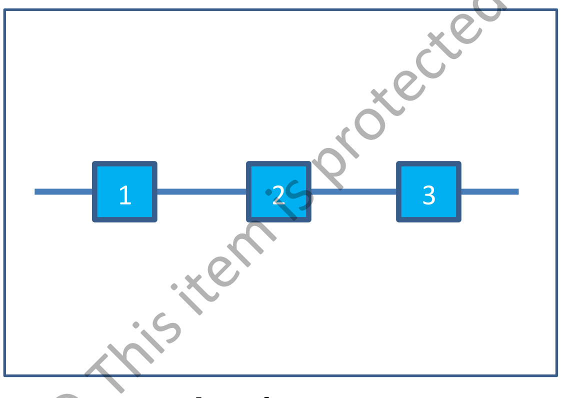
2.1 Introduction

This chapter presents the literature review which covers the topic of machine characteristics, failures category and reliability. For the reliability analysis in the research is based on Weibul distribution analysis and failure mode and criticality analysis. Then, the finding from this literature review is discussed on the last topic.

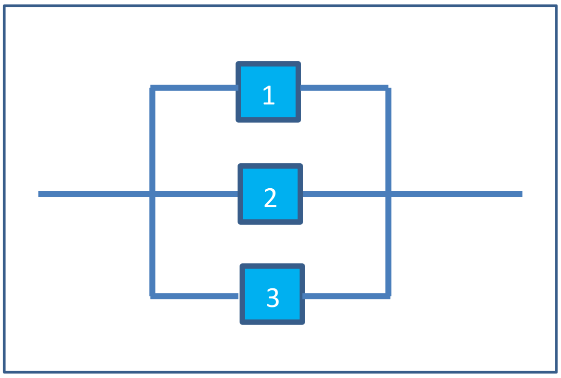
2.2 Machine characteristic

Machine is the device that comprises of the stationary parts and moving parts combined together to generate, transform or utilize the mechanical energy (Sharma and Agarwal, 1997). Generally each machine consist a combination of three components mechanical, electrical and electronic which build a system. A system from the dictionary of engineering defines as a group interacting, interrelated or independent elements forming a complex of whole. According Ebeling (1997) the machine system of these three components may be related to one another in two primary ways, either by serial or parallel configuration with typical system contains both serial and parallel relationship.

For serial configuration as shown on Figure 2.1a configure if a failure of one component to function affected the system to function. It's being informed by Laggoune et al. (2009) considering a system composed of a set of q components arranged in series, the failure of any component leads to the failure of the whole system. On the other hand, figure 2.1b shows for the parallel configuration where at least one component must functional for the system to function (Ebeling, 1997). This has being explained by Alsalamah (2005) if one section or pipeline is closed for maintenance, a reduced supply of water be able through other sections or pipeline. Meanwhile, in industry, most machines were designed in serial configuration. Hence, if any of the components failed in serial configuration caused the machine or the whole system breakdown.



a. Serial configuration



b. Parallel configuration

Figure 2.1: System configuration

Machine breakdown are due to unplanned maintenance or presents of any failure on the system as Liberopoulos and Tsarouhas (2004) mentioned when an unexpected failure occurs, the failed equipment stops (breakdown). Failure of the machine is influenced by two factors which are the physical failure and functional failure. Details of the factors are explained in following section.

2.3 Failure category

As being mentioned on the above section machine or component failure is categorized into two factors which are the physical failure (PF) and functional failure (FF) (Ahmad and Kamarudin, 2012). Failure defined by Stephen (2004) as any deviation or change in a product or a system from its satisfactory working condition to a condition that is below the acceptable or set operating standard for the system.

2.3.1 Physical failure

Physical failure (PF) is defined as structural damage that occurs when a material is subjected to force, loading or cyclic motion. Wear and burning of the lining layer are the frequent failures of journal bearings due to abnormal hydrodynamic condition, cause shutdown or even catastrophic accident to machinery (He et al. 2013). Meanwhile, Ahmad and Kamaruddin (2012) presented that the component is considered failed when the function of the component is terminated due to physical damage.

2.3.2 Functional failure

From the web exprobase.com functional failure (FF) being defined as non-fulfilment of wanted component function which divided into three categories of wrong functional structure, failure mode and interface disturbance. Furthermore the failure mode effect and criticality analysis during detail phase is based on failure mode analysis. According to Ahmad and Kamaruddin (2012) the component is considered failed when its performance does not reach the required level. Meaning that, although the component or the machine still functional but the performance may produce such quality not satisfied the required specification or customer requirements.

In conclusion failures will leads to the cessation of component or machine reliability. Furthermore, has being discussed reliability analysis paper by Alsalamah, (2005) failure of the component on the pipeline will affect the reliability of the system.

2.4 Reliability

Reliability means the ability of the component to fulfil what is required on a component application (Crowder et al, 1991). Meanwhile, in the guide to finding and using reliability data for Quantitative Risk Assessment, (2010) reliability is defined as the probability that equipment will perform a specified function under stated conditions for a given period of time. Furthermore, Eliashberg et al. (1997) presents reliability is measured in different unit of time such as operating time, cycle time, working shifts, working days or some other units of time studied the models and evaluated reliability as a function of time and usage. Where, presented by Ghodrati (2005) the basic measurement of reliability is the failure rate, where high component failure rate means lower reliability.

In maintenance, reliability analysis is the component failure characteristic can be represented by the random variable *T* (time to failure) and it can be formed into different failure functions shown in Table 2.1.

Table 2.1: Failure time function [Ebeling, 1997]

Failure Function		**Description**
Cumulative distribution function *(CDF)*	$F(t) = 1 - R(t) = Pr\{T<t\}$ (Probability of the failure occurs before spesified time, *t*)	Presents the failure distribution in cumulative form
Probability density function *(PDF)*	$f(t) = dF(t)/dt = -dR(t)/dt$	Interpret the shape of failure distribution
Failure rate or Hazard rate function	$\lambda(t) = f(t)/R(t)$	Characteristics of failure distribution identified whether in decreasing failure rate *(DFR)*, constant failure rate *(CFR)* and increasing failure rate *(IFR)*

Based on Table 2.1, the first failure function is Cumulative distribution function (CDF), *F(t)* represent the failure distribution of component in cumulative form. For Probability density function (PDF), *f(t)* describes the shape of the failure distribution such as Exponential, Lognormal, Normal and Weibull distributions. Finally, is the characteristics of failure distribution can be determined using Failure rate or Hazard rate function, $\lambda(t)$ whether the distribution of the failure laid on state of decreasing failure rate *(DFR)*, constant failure rate *(CFR)* and increasing failure rate *(IFR)*. Moreover, different reliability models interpreted differently for each of these failures functions.

2.4.1 Reliability analysis

The failure time (failure distribution) of a component can be modelled using different reliability models such as Exponential, Lognormal, Normal and Weibull models. For constant failure rate exponential distribution is used. According to Ebeling (1997) the exponential distribution is important model used in electric and electronic component failure time. Whereby, modelling failure time with increasing failure rate for fatigue and wear out used Normal and Lognormal distribution (Ebeling, 1997). Jianqiang and Keow (1997) used the Lognormal distribution to fit the failure time of cutting tool for the purposed of determination the best replacement interval. Recently, Tsarouhas (2011) review paper presented many researches due to a lack of failure and repair data, consider the probability of failure analysis on the system follows the exponential, Weibull and rarely the poisson distribution.

2.4.1.1 Reliability analysis using Weibull distributions

Brabadi (2013) presented the most popular reliability models in maintenance application where Weibull distribution is one of the most commonly used models for life data analysis due to its versatility. Xie et. Al (2000) used the Weibull distribution to model the lifetime of the component system for maintenance time determination. Lin and Titmuss (1995) used the Weibull distribution to estimate time of component replacement for age replacement maintenance.

In addition, the main purpose of failure time distribution using Weibull model is to determine the two parameters. The two parameter are the shape parameter β and scale parameter θ. The shape parameter β, refers to the characteristics of component life time whether in state of decreasing failure rate, DFR, constant failure rate, CFR or increasing failure rate, IFR on the bath tub curve as shown on Figure 2.2. Liberopoulos and Tsarouhas (2005) computed the parameter of Weibull distribution that fit the failure data on their study of the statistical analysis of failure data of an automated pizza production line.

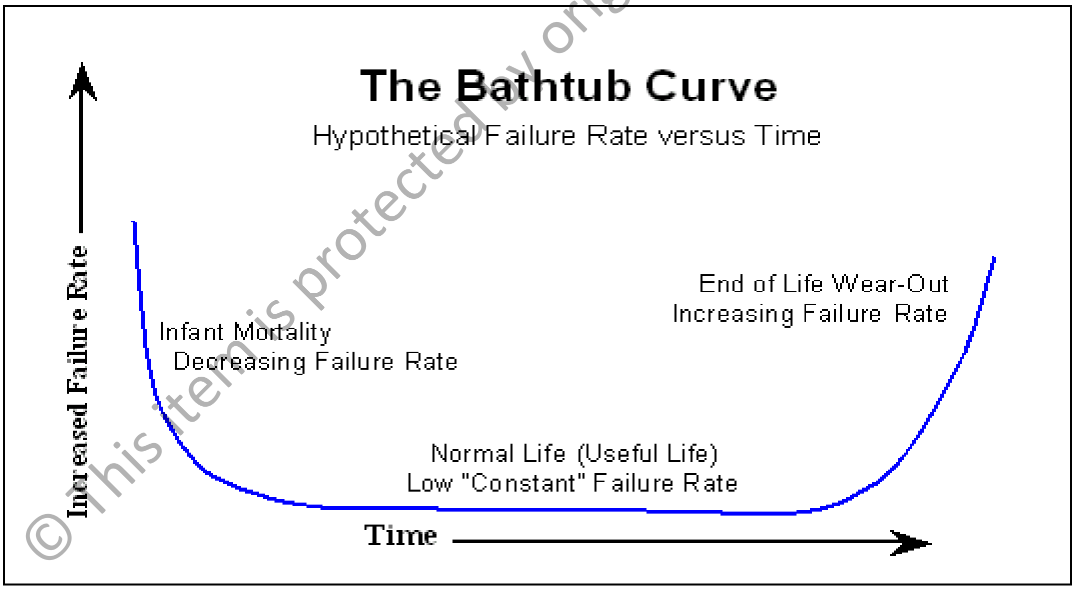


Figure 2.2: Bath tub curve [references Weibull.com]

The characteristics of component lifetime can be identified based on the different value of β, in Table 2.2. Beta, β in Abernethy (2001) determines which member of Weibull family of distribution is most fits or describes data.

Table 2.2: Characteristics of shape parameter, β

Parameter	**Rate**	**Property**
β	**< 1**	**Decreasing Failure Rate (Infant Mortality)** **(DFR)**
β	**= 1**	**Constant Failure Rate** **(CFR)**
β	**> 1**	**Increasing Failure Rate (Wear Out)** **(IFR)**

From Table 2.2 based on Warwick Manufacturing group (2007) explained a β value less than unity indicates the item or failure mode may be characterised by the first regime of decreasing hazard or failure rate known as infant mortality state in which the instantaneous probability of failure is decreasing with time in service. The group also defined the cause of this failure into two classifications. First, such failures may result from poor quality control on the manufacturing process or other mechanism which permits low quality components. The second cause is an inadequate standard of maintenance activity. Meanwhile, Abernethy (2001) defined $\beta = 1$, as random failure with an identical to the exponential distribution. The author mentioned that the MTTF is equal to θ where it presents the relationship of between θ and MTTF is a gamma function equation as shown below;

$$\text{MTTF} = \theta\Gamma[1 + 1/\beta] \tag{2.1}$$

Where from the formula above, the MTTF indicates the average time to failure of a component or machine in the system. Furthermore, If the Weibull shape parameter greater than one Arbenethy (1993) implies as wear out due to many mechanical failure mode. It means increasing probability failure of age, therefore decreasing the reliability. Such state refers to pumps having bearing and seal failure and from Weibull database (Appendix A) bolts indicates β = 10, pumps β = 6 and coolant β = 2.

The scale parameter θ, known as the characteristic life time of the units. The parameter θ is equal to the duration of useful time that is 63.2% of failures approximately will have occurred at the machine (Abernethy, 2001). Dodson (1994) developed failure model using the Weibull distribution which established the optimum interval between preventive maintenance action as a function of scale parameter of Weibull and tabular values based on Weibull shape parameter.

These reliability analysis is for the quantitative or numerical failure else the combination of quantitative and qualitative failure data used in reliability analysis using the Failure Mode Effect and Criticality (FMECA).

2.4.1.2 Failure Mode Effect and Criticality (FMECA)

FMECA is designed to analyse all sorts of the potential failure in each component, and by analysing and computing criticality, FMECA can determined the possible failure and its effect, its equipment in design manufacture and use process as to puts forward improvement. Jun and Huibin (2012) aiming at the plane-carried equipment of a certain type of aircraft and applying FMECA, conducted its reliability modelling and prediction of average of operational time. It's being developed originated in United States in 1950's where at first called failure mode effect analysis (FMEA). It's officially in Apollo program in the USA's aerospace industry in the mid of 1960's (Chen et. al, 2012).

FMECA has related standard divided into two, military and civilian standards. The MIL-STD-1629(A) represents military standard and civilian standard, such as QS9000 and IEC60812 (Chen, et al, 2012). Wei (1991) mentioned the aim of FMECA is to provide a systematic, critical examination of potential failure modes of plants and equipment and their causes, to assess the safety of various system or components.

Failure mode effects, and criticality analysis (FMECA) is a procedure that follows failure mode and effect analysis and where in each potential failure effect is classified according to its probability of occurrence and degree of severity. Failure mode defined as observable manners in which a component failed by (Ebeling, 1997). As for Borgovini et al (1993) defined the way on which the failure is observed, describe the way the failure occurs, and its impact on equipment operation. Where failure effect defined as the consequences a failure mode has on the operation, function, or status of an item (Wei, 1991). For example Ahmad et al (2012) states in FMECA results table, the loss of grip as a failure mode and the pulley of the cutting knife cannot move properly, thus degrading the cutting process (leading to product quality problems) as the failure effect for the critical component of transmission belt.