DEVELOP EFFECTIVE DECISION MAKING FOR REMANUFACTURING AUTOMOTIVE COMPONENTS

RDU 170387

DR MOHD YAZID BIN ABU

Faculty of Mechanical and Manufacturing Engineering

UNIVERSITI MALAYSIA PAHANG

April 2019

ABSTRACT

Remanufacturing is a process that returns the second-hand product that have the performance is similar or better that the new product. The remanufacturer cannot be predicting the end of life (EOL) of crankshaft to remanufacture, repair or reject due to the limited information provided by Original Equipment Manufacturer (OEM) which depend on a traditional inspection to make a decision. Subsequently, Traditional Cost Accounting (TCA) which the manufacturing overhead are driven by the production volume are being applied. The aim of this work is to develop a distinctive pattern of crankshaft and identify the critical and non-critical parameter of crankshaft based on the Mahalanobis Taguchi System (MTS), then applied the Activity Based Costing (ABC) as a method of estimation for the remanufacturing cost of crankshaft. In methodology, the scatter diagram is construct to develop the pattern recognition using T Method-3, Taguchi orthogonal array (OA) are applied to identify the important parameter using T Method and lastly, the ABC system is analysed the costing of critical parameters. Based on the MTS method, the EOL of crankshaft can be classified into 3 categories which are remanufacturable, rejected, and repairable. In this work, the MD of Mtu183 engine model were developed from 0.003165 to 0.005667 whereby for Man engine model were developed from 0.386108 to 2.004725. Hence, when apply Taguchi's orthogonal array, it shows there are 2 critical and 4 non-critical of crankpin whereby Man has 3 critical and 3 non-critical crankpin diameters of crankshaft. Lastly, when ABC is integrated with MTS method, these combinations produce the cheaper price compared with ABC integrate with traditional cost. The cost of combination MTS method with ABC are Man (MYR738.13) and Mtu183 (MYR687.90) compare with ABC with traditional which are Man (MYR800.01) and Mtu183 (MYR754.37).

ABSTRAK

Perkilangan semula adalah proses yang mengembalikan produk terpakai yang mempunyai prestasi yang sama atau lebih baik dari produk baru. Pengeluar semula tidak boleh meramalkan akhir hayat (EOL) untuk dikilangkan semula, dibaiki atau dibuang kerana maklumat terhad yang disediakan oleh Pengeluar Alatan Asal (OEM) yang bergantung kepada pemeriksaan tradisional untuk membuat keputusan. Selain itu, Kos Perakaunan Tradisional (TCA) yang mana overhed pengeluaran didorong oleh jumlah pengeluaran yang sedang digunakan. Matlamat kerja ini adalah untuk membangunkan corak tersendiri "crankshaft" dan mengenal pasti parameter kritikal dan tidak kritikal berdasarkan Sistem Mahalanobis Taguchi (MTS), kemudian menggunakan Aktiviti Berdasarkan Kos (ABC) sebagai kaedah penganggaran untuk kos pengilangan semula "crankshaft". Di dalam metodologi, rajah berselerak dibina untuk mengembangkan corak pengiktirafan menggunakan T Kaedah-3, ortogon Taguchi (OA) digunakan untuk mengenal pasti parameter penting menggunakan T Kaedah-1 dan akhirnya, sistem ABC digunakan untuk menganalisis kos parameter yang kritikal. Daripada kaedah MTS,EOL dapat mengklasifikasikan untuk dikilangkan, dibaiki atau dibuang mengikut nilai MD untuk enjin model Mtu183 yang didapati iaitu daripada 0.003165 ke0.005667 manakala untuk model Man ialah daripada 0.386108 ke 2.004725. Oleh itu, daripada kaedah OA, terdapat 2 parameter kritikal dan 4 parameter tidak kritikal untuk enjin Mtu183 manakal didapati 3 parameter kritikal dan 3 parameter tidak kritikal untuk enjin Man. Akhirnya, apabila MTS digabungkan dengan MTS, gabungan ini akan membuatkan harga "crankshaft" makin murah daripada kos tradisional . Kos untuk gabungan ABC dan MTS ialah Mtu183 (RM687.90) dan Man (RM738.13) manakal untuk gabungan ABC dan tradisional ialah Man (RM800.01) dan Mtu183 (RM754.37).

TABLE OF CONTENTS

LIST OF TABLES

UMP

LIST OF FIGURES

LIST OF SYMBOLS

$\bar{x}$	Average
β	Sensitivity
η	SN ratio
L	Linear expression
ST	Total variation
Sβ	Variation of proportional item
Ve	Error variance

LIST OF ABBREVIATIONS

ABC	Activity Based Costing
EOL	End-of-life
OA	Orthogonal array
MS	Mahalanobis Space
MTS	Mahalanobis Taguchi System
MD	Mahalanobis Distance

CHAPTER 1

INTRODUCTION

1.1 Introduction

The Great Depression in the 1930 at USA can be used as a term for remanufacturing (Gray, 2007) and from the past years usually has received increasing attention in the world. The percentage for increasing the number of yearly published scientific paper is 166 % during the year 2009 to 2014; the triplication was found the CIRP community at the same time. There is long tradition of remanufacturing which are capital intensive and life expectancy (Seliger, 2007). Besides, this tradition can be achieved where the average cost reduction is lower than average cost new production which is 45 to 65%.

The concept of remanufacturing can be described by USIT, 2012 when the end-of-life (EOL) is restore by industrial process to be good same as original working. In globally, remanufacturing is widely used in sector of automotive part and also automatically product, heavy earth movers, compressor, aerospace and aircraft. These part in that sectors will get worn out during operations and eventually half of these parts is static motionless supporting parts So that, the remanufacturing process has five phases which are disassembly, inspection, cleaning and refurbishing, assembly and final testing (Steinhilper, 2001; Lindahl, 2006; Matsumoto and Umeda, 2011). However, when the product is disassembled, before worn out the parts, those must be clean and examine. So, it can be decided a decision either to replace new parts or refurbished.

In addition, the remanufacturing is not only give profit for all company and business, but also for the environment and customers. The advantages for remanufacturing concept are this concept must provide a cheapest price of product quality than a product which is not remanufactured, less using raw materials, reduce waste and also high financial saving. According to Snodgress, 2012, remanufacturing, can save up to 85% raw materials, the consumption of electrical and thermal energy can reduce by 60 to 85%, less water is used by 90% and also the greenhouse gas emission can be avoided according (Gray ,2007). It is also reduced the impact of environmental considerably.

The crankshaft is a very complex system which consist of the parts of connecting rod, piston, damper, flywheel and bearing. The crankshaft has two types which has the motion either to convert circular to reciprocating motion or vice versa. The application that related from water powered saws based on the combination of crankshafts with linking rods for cutting rectangular blocks of stone to modern internal combustion engines. Hence, the crankshaft in needed in this application because to translate the motion of piston from reciprocating into rotation. Therefore, these components must do preventive maintenance and repair to avoid the surface had worn. There are two causes that had worn which had depend on the shaft neck uneven stress and oil of impurity.

The concept of MTS can be defined when the multivariable data sets are collected are large number and followed by separation of data which consist of healthy data sets and unhealthy data sets. There are four phases that can be summarized of MTS which are construction of MTS, the validation of Mahalanobis Space (MS), identification of useful characteristic and making the decision. For the phase 1, it can be summarized when observed the characteristic of healthiness data and the value of MD is calculated by using all formula include formula MD, mean, standard deviation, normalized data matrix and matrix element. Besides, for the phase 2, it can be explained when observed the normal data group is selected and calculated the value of MD. So that, after calculation it can prove when MS is suitable for the application when MD value of abnormal group is higher than normal group. Moreover, for the phase 2, it is about the right set of characteristics can be determined by using two ways which are Orthogonal arrays (OAs) and signal-to-noise ratios (S/N). For phase 4, making decision is most important when MD value is less than an equal by 1.

Therefore, related to MTS, there are many benefits that can get from MTS system which are can increase the accuracy of product, can reduce the high measurement, can maintain the inspection of accuracy level and so on.

Last but not least, the concept of ABC system which is overhead cost can divide into various cost pool. The dividing of cost pool consists the cost related activities that use up by product and it is distributed to product by using unique factor that approximate the consumption of cost. This system can improve accuracy of product cost data. There two stages of ABC system which are resource cost and activities cost. The aim for resource cost to determine what and how much activities consume company's resource and the activities cost is depend on how much cost to produce the product based on the activities not volume-based quantities. A part from that, there are many benefits for this system which can provide more relevant information about economic consequence, reduce the non-value-added activities, and offers cheapest labor cost based on product costing.

1.2 Problem Statement

There is no optimization process which concern a critical parameter of crankshaft during grinding process of remanufacturing. Meanwhile, this issue provides many wastes in term cost, quality and time.

In addition, in the current practice by most of remanufacturers worldwide assume that the manufacturing overhead of the company is depend on the volume of production. As a result, inaccurate cost of remanufactured product normally produced. In order to get the accurate manufacturing cost per unit, the overhead cost must be considered the number of activities needed but not the number of part produced.

By considering non-critical parameters and volume-based costing, it can produce inaccurate profit margin estimation and incorrect decision either to remanufacture or reject the remanufactured product.

1.3 Research Objectives

The research objectives were listed below:

i. To identify critical parameters during grinding process using MTS.

ii. To estimate cost of remanufactured crankshaft using ABC concept.

iii. To make a decision which is 40% cheaper than original price either to reject or remanufacture crankshaft based on remanufacturing requirements.

1.4 Research Scope

The research scope was listed below:

i. The pattern recognition was analyzed using T method-3, identification of important parameters was done using T method-1 and the costing was analyzed using ABC system.

ii. The standardized crankshaft engine models were limited to six; Caterpillar, Detroit, Hatz, Man, Perkins, and Mtu183.

iii. The costing was focused on remanufacturing process only.

1.5 Significant Studies

It is hoped that the finding of this research study will help to reduce all the categories wastes including transportation defects of product which do not conform by quality, inventory used more space to store the product, overproduction of product, motion and extra processing to produce the product. In practically, ones of the categories will show the high positive impact when do the remanufacturing crankshaft such as overproduction of the product. This is because when the company in the worldwide do the right decision so that the remanufacturing crankshaft will avoid overproduction of product.

Relation to this research, when ABC system is practically do in the real environment in the factory, there are many advantages that will get from this system such as get better management decisions, enhanced control over overhead cost and use of more cost pools to assign overhead cost. So that, ABC system is more better system than volume-based costing concept.

The profitability is the primary goal of the primary goal of all business ventures. Although, the price of remanufacture crankshaft is 40 % cheaper than original price, this factor will not give effect for profitability because when do the remanufacture of crankshaft, it will give benefit in term of extended life of crankshaft that already had.

1.6 Organization of Thesis

Chapter 1: Introduction

This chapter is explained about the detail information of introduction of project, problem statement, research objectives, research scope and significant studies.

Chapter 2: Literature Review

This chapter is discussed a literature study which consist of history of MTS and ABC system, concept of MTS and ABC system, the advantages and limitation of ABC system and MTS and also provide formula of MTS. In further detail, this chapter also discuss the issue, application and all the results that are related to the MTS and ABC system.

Chapter 3: Research Methodology

This chapter is exposed the detail of research methodology of ABC system and MTS that are related to remanufacturing crankshaft. This method has four stages that consist of problem definition, data collection, data analysis and conclusion. Besides, this methodology also discussed the detail analyzed method which are T-Method 1, T- Method 3 and ABC that are related to this project.

CHAPTER 2

LITERATURE REVIEW

2.1 MAHALANOBIS TAGUCHI SYSTEM (MTS)

2.1.1 Concept of MTS

P.C Mahalanobis is a very famous statistician at India who was established of the concept of Mahalanobis Distance (MD). The MD concept can be used when the calculation of two unknown is similar with spatial orientation which far apart located (Feng et al, 2011). MTS is a set of multivariate data which a large number that separate the normal data set (heathy) and abnormal data set (unhealthy), (El-Banna, 2014). MD can calculate and scale by using the healthy data set and also by serving as baseline metric. Hence, divide the number of features that used in MD calculation will get the analysis of scaling the MD. Therefore, the scale MD of average length is approximately close to the one it is known the healthy data set. Subsequently, when the MD is larger than one it known as unhealthy data sets. The feature of multivariable data is good or not is depend on the amount of data which multivariable. If the higher number of multivariable data approaching in MTS, the good and important features. Therefore, if larger MD scale, the highest rank of important features in MTS.

There are four steps to summarize the MTS as below:

1. Data is partitioned into two set which are validation and training. Both of sets must be partitioned which consist of normal (healthy) and abnormal (unhealthy) sets.

2. Using following training data set:

a. The healthy data is calculated by using MD scale.

b. The calculation of unhealthy data is same as the MD scale of healthy data. This MD scale is calculated test the sensitivity of the MD measure.

3. There are two experiment which Taguchi and orthogonal array is applied which to increase the MD scale of unhealthy data. This aim of both experiment is to make features of screening process.
4. The classification of validate or not is depend on performance of MD. If the result of screening process shows the maximum MD, the unhealthy data is valid.

The main reason MD is used due to its sensitivity towards inter-variable changes in data. The reasons that still used classical methods because the variance and covariance are depend the data rather than average, which makes the calculations robust. The differentiate the normal group from an abnormal group by using MD according (Mohan, Saygin, & Sarangapani, 2007). The others characteristic will be explored when the MD fail to detect the unhealthy group using particular characteristic. So, the Taguchi is applicable applied when the right characteristics is known also the calculating of MD are determined. The evaluation for the contribution of each characteristic possible to reduce the number of characteristics. To choose the best variables that is important, it can be implement the Taguchi method which is used the orthogonal arrays and signal-to-noise ratios. According to (Mohan et al, 2007), Mahalanobis Taguchi System has four phases which are:

Phase 1: Construction Mahalanobis Taguchi System

- Determine and define the characteristic of normal data which has healthiness characteristic.
- Mean can be calculated to known the characteristic of ideal set of data.
- The value of standard deviation is calculated for each characteristic.

- The normalized data matrix (Zij) and transpose (ZTij) are formed to get the normalize each characteristic.
- The value of zero known as normalized data.
- The standard deviation is one.
- The correlation matrix (C) is formed and the matrix elements (cij) is calculate for the normalized data.
- Then, the inverse of the correlation matrix (C−1) must be calculate.
- Calculate MD:

Phase 2: Validation of Mahalanobis Space

- Based on the observation of normal group which selected data, the MD value can be calculate respectively.
- To differentiate the characteristic of normal group and abnormal group, standard deviation and mean can be as the correspond characteristic.
- When the abnormal case has in the MDs computation, this case will use the method correlation matrix.
- When appropriate characteristic is selected, the MS is suitable for the application domain and MDs corresponding to the abnormal group will get the higher value than that of the normal group.

Phase 3: Identification of useful characteristics

- Based on the method of orthogonal arrays (OAs) and signal-to-noise ratios (S/N), this method will be determined the right or wrong the characteristic of data set.

- The signal-to-noise ratio, obtained from the abnormal MDs. There is used for the response for each combination of OA.

- Orthogonal array can be described when a table listing all the combinations of the characteristics.

- Orthogonal array can be represented as level-1 whereby level-2 represents the absence of that characteristic.

- There are two criteria which size of orthogonal array will small or large is depend the level and the numbers of characteristic.

Phase 4: Decision making

- Abnormal behavior can be determined when MD>>1, so to determine the MD value, there are three rules must follow which are characteristic of important will construct, application must always monitor, and data must be collect.
- When the MD of the current application falls, it can determine under MD range, and then take the respective corrective action.
- The lower the MD value, the better and normal the condition of data. So, the data must be range in MD ≤ 1.

Based on the 4 phases in MTS, there is clearly stated the normal and abnormal condition are depend on value of MD. The lower the MD, the less of corrective action.

2.1.2 Advantages and Limitations of Mahalanobis Taguchi System

The MTS is a famous system that used to evaluate and minimize in quality engineering. So that, there are advantages and limitation for these systems listed in Table 2.1 below:

UMP

Table 2.1: Advantages and Limitations of MTS

Advantages	Limitations
• To increase the accuracy of the product. (El-Banna, 2014)	• Hardly applicable. (Liparas, Angelis, & Feldt, 2011)
• The MTS is a dimensionless. (Srinivasaraghavan & Allada, 2005)	• The lack of explanation for using the MTS measurement scale. (Liparas et al., 2011)
• To accounted of the average value, varience, and covariance of the variables measured.(Srinivasaraghavan & Allada, 2005)	• The lack of an operational definition that specifies the criteria for determining if the MDs for the abnormal observation are higher than the MDs for the normal observation.
• To accounted the for ranges acceptability of varience between variables.(Srinivasaraghavan & Allada, 2005)	• The lack of explanation using the MTS measurement scale.
• Reduce the high measurement and maintain the inspection of accuracy level.	• The use of fractional factional design to reduce the number of runs.

The limitations of MTS will become advantages when improving this method based on the limitation such as the researcher must be provided more explanation about MTS measurement scale, so it is easier for a company to improve system in their company.

UMP

2.1.3 Issues in Mahalanobis Taguchi System

There are many issues that are related to MTS. Table 2.2 is shown all the issues that is related to MTS.

Table 2.2: Issues in MTS

Author	Method	Issue	Result
Su and Li (2002)	-MTS	An automatic method for establishing a threshold based on statistical concepts	MTS and ANN were used for classification and forecasting and application of the reduced models were compared with the complete model to show the robustness of models
Wang et al. (2004)	-MTS	It is the case when there is multivariable data	MTS had better performance in comparison with linear discriminant analysis method.
Yang & Cheng, (2010)	-MTS	The bump height efficiency problem.	MTS is used to reduce measurement point of the bump height that will also maintain the accuracy of inspection level.
Feng et al. (2011)	-MTS	To describe the welding fault.	The flow rate will change is depend on type of contact tips, shielding gas and also arc voltage. So, the weldments that do not have any fault will guide and monitor new weldments to avoid any fault in welding process.
Liparas et al (2013)	-MTS -Mahalanobis Space	Using clustering method for selection of normal items for the Mahalanobis space	The cluster that leads to minimum overlapping was selected
Wang et al. (2013)	-MTS -X bar control chart	X bar control chart was used in order to select normal items	Narrower control limits had a better effect on the case study. Using the variables that led to a higher gain does not always cause the best performance

El-Banna (2014)	-MGA -MTS -Synthetic Minority Over Sampling (SMOTE)	Imbalance data for spot welding.	Avoid non-added value activity and increase productivity.
(John, 2014)	-MTS -Pareto chart	Field failures of splined shaft.	Critical characteristic is identified and carried out the usage of profile analysis.
N Deepa and K Ganesan (2016)	-MD -Taguchi -Matlab	Agriculture crop selection cannot be formulated from one criterion but from multiple criteria.	Combination of Mahalanobis Distance and Taguchi method is used to recognize the important criteria.
Haldar, Khan, Ali, and Abbas (2017)	-MTS -Principal component analysis (PCA) -Fuzzy C-Means System	Classification of arrhythmic will reduce is depend on setting attributes of ECG.	Experiment result show Fuzzy C-Means is better than conventional FCM.

2.1.4 Application of Mahalanobis Taguchi System

Table 2.3 is shows the application of MTS and also the results of when apply MTS method in different work environment.

Table 2.3 : Application of MTS

Author	Application	Result
Cudney et al. (2006)	Vehicle handling	Consumer satisfaction rating was predicted using the reduced model and regression analysis
Su and Hsiao (2007)	Mobile phone manufacturing	Superiority and robustness of MTS in comparison with other classification methods were identified
Cudney et al. (2007)	Medical diagnosis	Smaller data sets

	(breast cancer)	lead to high performance of MTS in comparison with ANN. The time to reach the results in MTS is less than ANN
Das and Datta (2007)	Hot rolled steel production	Used ideal mechanical properties
Mohan et al. (2008)	Fastening a handheld pull-type pneumatic tool	Application to online quality control
Khanzode and Maiti (2008)	Casting	MTS was implemented to determine the variables which have the largest impact on the response
Lee and Teng (2009)	Economics	The accuracy of MTS was compared with logistic regression and artificial network and MTS was introduced as an operational method
Pal and Maiti (2010)	Foundry process control	The proposed method leads to higher SN ratios and cost based weights were used to show the importance of classification errors
Su et al. (2012)	Obstructive sleep apnea	MTS was compared with other common methods and superiority of MTS was proved
John (2014)	Splined shaft	Identifying the critical characteristic that lead the failure of splined shaft and used the profile analysis.

Based on the application and the results above, MTS method is good and suitable to apply in all different wok environment and also will give the better system.

2.2 ACTIVITY BASED COSTING

2.2.1 Introduction

The ABC was established by Kaplan and Cooper of Harvard Business School in the 1980s, there is no confirmation to use this term which is ‘‘Activity-Based Costing’’. Traditional full costing and variable costing will be obsolete in modern manufacturing environment and cause the dissatisfaction of dominate cost at that time. (Cooper and Kaplan, 1988a). A series of ‘‘innovative action research cycles’’ (Kaplan, 1998) is ventured by Robert S. Kaplan and Robin Cooper during 1987 to 1992 based on ABC concept to develop. Subsequently, Kaplan and Cooper to improve full-cost product calculation, the cost objects and the hierarchy of the activities will make the model grew into a more full-fledged Moreover, accuracy of the product cost will be improve when using the ABC system whereby the traditional cost system can be define as distribution the overhead cost over the product based on the volume based which many types direct labor cost such as for material, machine, and hours. Therefore, no problem is detected when distort the product costs in the traditional manufacturing environment. Based on the promotion of automation and computerization, the environment in manufacturing will grow rapidly because of profitability to get among the remanufacturers.

Based implementing of the promotion project in the 1980s, there are many organization which grows rapidly which ABC system such as Computer Aided Manufacturing-intemationsl (CAM-I) and the National Association of Accountants. ABC has been applied to various industries such as electronics (Merz, 1993), auto (Miller, 1994), aerospace and defense (Moravec, 1992), aircraft (Haedicke, 1991), shipbuilding (Porter, 1993), chemistry (Morris, 1993), printing (Rodgers, 1993), airline (Banker, 1993), insurance (Newberry,1994), banking (Isaac, 1993), telecommunication (Gwynne, 1993), and health care (Carr, 1993). Product design by ABC (Bartleyy, 1991), improvement of efficiency (Cashell, 1992), measurement of performance (Greene, 1990), reduction of set-up time (Hedge, 1992), analysis of product-mix (Tsai Wen, 1991), environmental quality management (Russell, 1993), measurement of quality cost (Tsai Wen, 1994), and budgeting (Connolly, 1994). Besides, ABC has also been used to analyze the costs of non-manufacturing functions of companies such as, purchasing (Roehm, 1991), information system (Menzano, 1991), R&D, innovation and payroll (Pederson, 1991), and marketing (Lewis, 1991).

2.2.2 Concept of Activity Based Costing

In the early ABC systems, overhead cost is divided into various cost pools, where each cost pool contains the cost of related activities consumed by products and is distributed to products by using a unique factor that approximate the consumption of cost. This unique factor, called as allocation basis in the traditional cost system, maybe volume-related and volume-on related. So that, the volume-related is including direct labor hours and machine hours and the volume on related such as number of orders, setup hours and number of inspection. The early ABC system improves significantly the accuracy of product cost data.

There are two stages of ABC which listed below:

Stage 1: Resource

- Activities is assign as resource cost which that the resource drivers are the factors chosen to approximate the consumption of resources by the activities.
- An activity cost pool is the total cost associated with an activity.

Stage 2: Activity

The distribution of activity driver is depending on the activity cost pool. The aim of activity cost pool is to measure all the activities that consumed by the product.

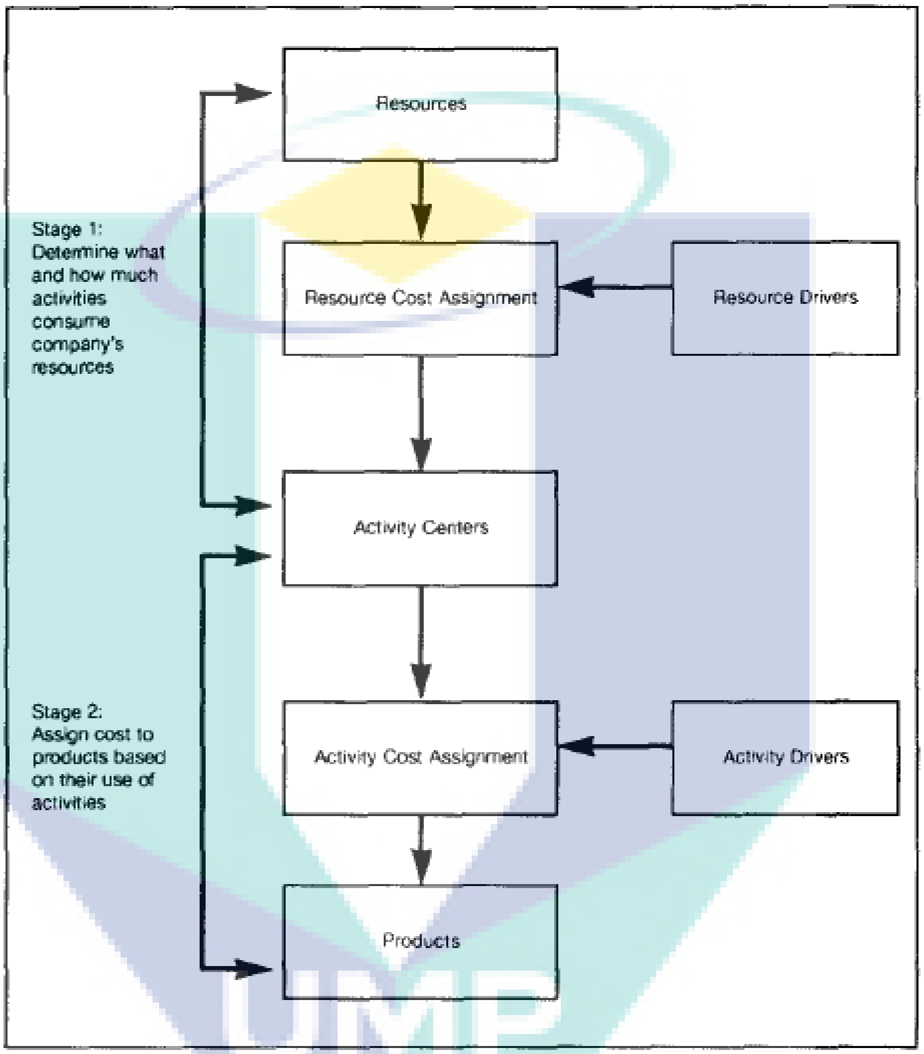


Figure 2.1: Activity Based Costing information system

2.2.3 Advantages and Limitation of Activity Based Costing

There are many approaches of advantages and limitations of ABC system. Table 2.4 is shown the advantages and limitation of ABC.

Table 2.4: Advantages and Limitation of ABC

Advantages	Limitation
• Become more effective and efficient to help the firm successful in worldwide. • Spend the resource to provide a clear picture and customer value is being created and either to make or lost the money. • To get a better alternative to labor-cost-based product costing. • Identifies value-added activities. • Eliminates non-value-added activities. • To get more relevant information for evaluating the economic consequences of resource-allocation decisions. • To get more accurate product-cost information for evaluating the profitability.	• Hard to define the output. • The cost driver and activities are not determined straight forward in many cases. • Data collection and measurements is more complicated than manufacturing. • Less predictable of service request of activity in response. • Difficult to link the output activities is a high portion of total cost that is represent by joint capacity. • Usefulness of supporting short-term decisions

ABC system is good to apply, because this system will give the accurate product cost also will help the company become successful and get more profit rather than loss of profit.

2.2.4 Comparison of Activity Based Costing and Traditional Cost Accounting (TCA)

ABC system is better than TCA system. So, Table 2.5 is shown the comparison of ABC and TCA system.

Table 2.5: Comparison ABC and TCA

	ABC System	TCA System
Cost Driver	As many as needed	Material, cost, machine hours, or labor hours.
Capacity Expenses	Practical capacity	Budget by production volume
Cost Classification	Variable costs	Variable and fixed costs
Expenses	Partially absorbed	Fully absorbed
Depreciation	Machine hour-usage	Straight-line
General, Administrative, Marketing, and Selling Expenses	Assigned to products	A period expense
R&D Expense	A period expense to products	A period expense
Cause of Costs	Depend on activities	Depend on products
Main Purpose	For product costing	For financial reporting

Source : Rafati & Poels (2016)

Based on the comparison, it is clear stated ABC system is better than TCA system in all the comparison. This is because ABC will provide the detail information of cost driver as much as possible to get the accurate product costing.

2.2.5 Application of Activity Based Costing

There are many applications that can prove the ABC is better than TCA. Table 2.6 is shown the application of ABC.

Table 2.6: Application of ABC

Author	Application	Issue
Kim (2002)	Hybrid genetic algorithm and neural network	There are no general criteria of ABC to select relevant cost drivers
Thyssen (2006)	Product Modularity	The decision maker is telling that result the comparison of variable cost of the multipurpose module and average variable cost for the product-unique module are carried out by ABC analysis.
Baykasoglu (2008)	Land transportation company	Difficult to determine and evaluate true cost
D.Banker (2008)	World Class Manufacturing practices	There is no significant direct impact of ABC on plant performance, as measured by improvements in unit

		manufacturing costs, cycle time, and product quality.
Qian (2008)	Design and development of rotational parts	Presents a cost-estimation model that ABC with parametric cost representations of the design and development phases of machined rotational parts.
Lin (2012)	Financial performance and customer service	Explore the relation between financial performance and customer service.
S.Maiga (2014)	Assessing self-selection and endogeneity	Investigating the association between four manufacturing plant performance measures. And ABC adoption
Rios-Manriques (2014)	Viable instrument	To identify the viable instrument of ABC is the small or medium enterprises.
R.Jusoh (2015)	Technological and environmental	The influence of environmental factors and technological on the diffusion of ABC.
Yang (2016)	Public transport infrastructure	To resolve the strategic decision making under resource constraints and the carbon footprint factor projects in Taiwan.

Based on the application and the results above, ABC system is good and suitable to apply in all different wok environment and also will give the accurate cost.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains the detail information about the research methodology of ABC and MTS that are employed in the study of these concept. There are four stages in that are highlighted which are phase 1, problem definition, phase 2, data collection, phase 3, data analysis and phase 4, interpretation and conclusion. Besides, problem definition is about literature review in order to prove the research gap in remanufacturing and identify the objective to ensure the work is in the right path within the boundary. Moreover, general analysis requirements are needed to determine the suitable tools to be used. Phase 2 is about data collection, mainly consists of endorsement remanufacturing company, automotive selection, parameter selection, and data collection. Subsequently, phase 3, consist of pattern recognition, parameter evaluation and ABC system. The T-method 3 is used in pattern recognition to classify the EOL either the crankshaft is rejected, remanufacturing and repairable while the T-method 1 is used to identify the parameter evaluation of critical crankpin and the cost to produce those critical crankpins are calculated based on their related activities. Lastly, phase 4 discussed the findings and summarize in order to formulate the overall conclusion.

3.2 Flowchart Methodology

Figure 3.1 is show the flowchart methodology to get the results in Chapter 4. For stage 1, identified the problem of categorized of unit data or signal data. Moreover, for stage 2, collect the data of crankpin diameter of crankshaft for both engine model which Man and Mtu183. So, data will analyze using T Method 3 (pattern recognition) and T Method 1 (parameter evaluation) and also applied ABC system to get the accurate product cost. Last stages will be carried the interpretation of the result and conclusion for all the stages.

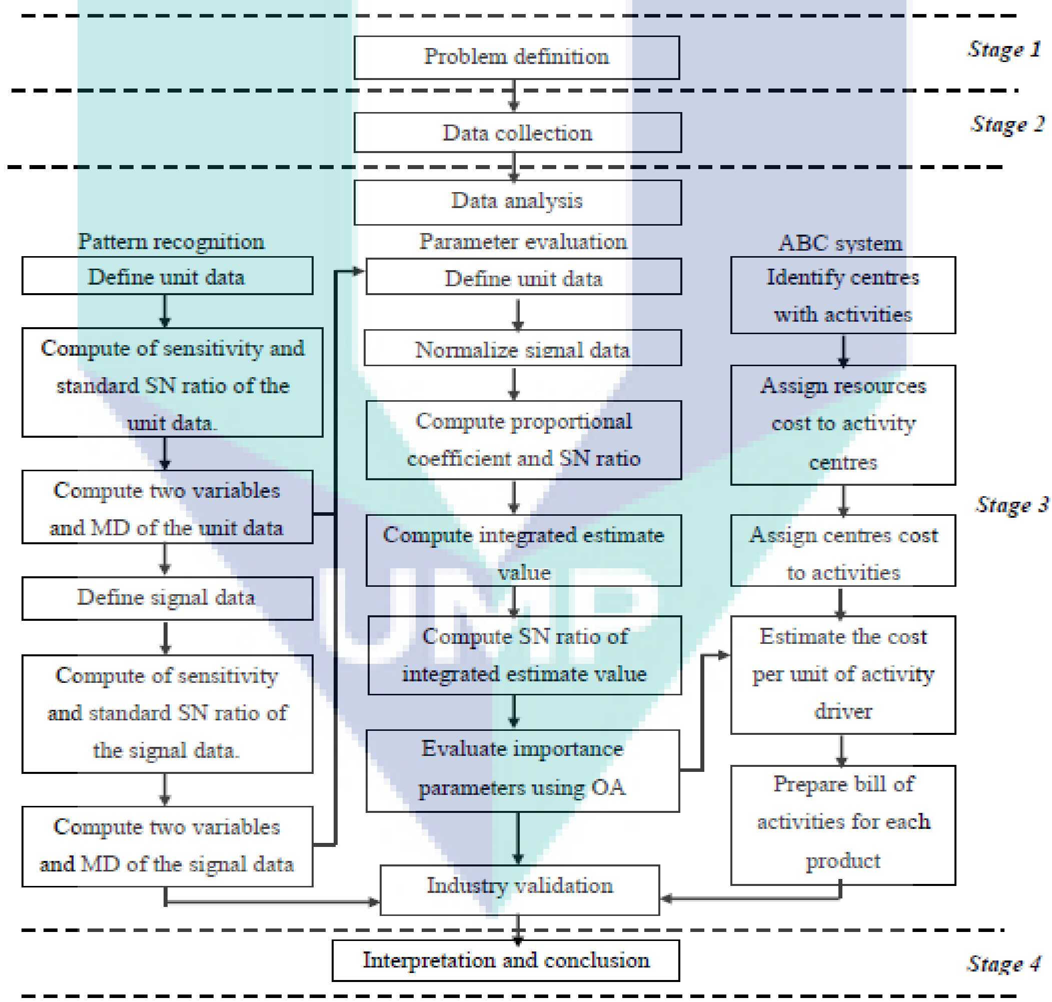


Figure 3.1: Flow chart Methodology

Unfortunately, industry validation is not considered in the stages because this validation needed a long time and not enough in two semesters.

3.3 PHASE 1: PROBLEM DEFINITION

Problem 1: Optimization

There is no optimization which concern at critical parameters of crankshaft during grinding process of remanufacturing

Problem 2: Costing

Most of remanufacturers worldwide assume that manufacturing overhead of the company depend on the volume of production.

Problem 3: ABC

When do the incorrect decision to remanufacture, it will affect the inaccurate profit margin estimation by considering volume based-costing and non-critical parameters.

3.4 PHASE 2: DATA COLLECTION

3.4.1 Endorsement Remanufacturing Company

Remanufacturing of automotive parts and components is perhaps the most mature remanufacturing market in the world and remained largely invisible compared to the manufacturing (Wu & Wu, 2016). One of the company from 32 remanufacturing companies is XXX Sdn. Bhd. in Malaysia having accomplish remanufacturing product criteria with respect to the expected life span, warranty, cost, and performance.

3.4.2 Selection of Automotive Component

XXX Sdn. Bhd is not mass production company because this company does not produce large quantities of product during shortest time. This company has several numbers of EOL components such as the big-end and small-end connecting rods, the main journal and crankpin of crankshafts, camshaft, upper and lower cylinder liner bores, cylinder heads and crankcases in remanufacturing.

Hence, the crankshaft has been selected as an automotive component in this study to further analysis and a few crucial areas of crankshaft such as the oil hole, counterweight, main journal and crankpin that need to be selected in order to constrict the scope.

3.4.3 Parameter Selection

In actual industry practice, both part which are crankpin and main journal are very important part for the crankshaft which to ensure the diameter will meet the remanufacturable tolerance.

When heat is generated inside the engine, this operation will cause the motion of piston in crankshaft either it rotary motion or reciprocal motion. After that, the power will convey as energy reservoir. The camshaft will be connected to the crankshaft since the inlet and exhaust valves must be opened and closed during the stroke of the piston. Therefore, the crankpin is considered as had a big role in converting reciprocating motion into rotary motion in this research and fulfilled the criteria.

3.5 PHASE 3: DATA ANALYSIS

There are three stages of data analysis were done manually which are parameter evaluation, pattern recognition and ABC system.

3.5.1 Parameter Evaluation using T-Method 1

T Method 1 is a sub-method of MTS for parameter evaluation. It is functionally to analyze the importance of any variables against the output. So that, in the previous sub-topic there are 6 crankpin diameter and MD which is generated will be used as input and output. By using T Method-1, there is no relationship among engine model and each engine model are evaluated separately. To apply this method, it is important to ensure that the data is normal or densely populated in the medium range by constructing a histogram. The highest sample will be defined as a unit data while remaining number of samples will be defined as signal data. As shown in Table 3.5, n represent number of samples that will be obtained for the unit data.

Table 3.5: Input and Output of Unit Data

Item/Variable					
Data No.	**1**	**2**	**…**	**K**	**Output value**
1	x_{11}	x_{12}	…	x_{1k}	y_1
2	x_{21}	x_{22}	…	x_{2k}	y_2
…	…	…	…	…	…
n	x_{n1}	x_{n2}	…	x_{nk}	y_n
Average	$\bar{x}_1$	$\bar{x}_2$	…	$\bar{x}_k$	$\bar{y} = M_0$

From the number in the unit data, the average value for each parameter and the average output value of output can be calculated by using Equation 3.1 and Equation 3.2.

$$\bar{x}_j = \frac{1}{n}\left(x_{1j} + x_{2j} + \cdots + x_{nj}\right)\ (j = 1,2,\ldots,k) \tag{3.1}$$

$$\bar{y} = M_0 = \frac{1}{n}(y_1 + y_2 + \cdots + y_n) \tag{3.2}$$

The remaining sample of unit data is signal data. The sample of signal data is marked by using this symbol. The signal data is shown in Table 3.6 below. The signal data also used for finding the proportional coefficient β and SN ratio.

UMP

Table 3.6: Input and Output of Signal Data

Data No	Item/Variable				Output Value
	1	**2**	**…**	**k**	
1	x'_{11}	x'_{12}	…	x'_{1k}	y'_1
2	x'_{21}	x'_{22}	…	x'_{2k}	y'_2
…	…	…	…	…	…
l	x'_{l1}	x'_{l2}	…	x'_{lk}	y'_l

Signal data is normalized by using the average values of parameter and the output values of samples in the unit data. Hence, redundancy can be eliminate and the data will be correct and accurate when used the normalize signal data. Equation 3.3, Equation 3.4 are shown the normalization and Table 3.7 is shown the normalize signal data.

$$X_{ij} = x'_{ij} - \overline{x}_{\mathrm{j}} \tag{3.3}$$

$$M_i = y'_i - M_0 \; (i = 1,2,\ldots,l) \tag{3.4}$$

Table 3.7: Normalized Signal Data

Item/Variable					
Data	**1**	**2**	**…**	**k**	**Output Value**
1	X_{11}	X_{12}	…	X_{1k}	M_1
2	X_{21}	X_{21}	…	X_{2k}	M_2
…	…	…	…	...	…
l	X_{l1}	X_{l2}	…	X_{lk}	M_l

The proportional coefficient β and SN ratio η for each parameter will be calculated by using the Equation 3.5, Equation 3.6, Equation 3.7, Equation 3.8, Equation 3.9 and Equation 3.10.

Proportional coefficient $\beta_1 = \frac{M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{l1}}{r}$ (3.5)

SN ratio $\eta_1 = \{ \frac{\frac{1}{r}(S_{\beta 1} - V_1)}{V_{e1}}$ (when $S_{\beta 1} > V_{e1}$) (3.6)

(when $S_{\beta 1} \leq V_{e1}$)

Where:

Effective divider r $= M_1^2 + M_2^2 + \cdots + M_l^2$ (3.7)

Total Variation $S_{T1} = X_{11}^2 + X_{21}^2 + \cdots + X_{l1}^2$ (f = l) (3.8)

Variation of Proportional Term $S_{\beta 1} = \frac{(M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{l1})^2}{r}$ (3.9)

Error Variation $S_{e1} = S_{T1} - S_{\beta 1}$ (3.10)

When the output value of proportional coefficient, β shown the positive value, it is indicates the gradient is ascending to the right but if the value of β negative, it is shown the gradient is descending to the right. In basic study, the value of η should be positive, but if the value is negative, automatically turns to zero. It means the relationship between input and output is no longer significant.

Table 3.8: Proportional coefficient β and SN ratio η item by item

B,η	Item/variable			
	1	**2**	**…**	**k**
Proportional β	β_1	β_2	…	β_k
SN ratio η	η_1	η_2	…	η_k

An item-by-item estimated value is found for each piece of signal data using proportional coefficient β and SN ratio η, item by item. The estimated value of the output of item 1 for the i-th signal data is shown below in Equation 3.11.

$$\widehat{M}_{i1} = \frac{X_{i1}}{\beta_1} \tag{3.11}$$

An integrated result is obtained by weighting it with SN ratio, which is the estimated measure of precision of each parameter. Thus, the integrated estimated value of the signal data can be calculated as Equation 3.12.

$$\widehat{M}_i = \frac{\eta_1 \times \frac{X_{i1}}{\beta_1} + \eta_2 \times \frac{X_{i2}}{\beta_2} + \cdots + \eta_k \times \frac{X_{ik}}{\beta_k}}{\eta_1 + \eta_2 + \cdots + \eta_k} \quad (i = 1,2,\ldots,l) \tag{3.12}$$

The real values which is measured values of signal and the integrated estimate values is shown in Table 3.9.

Table 3.9: Measured Values and Integrated Estimate Values of Signal Data

Data No	Measured value	Integrated Estimate Value
1	M_1	$\widehat{M}_1$
2	M_2	$\widehat{M}_2$
:	:	:
:	:	:
l	M_l	$\widehat{M}_l$

The Integrated SN Ratio is computed using the Equation 3.13, Equation 3.14, Equation 3.15, Equation 3.16, Equation 3.17, Equation 3.18, and Equation 3.19. Based on the study Quality Engineering, there are a few orthogonal array to find the integrated estimate value but it must suitable for SN ratio.

Integrated Estimate SN Ratio $\eta = 10 \log(\frac{\frac{1}{r}(S_\beta - V_e)}{V_e})$ (3.13)

Where :

Linear equation $L = M_1\widehat{M}_1 + M_2\widehat{M}_2 + \cdots + M_l\widehat{M}_l$ (3.14)

Effective divider $r = M_1^2 + M_2^2 + \cdots + M_l^2$ (3.15)

Total variation $S_T = \widehat{M}_1^2 + \widehat{M}_2^2 + \ldots + \widehat{M}_l^2$ $(f = l)$ (3.16)

Variation of proportional term $S_\beta = \frac{L^2}{r}$ $(f = 1)$ (3.17)

Error variation $S_e = S_T - S_\beta$ $(f = l - 1)$ (3.18)

Error variance $V_e = \frac{S_e}{l-1}$ (3.19)

The relative importance of an item is evaluated in terms of the extent to which the Integrated Estimate SN Ratio deteriorates when the item is not used. For the evaluation, a two-level orthogonal array which means a 4 × prime version of the level series is advisable is used.

After that, the condition of integrated estimate SN ratio can be compared by using orthogonal array method. For examples, if 6 parameters were assigned as shown in the Table 3.10.

Table 3.10: Orthogonal array L_{12} and assignments of items

	Parameter											
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	Integrated Estimate SN Ratio η (db)
No	1	2	3	4	5	6	7	8	9	10	11	
1	1	1	1	1	1	1	1	1	1	1	1	η_1
2	1	1	1	1	1	2	2	2	2	2	2	η_2
3	1	1	2	2	2	1	1	1	2	2	2	η_3
4	1	2	1	2	2	1	2	2	1	1	2	η_4
5	1	2	2	1	2	2	1	2	1	2	1	η_5
6	1	2	2	2	1	2	2	1	2	1	1	η_6
7	2	1	2	2	1	1	2	2	1	2	1	η_7
8	2	1	2	1	2	2	2	1	1	1	2	η_8
9	2	1	1	2	2	2	1	2	2	1	1	η_9
10	2	2	2	1	1	1	1	2	2	1	2	η_{10}
11	2	2	1	2	1	2	1	1	1	2	2	η_{11}
12	2	2	1	1	2	1	2	1	2	2	1	η_{12}

Item by item normalization of data with unknown output value in the unit data is performed by using the average value x_j so that it can conclude that the computation can be performed on the integrated estimate value, $\widehat{M}$, of the normalized unknown data as in the case of signal data. After that, the output value of the signal data is normalized, the integrated estimate value $\hat{y}$ of the pre-normalization which is actual output is compute on the basis of normalized integrated value by using the Equation 3.20.

$$\hat{y}_i = \hat{M}_i + M_0 \ (i = 1,2, \dots, l) \quad (3.20)$$

There are two level of the orthogonal array consist of level 1 and level 2. The level one means 1 is the item that will be used whereas level two is the item that will not be used. In relation to the factorial effect graph, descending the line from left to right indicates that parameter has an effect of elevating the output. It means the larger value of SN ratio it is considered used but the smaller SN ratio it is considered not used for parameter. When the degree of contribution turns to be positive so that the parameter is classified as critical. Otherwise, ascending the line from left to right indicates that the parameter has an effect of lowering the output.

3.5.2 Crankshaft Classification using T-Method 3

The MTS is a sub-method for pattern recognition in the T Method-3. The T Method-3 is the T Method that has the ability to classify objects into two categories which one is inside and another one is outside the unit space. The one is inside means the unit data or reference space and the outside the unit space means signal data. T method-3 starts with defined the unit data and computation of the average value of each parameter, where the unit data are selected based on their highest number of samples among other samples. The n as shown in Table 3.11 is defined as the number of samples have been acquired from the unit data and the classification will be clearer when the n items is larger since it represents a point in a scatter diagram. Subsequently, the k items represents the number of parameters, which are the linear equation will be stronger, thus will generate an accurate center point when the k generated is larger

Table 3.11: Average value and linear equation of unit data

Data No.	Parameter				Linear formula L
	1	2	…	k	
1	x_{11}	x_{12}	$\cdots$	x_{1k}	L_1
2	x_{21}	x_{22}	$\cdots$	x_{2k}	L_2
...	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
n	x_{n1}	x_{n2}	$\cdots$	x_{nk}	L_n
Average	$\hat{x}_1$	$\hat{x}_2$	$\cdots$	$\hat{x}_k$	

From the number of samples in the unit data, the average value for each parameter can be calculated by using Equation 3.21.

$$\hat{x}_j = \frac{1}{n}\left(x_{1j} + x_{2j} + \cdots + x_{nj}\right) \quad (j = 1,2, \ldots, k) \tag{3.21}$$

The Equation 3.22 is shown the formula of sensitivity β. The β indicates the gradient of incline that is shown straight line. So that, it can conclude when the ascending the line to the right indicates that the L is positives, whereas descending the line to the right indicates that the L is negative.

$$\beta_1 = \frac{L_1}{r} \tag{3.22}$$

Where :

Linear equation, $L_1 = \bar{x}_1 x_{11} + \bar{x}_2 x_{22} + \cdots + \bar{x}_k x_{1k}$ (3.23)

Effective divider, r= $\bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2$ (3.24)

To obtain the value of Equation 3.29 which is Standard SN ratio, η_1 the calculation must be calculate by the following equation which are Equation 3.25, Equation 3.26, Equation 3.27 and Equation 3.28.

Total variations, $S_{T1} = x_{11}^2 + x_{12}^2 + \cdots + x_{1k}^2$ (f = k) (3.25)

Variation of proportional term, $S_{\beta 1} = \frac{L_1^2}{r}$ (f = 1) (3.26)

Error variation, $S_{el} = S_{T1} - S_{\beta 1}$ (f = k-1) (3.27)

Error varience, $V_{el} = \frac{S_{el}}{k-1}$ (3.28)

When the value of SN ratio is larger, so that the relationship between the input and output will be stronger.

Standard SN Ratio, $\eta_1 = \frac{1}{V_{el}}$ (3.29)

From the Equation 3.29, the expression standard SN ratio is used as the standard signals with treat the average values of the items of the unit space; the dividend might as well be represented by r but the numeral one has been chosen because it is frequently to all members. Table 3.3 shows the sensitivity β and standard SN ratio η for each in the unit data are then found in a similar manner.

Table 3.12: Sensitivity β and Standard SN ratio η for all samples in the unit data

Data No	Sensitivity β	SN ratio η
1	β_1	η_1
2	β_2	η_2
:	:	:
:	:	:
n	β_n	η_n

The two variables which are Y_1 and Y_2 will be compute by using two items, these items are sensitivity, β and standard SN ratio, η in Table 3.13. The new variable Y_1, β, is used, as is Y_2 will first be converted as follows to allow an evaluation of any scatter from the standard variation.

$$Y_{i1} = \beta_i \quad (\text{i} = 1,2,\ldots,n) \tag{3.30}$$

$$Y_{i2} = \frac{1}{\sqrt{\eta_i}} = \sqrt{V_{ei}} \quad (\text{i} = 1,2,\ldots,n) \tag{3.31}$$

The average of Y_1 and Y_2 for prediction of unit data origin as shows in Equation 3.32 and Equation 3.33.

$$\bar{Y}_1 = \frac{1}{n}(Y_{11} + Y_{21} + \cdots + Y_{n1}) \tag{3.32}$$

$$\bar{Y}_2 = \frac{1}{n}(Y_{12} + Y_{22} + \cdots + Y_{n2}) \tag{3.33}$$

The Mahalanobis Distance (MD) can be calculate by using Equation 3.34. When the A value is non-negative, so that the value of MD is always come out with zero or positive value. When the larger of total value of remanufacturable tolerance acquired, so that the larger value of MD will be developed.

$$\text{Mahalanobis Distance, } D^2 = \frac{YAY^T}{k} \tag{3.34}$$

The Table 3.13 and Table 3.14 is shown the results after finding the value of MD. Consequently, the distance measurement of samples in the unit data taken individually is used by the MT Method.

Table 3.13 : Y_1 and Y_2 in the unit space

Data No.	$\boldsymbol{Y_1}$	$\boldsymbol{Y_2}$
1	Y_{11}	Y_{12}
2	Y_{21}	Y_{22}
:	:	:
:	:	:
n	Y_{n1}	Y_{n2}
Average	$\bar{Y}_1$	$\bar{Y}_2$

Table 3.14 : Distances of samples in unit space

Data No.	**Distance, $\boldsymbol{D^2}$**	**Distance, D**
1	D_1^2	D_1
2	D_2^2	D_2
…	…	….
n	D_n^2	D_n

The purpose of signal data is to evaluate the discriminating ability of a data. So that, the signal data can be more than one but it should less than number of samples compared to unit data. Table 3.15 is shown the value should have in signal data information

Table 3.15: Signal data parameter and linear formula

Data No.	Parameter				Linear equation, L'
	1	**2**	**…**	**k**	
1	x'_{11}	x'_{12}	…	x'_{1k}	L'_1
2	x'_{21}	x'_{22}	…	x'_{2k}	L'_2
…	…	…	…	…	…
l	x'_{l1}	x'_{l2}	…	x'_{lk}	L'_l

To obtain the calculation of sensitivity, β, Equation 3.37, there is two equations must be completed which are Linear equation, L'_1 ,Equation 3.35 and effective divider, r Equation 3.36.

$$\text{Linear equation, } L'_1 = \bar{x}_1 x'_{11} + \bar{x}_2 x'_{12} + \cdots + \bar{x}_k x'_{1k} \quad (3.35)$$

$$\text{Effective divider, } r = \bar{x}_1^2 + \bar{x}_2^2 + \cdots + \bar{x}_k^2 \quad (3.36)$$

$$\text{Sensitivity, } \beta = \frac{L'_1}{r} \quad (3.37)$$

Moreover, to find the standard SN ratio, η, Equation 3.43 for each piece of signal data, there must be completed calculated for the following equations is shown below which are Equation 3.38, Equation 3.39, Equation 3.40, Equation 3.41, and Equation 3.42.

$$\text{Total variation, } S_{T1} = x'^2_{11} + x'^2_{12} + \cdots + x'^2_{1k} \quad (3.38)$$

$$\text{Variation of proportional term, } S_{\beta 1} = \frac{L'^2_1}{R} \quad (3.39)$$

$$\text{Error variation, } S_{e1} = S_{T1} - S_{\beta 1} \quad (3.40)$$

$$\text{Error variance, } V_{e1} = \frac{S_{e1}}{k-1} \quad (3.41)$$

$$\text{Standard SN ratio, } \eta_1 = \frac{1}{V_{e1}} \quad (3.42)$$

After calculate all the formula the first issue been solved using this procedure of T method-3 by constructing the crankshaft classification in a scatter diagram.

3.5.3 Activity Based Costing

Activity Based Costing (ABC) is a methodology that can be used to measure the both of costs which are cost of cost objects and the performance of activities. It evolved in the mid-1980s to improve the allocation of manufacturing overhead costs to products, but it soon became apparent that activity-based costing could be expanded to include non-manufacturing costs. There are 4 stages to implement ABC in a system so that, a system will manage properly.

Step 1: Identify and Classify Activities and Allocate Overhead to Cost Pools

This step is about how the companies to identify the activity cost pools by using the ABC system. Consequently, overhead cost is assigned directly to the activity cost pool.

Step 2: Identify cost drivers

Next, it is about the cost driver must accurately measure the actual consumption of the activity by the various products.

Step 3: Compute Overhead Rates

This step is about how to calculate and compute an activity-based overhead rates per cost driver.

Step 4: Assign Overhead Cost to Product

To assign overhead cost, there are calculation must be considered to get the activity-based overhead rates per cost driver by the number of cost drivers expected to be used per product.

3.6 PHASE 4: INTERPRETATION AND CONCLUSION

The last stage of this research processes is focused on deriving conclusions from the data analysis. This will be further elaborated in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter is illustrated classification of End of life crankshaft and identification of critical and non-critical parameters of crankpin using Taguchi's orthogonal array for the purpose of optimization. Then, ABC system was integrated with critical parameter to estimate the final cost of engine model.

4.2 PATTERN RECOGNITION

4.2.1 Crankshaft Classification using T-Method 3

Scatter diagram is used to classify the engine model from the EOL crankshaft into recovery operation. There are three classification of crankshaft which are remanufacture, repair, or reject. The total value of remanufacturable tolerance generates the larger of the values of MD. OEM provides the larger tolerance of remanufacturable and it is closer to the maximum remanufacturable tolerance. Otherwise, when the smaller MD is generated, it will give the larger the total value of rejected tolerance that acquired to the minimum tolerances provided by OEM. The highest number of samples can be considered by unit data and the remaining of engine models can be considered by signal data.

4.2.1.1 Mtu183 Engine Model

Based on the number of samples, there can be classified these samples into three classification which are remanufacture, repair, and reject. As shown in Table 4.1, it shows the data information of Mtu183 engine model and the raw data can be referred in the Appendix A.

Table 4.1: Data Information of MTU183 engine model

Engine Model	No. of sample	Remanufacturable tolerance provided by OEM (mm)	
		Lower Limit	Upper Limit
MTU 183	15	113.980	114.000

The scatter diagram of Figure 4.1 shows the relationship between two variables which are Y1 and Y2 of MTU 183 engine model. The blue distribution is indicating the remanufacturable group, the orange distribution is indicating the repairable group whereby the black distribution is indicating the rejected group. Based on the Figure 4.1, the scatter diagram can be described the goodness of fit or the badness of fit of the linear model which is depend on coefficient of correlation, r. Based on the result in Appendix A, the value of r is 0.80250591 which is positive correlation. So, it means the closer value of r to 1.00, the better is the fit, with a value of 1 meaning that all point falls on the line.

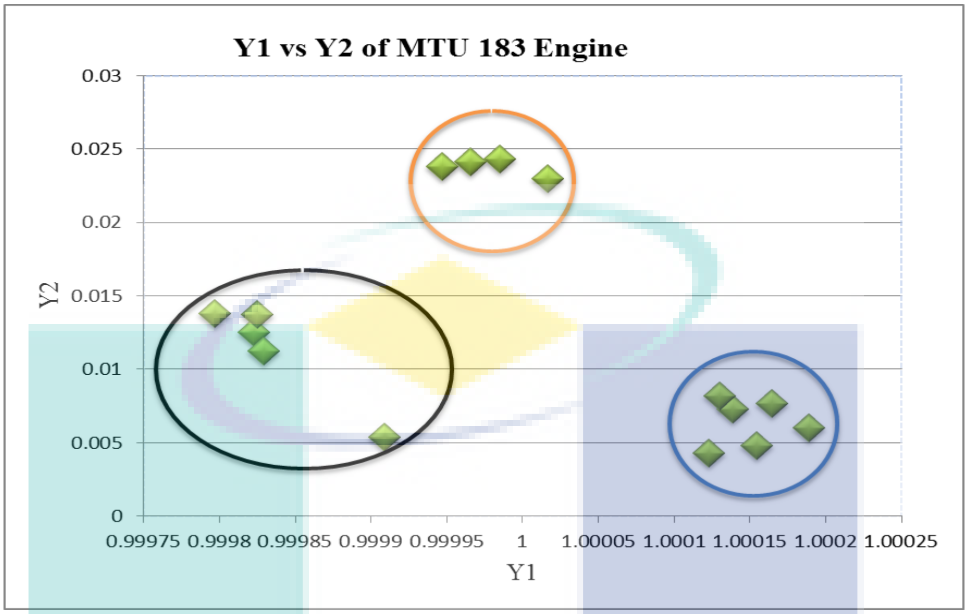


Figure 4.1: Scatter diagram of Mtu183 engine model

4.2.1.2 Man Engine Model

A Man engine can be described by a mechanism of reciprocating ladders and stationary platforms that installed in mines to monitor the assist's journey from and to working level. In the 19th century until twentieth century, the German invented a prominent feature of tin and copper mines in Cornwall. So, the Man group which is the vehicles companies, mechanical engineering and engines aims to improve the value in fast-developing business areas including Commercial Vehicles and Power Engineering. There is overview of the Man engine product such as on-road-buses and special vehicles, off-road-railway, off-road construction and agriculture and for the power including diesel and gas. Table 4.2 shows the data information of the Man engine model and the raw data with the result can be refer in Appendix A.

Table 4.2: Data Information of Man engine model

Engine Model	No. of sample	Remanufacturable tolerance provided by OEM (mm)	
		Lower Limit	Upper Limit
Man	15	112.0200	112.0400

The scatter diagram of Figure 4.2 shows the relationship between two variables which are Y1 and Y2 of MAN engine model. The green distribution is indicating the repairable group whereby the red distribution is indicating the remanufacturable group. Based on the Figure 4.2, the scatter diagram can be described the goodness of fit or the badness of fit of the linear model which is depend on coefficient of correlation, r. Based on the result in Appendix A, the value of r is 0.253406287 which is positive correlation. So, it means the closer value of r to 1.00, the better is the fit, with a value of 1 meaning that all point falls on the line. Although the value of r is far away from 1.0 but it is considered the better fit also because it is in the range of closer 1.0.

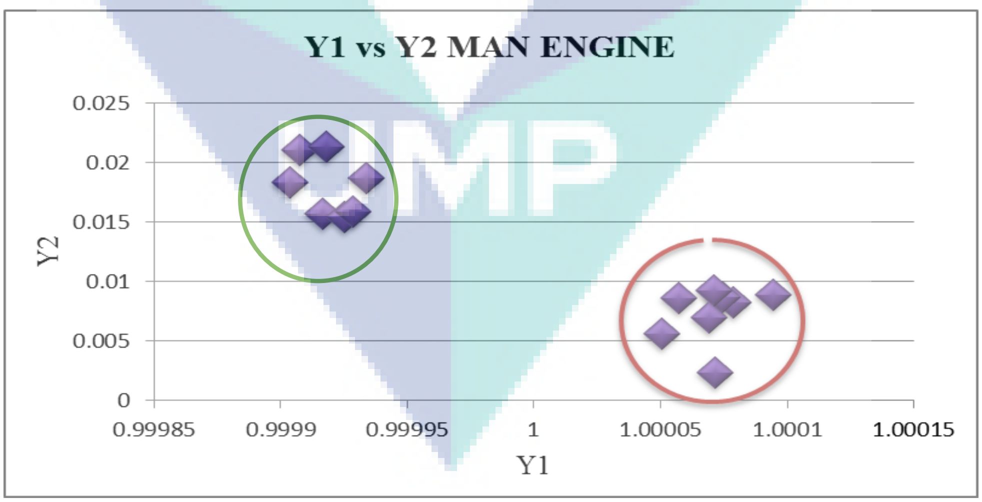


Figure 4.2: Scatter Diagram of Man engine model

4.2.2 Scatter Diagram Combination

Figure 4.3 is illustrated the scatter diagram combination of both engine models. It is show clearly the tabulation of data can be classified into two engine models. For the Man engine models, there can be classified into two group which are repairable group and remanufacturable group. For the Mtu183 engine model, there can be classified into three groups which are remanufacturable group, repairable group, and rejected group.

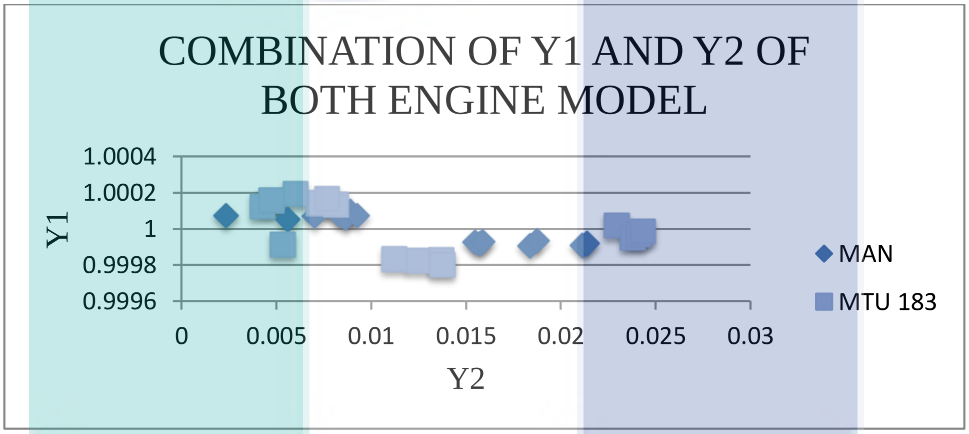
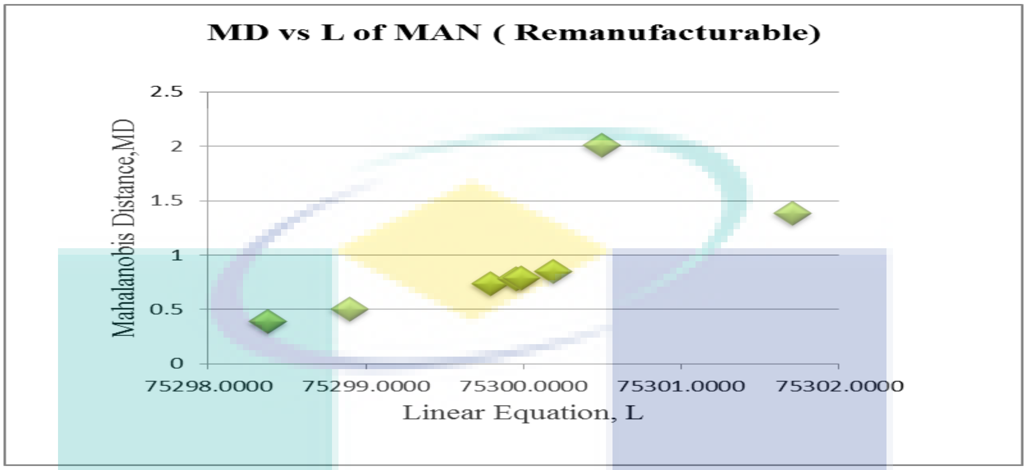


Figure 4.3: Combination of Y1 and Y2 of Both Engine Models

Figure 4.4 is shows the relationship between tolerances of remanufacturable and MD that can be referred in Appendix A which considered the resulting data of remanufacturable sample for MTU 183 engine model and MAN engine model. According to the scatter diagram for the samples remanufacturable of both engines, the result shows the positive value of sensitivity, β, and the distribution of linear equation, L is larger for both engine models by ascending from left to the right. So, it is proved that stated by OEM for both engine model that are generated the larger value of MD.

a)



b)

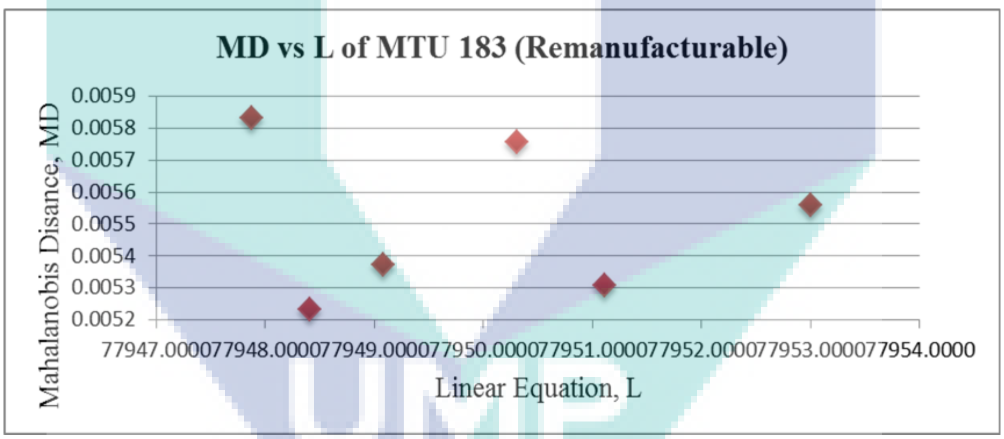


Figure 4.4: Relationship between tolerances of remanufacturable and MD for a) Man engine model and b) Mtu183 engine model.

By referring in Appendix A, the Figure 4.5 is shows the relationship between tolerances of rejected and MD are obtained by taking the resultant data of rejected sample for MTU 183 engine model. Based on scatter diagram of sample rejected of MTU 183 engine model, it shows the positive value of sensitivity, β, and the linear equation, L of the rejected tolerance is smaller by ascending of distribution from left to the right. Therefore, it is supported the hypothesis of rejected tolerance that generated the smaller values of MD.

When the value of average sensitivity, β, is lower than -1.0 that belongs to the unit data and the distribution shows the descending from left to the right. Therefore, the hypothesis of remanufacturable and rejected is not support for the engine.

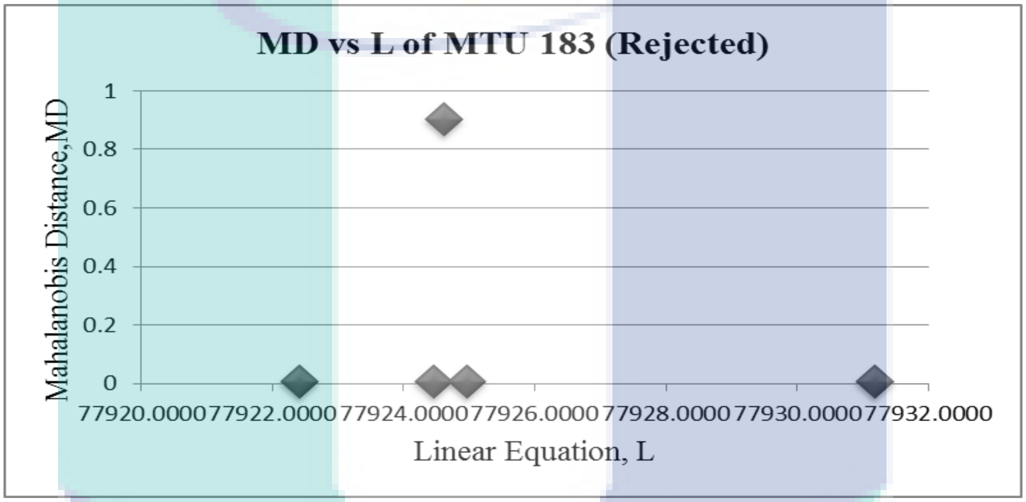


Figure 4.5: Relationship between tolerances of rejected and MD for Mtu183 engine model

4.3 PARAMETER EVALUATION

4.3.1 Parameter Evaluation using T-Method 1

The Taguchi's array method is used to measure and evaluate the critical and non-critical parameter crankpin of crankshaft for both remanufacturable engine model which are Mtu183 and Man. According to the factorial effect, the higher SN ratio of parameter crankshaft in used (Level 1) indicates the higher the positivity contribution degree of parameter. Otherwise, the lower SN ratio of parameter is not used (Level 2) that indicates the lower the positivity contribution degree of parameter. Hence, the factorial effect graph in descending line from left to the right is indicates the parameter is significant and the crankshaft is critical. Thus, the quality of inspection will be improving when the number of parameter is reducing.

4.3.1.1 Mtu183 Engine Model

As shown in Figure 4.6, the histogram of MTU 183 engine model which has 15 samples that can be classified as 6 crankpin diameter of remanufacturable data that has input ranging from 113.9808 mm to 113.998 mm with output ranging from 0.00523 to 0.00582 of MDs, 5 crankpin diameter of rejected data that has input ranging from 113.932 mm to 113..9687 mm with output ranging from 0.00461 to 0.90132 of MDs and another 4 crankpin diameter has input ranging from 113.9356 mm to 113.9993 mm and has the output ranging from 0.00311 to 0.00326 of MDs. Based on the histogram created, the peak distribution which is 8 frequencies that range from 0.005 to 0.006 MDs is considered as the unit data and another frequency distribution are considered as normalized signal data. The normalized signal data is very important for the purpose of prediction and estimation especially in evaluating of parameters. Therefore, the recognition will be accurate and improve successfully.

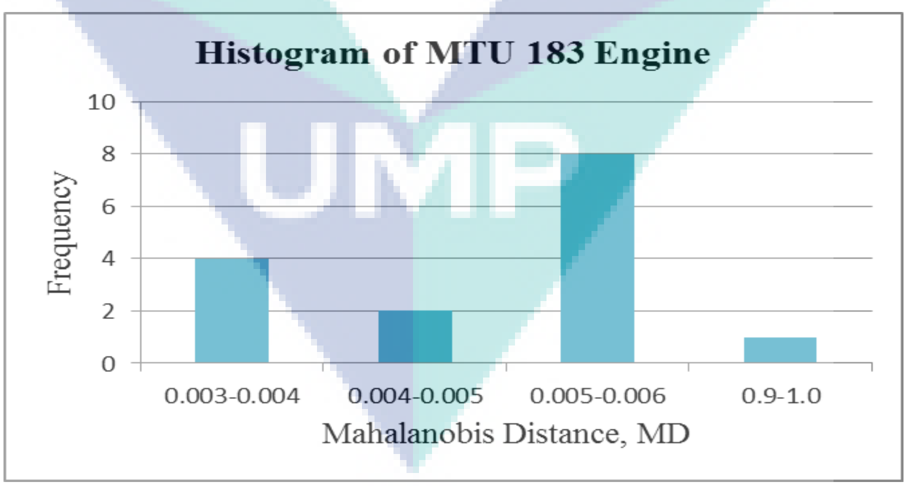


Figure 4.6 : Histogram of Mtu183 engine model

As the Table 4.3 show the valuable parameter of proportional coefficient, β, actual SN ratio and the correction of SN ratio, η of MTU 183 engine model. Based on values of proportional coefficient, β, there is show all the negative values because of the average from each crankpin diameter unit data is larger so it is affected for the data every crankpin of normalized signal data. Consequently, the relationship of the parameters with the MD value will give the result of SN ratio. There are two stronger relationships which is crankpin diameter of 1 and 4 that are appropriate use for integrated estimation SN value. Therefore, the crankpin diameter of 2, 3, 5 and 6 are shows the negative value of SN ratio, so it will turn out and it will be treated as zero value and the parameter will not be used in the general estimation. In other words, the negative value of SN ratio is shows to the variation of proportional term, $S\beta \leq Ve$ which are -0.684936068, -0.8270038, -0.453204101, and -0.254204244 respectively. When the value of SN ratio is larger, the contribution of the degree to the integrated estimate MD also becomes the larger value.

Table 4.3: Proportional coefficient β and SN ratio η of Mtu183 engine model

Item Number	1	2	3	4	5	6
Proportional constant, β	-0.048304498	-0.015674387	-0.019152818	-0.053786	-0.023193005	-0.03026655
SN ratio, η	1.476559712	-0.684936068	-0.8270038	3.914312	-0.453204101	-0.254204244
SN ratio, η after correction	1.476559712	0	0	3.914312	0	0

L_{12} orthogonal array is used for MTU 183 engine model because it is deal with the six items of crankpin diameter, hence it is 4 x prime type array that will minimize the interaction between the items. Regarding of Table 4.5 that generate the SN ratio, η value of 8.53564 dB (decibel) in data number 1 with probable combinations. The values of integrated SN ratio, η, are calculated by using from the Equation 3.1 to Equation 3.19. So, to more understand it must go through all the equation to get the correct value of integrated SN ratio.

Table 4.4: L_{12} of orthogonal array for Mtu183

	Crankpin Diameter						
Data No	1	2	3	4	5	6	η(dB)
1	1	1	1	1	1	1	8.53564
2	1	1	1	1	1	2	8.53564
3	1	1	2	2	2	1	1.69251
4	1	2	1	2	2	1	1.69251
5	1	2	2	1	2	2	8.53564
6	1	2	2	2	1	2	1.69251
7	2	1	2	2	1	1	0
8	2	1	2	1	2	2	5.926554
9	2	1	1	2	2	2	0
10	2	2	2	1	1	1	5.926554
11	2	2	1	2	1	2	0
12	2	2	1	1	2	1	5.926554

The method of orthogonal array L_{12} is important to evaluate the parameters which are effective and non-effective parameter for purpose of integrated estimation. Hence, level 1 can be described for the item that will be used whereby the level 2 as the item that will not be used as illustrated in the Table 4.4. As the Table 4.6 is show the result of contribution degree that obtain by calculating the average of each crankpin diameter regarding of level 1 and level 2.

Table 4.5: Integrated estimate SN ratio η by level of Mtu183

SN ratio η(dB)						
Parameter	Crankpin Diameter 1	Crankpin Diameter 2	Crankpin Diameter 3	Crankpin Diameter 4	Crankpin Diameter 5	Crankpin Diameter 6
Level 1	5.114075	4.115057531	4.115057531	7.231097365	4.115057531	3.962294906
Level 2	2.963277	3.962294906	3.962294906	0.846255073	3.962294906	4.115057531
Degree of Contribution	2.150798	0.152763	0.152763	6.384842	0.152763	-0.15276

Based on the result of integrated SN ratio, η of level 1 and level 2 from Table 4.5 are illustrated into bar graph of degree of contribution of MTU 183 engine model as shown in Figure 4.7. At look from the pattern, it is clear the crankpin diameter 4 shows the highest difference, followed by crankpin diameter 1, 2, 3, and 5. Therefore, the highest contribution degree which is 6.384842 dB from crankpin diameter 4 will gain the SN ratio for level 1 as used parameter, 7.231097365 dB and for level 2 as not used parameter, 0.846255073 dB. Therefore, the crankpin diameter 4 has highest output contribution and considered of critical crankpin. Otherwise, the lowest contribution degree which is -0.15276 dB from crankpin diameter 6 will gain the SN ratio for level 1 as used parameter, 3.962294906 dB and for level 2 as not used parameter, 4.115057531 dB and this crankpin diameter can be considered not-critical crankpin.

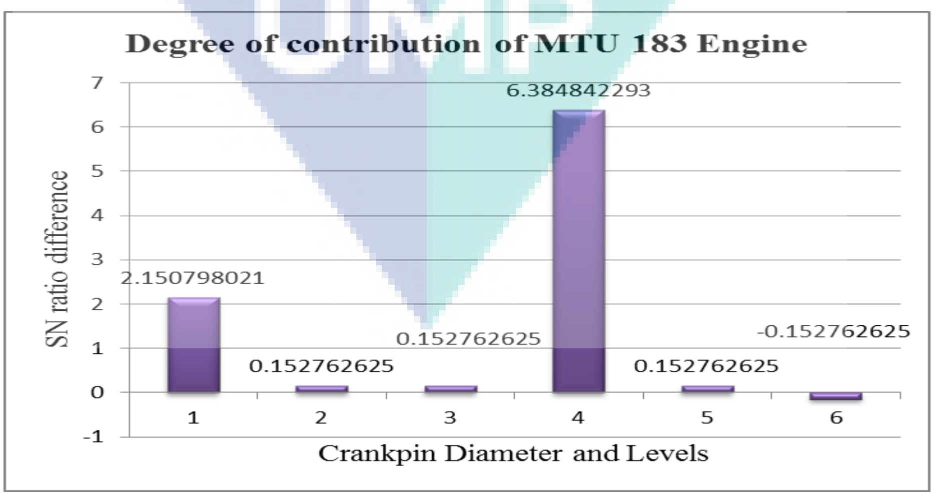


Figure 4.7: Evaluation importance through Degree of contribution of Mtu183 engine model

4.3.1.2 Man Engine Model

Figure 4.6 is show the histogram of MAN engine model which has 15 samples that can be classified as 8 crankpin diameters of remanufacturable data that has input ranging from 112.0202 mm to 112.0395 mm with output ranging from 0.386108424 to 2.00475235 of MDs, another 8-crankpin diameter of repairable data that has input ranging from 111.9909 mm to 112.0387 mm with output ranging from 0.724391458 to 1.510771042 of MDs. Based on the histogram created, the peak distribution which is 4 frequency that range from 0.6 to 0.8 MDs is considered as the unit data and another frequency distribution are considered as normalized signal data. The normalized signal data is very important for the purpose of prediction and estimation especially in evaluating of parameters. Therefore, the recognition will be accurate and improve successfully.

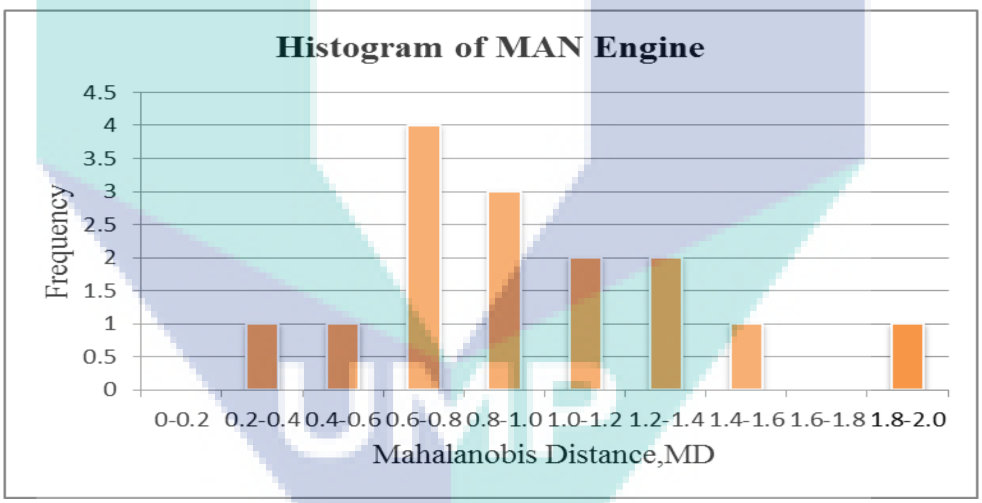


Figure 4.8: Histogram of Man Engine

According Table 4.6 is show the valuable parameter of proportional coefficient, β, actual SN ratio and the correction of SN ratio, η of Man engine model. Based on values of proportional coefficient, β, there is show all the negative values because of the average from each crankpin diameter unit data is larger so it is affected for the data every crankpin of normalized signal data. Consequently, the relationship of the parameters with the MD value will give the result of SN ratio. There are two stronger relationships which is crankpin diameter of 5 and 6 that are appropriate use for integrated estimation SN value. Therefore, the crankpin diameter of 1, 2, 3 and 4 are shows the negative value of SN ratio, so it will turn out and it will be treated as zero value and the parameter will not be used in the general estimation. In other words, the negative value of SN ratio is shows to the variation of proportional term, $S\beta \leq Ve$ which are -0.260077084, -0.039864999, -0.034503604, -0.071116548 respectively. When the value of SN ratio is larger, the contribution of the degree to the integrated estimate MD also becomes the larger value.

Table 4.6: Proportional coefficient β and SN ratio η of Man engine model

Item number	1	2	3	4	5	6
Proportional constant, β	0.002230812	0.005987936	-0.006203789	-0.010535786	-0.019623583	-0.016433739
SN ratio, η	-0.260077084	-0.039864999	-0.034503604	-0.071116548	0.420078979	0.148980716
SN ratio, η after correction	0	0	0	0	0.420078979	0.148980716

L_{12} orthogonal array is used for Man engine model because it is deal with the six items of crankpin diameter, hence it is 4 x prime type array that will minimize the interaction between the items. Regarding of Table 4.6 that generate the SN ratio, η value of -4.63069 dB (decibel) in data number 1 with probable combinations. The values of integrated SN ratio, η, are calculated by using from the Equation 3.1 to Equation 3.19. So, to more understand it must go through all the equation to get the correct value of integrated SN ratio.

Table 4.7: L_{12} of orthogonal array for Man.

	Crankpin Diameter						
Data No	1	2	3	4	5	6	η(dB)
1	1	1	1	1	1	1	-4.63069
2	1	1	1	1	1	2	-0.37667
3	1	1	2	2	2	1	-8.66406
4	1	2	1	2	2	1	-8.66406
5	1	2	2	1	2	2	0
6	1	2	2	2	1	2	-0.37667
7	2	1	2	2	1	1	-4.63069
8	2	1	2	1	2	2	0
9	2	1	1	2	2	2	0
10	2	2	2	1	1	1	-4.63069
11	2	2	1	2	1	2	-0.37667
12	2	2	1	1	2	1	-8.66406

The method of orthogonal array L_{12} is important to evaluate the parameters which are effective and non-effective parameter for purpose of integrated estimation. Hence, level 1 can be described for the item that will be used whereby the level 2 as the item that will not be used as illustrated in the Table 4.7. As the Table 4.8 is show the result of contribution degree that obtain by calculating the average of each crankpin diameter regarding of level 1 and level 2.

Table 4.8: Integrated estimate SN ratio η by level of Man

	SN ratio η(dB)					
Parameter	Crankpin Diameter 1	Crankpin Diameter 2	Crankpin Diameter 3	Crankpin Diameter 4	Crankpin Diameter 5	Crankpin Diameter 6
Level 1	-3.785358685	-3.050351645	-3.785358685	-3.050351645	-2.50367913	-6.647375805
Level 2	-3.050351645	-3.785358685	-3.050351645	-3.785358685	-4.3320312	-0.12555635
Degree of Contribution	-0.73501	0.735007	-0.73501	0.735007	1.828352	-6.52182

Based on the result of integrated SN ratio, η of level 1 and level 2 from Table 4.8 are illustrated into bar graph of degree of contribution of Man engine model as shown in Figure 4.9. At look from the pattern, it is clear the crankpin diameter 5 shows the highest difference, followed by crankpin diameter 2 and 4. Therefore, the highest contribution degree which is

1.828352 dB from crankpin diameter 5 will gain the SN ratio for level 1 as used parameter, -2.50367913 dB and for level 2 as not used parameter, -4.3320312dB. Therefore, the crankpin diameter 5 has highest output contribution and considered of critical crankpin. Otherwise, the lowest contribution degree which is -6.52182 dB from crankpin diameter 6 will gain the SN ratio for level 1 as used parameter, -6.647375805 dB and for level 2 as not used parameter, -0.12555635 dB and this crankpin diameter can be considered not- critical crankpin followed by crankpin diameter 1 and 3.

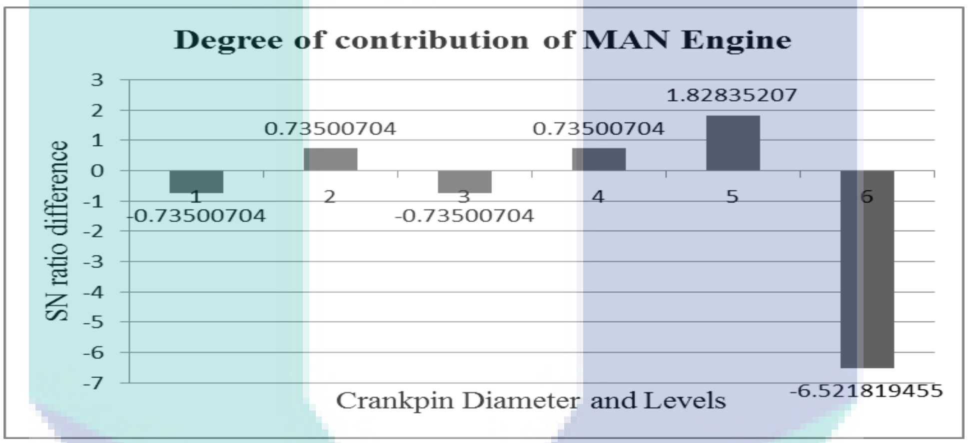


Figure 4.9: Evaluation importance through Degree of contribution of Man engine model

4.4 ACTIVITY BASED COSTING

Before this, the critical parameter which had analysed in previous had used MTS evaluation technique that is integrate with the ABC system that is consider the issue of the volume-based change to an activity-based cost driver. The number of overhead categorized is larger from the beginning will give the closed exact value of the overhead apportionment whereby the remanufacturing cost is closer to an accurate value when the number of activities centre is larger. Since overhead apportionment based on the number of activities is more accurate, the final remanufacturing cost is probable to acquire a better estimation even though the different of complexity for each engine model. In addition, ABC system has the possibility to control the overhead cost which depend on the diversity of activities that had perform in the company.

4.4.1 Identification of centre with their activities

There are six department of apportionment of activities which are administration, factory management, quality control, remanufacturing, and sales and dispatch. The purpose of all activities is to produce the remanufactured crankshafts that are really affected to the industry's business. Table 4.9 is show all the centers with their activities that had been approved by the Head of Workshop.

Administration centre is very important to manage the process accounts of payables and receivables and it is also to ensure the accurate payment of benefits and allowances. Corporate management centre is a driver of any business at the top level because the function has a big influence as it has the responsibility of acquiring sufficient resources for the organization's operations. Although these activities centre are not directly influencing the remanufacturing operation of crankshaft, their indirect role in acquiring the core from domestic suppliers is important. The factory management centre is important to ensure the lean operation and provide the required space of sufficient facilities. This centre is always become assistance for remanufacturing centre in an efficient manner. Remanufacturing is very important to produce a new crankshaft that is similar of expected life span and 1-year warranty. There are three major activities of remanufacturing which are grinding, polishing, and cleaning processes. The role of quality control is to ensure the performance of crankshaft that meet the client's requirements according standard given by OEM. Sales and dispatch centre will manage the sales and order account and to make sure the end-product will deliver to the customer in good condition without any complaints.

Table 4.9: Centres with their activities

No	Centre	Activities
1.	Administration	1. Manage the accounts receivable / payable systems in order to ensure complete and accurate recording of all monetary transections. 2. Ensure accurate payment of benefits and allowances with respect to the preparation of payrolls.
2.	Corporate management	1. Acquire sufficient resources for the organization's operations. 2. Provide continuity for the organization by setting up a corporate and legal framework.
3.	Factory management	1. Provide worker schedule efficiently in order to ensure running productions meet the targets. 2. Implement the factory manufacturing strategic plans by estimating the quantity of machines, tools, and transportation.
4.	Quality control	1. Maintain record pertaining to inspection on all tools and equipment. 2. Record the crankpin diameter and crankshaft hardness.
5.	Remanufacturing	1. Grinding, polishing and cleaning operation performed according to the standards provided by OEM.
6.	Sales and Dispatch	1. Manage sales and order account. 2. Prepare packaging plans prior to dispatching the crankshafts.

4.4.2 Assigning resource cost to activity centres

The second step is to assign resource cost to activity centres which is six departments with allocate the amount of MYR137,000.00 for crankshaft by the corporate management department, administration, factory management, quality control, remanufacturing, and sales and dispatch. There are two types of cost which are direct and indirect costs are covered by overhead category by each department. These types of costs are covered including wages, depreciation, consumables, energy, building and other costs. Table 4.10 clearly show that the apportionment of overhead of each department be more accurate when the number of department and overhead categories is larger.

Table 4.10: Assigning resources cost to centres

Overhead category	Activity centre											
	Administration (17%)		Corporate management (19%)		Factory management (11%)		Quality control (19%)		Remanufacturing (26%)		Sales and Dispatch (8%)	
Wages	72%	16768.8	63%	16398.9	68%	10247.6	63%	16398.9	46%	16385.2	55%	6028.00
Depreciation	4%	931.60	3%	780.90	3%	452.10	8%	2082.40	21%	7480.20	3%	328.80
Consumables	2%	465.80	0%	0	0%	0	0%	0	6%	2137.20	1%	109.60
Energy	8%	1863.20	3%	780.90	4%	602.80	2%	520.60	7%	2493.40	4%	438.40
Building cost	7%	1630.30	5%	1301.50	5%	753.50	3%	780.90	1%	356.20	3%	328.80
Other cost	7%	1630.30	26%	6767.80	20%	3014.00	24%	6147.20	19%	6767.80	33%	3616.80
Total (MYR)		23290.00		26030.00		15070.00		26030.00		35620.00		10960.00
Grand Total (MYR)												137, 000.00

Based on Table 4.10, the highest apportion of overhead is remanufacturing department that belong percentage of 26 % among others department percentage. The total of remanufacturing cost is MYR35620.00 that allocates the amount of MYR16,385.20 for overhead category of wages. It is to produce the crankshaft that the centre has 1 leader, 2 workers for cleaning process and 4 workers for the grinding and polishing with their compensation rate is approximately MYR900.00, MYR450.00, and MYR400.00 respectively per month. Telephones, printers, air conditioners, computers, can be categorized into depreciation that allocate approximately MYR7480.20 since this department has work area in both inside and outside the office. Grinding, polishing and cleaning machines maintenance is approximately MYR15,000.00 while maintenance for tool setup is MYR5,000.00 The total of the consumables is MYR2,137.20 with respect to the documentation (MYR2.10 per pack*5 unit*12month), renewal formal workers appearance (MYR2.30*7 workers), stone grinder (MYR680.00 per year), grid paper (MYR401.65 per year), detergent for cleaning process (MYR800.00), safety shoes (MYR2.40*7) and tissue (MYR96.65 per year). The department uses the energy usage with the total cost around MYR2493.40 which include the office (MYR61.78*12), grinding machines (MYR57*12), polishing machine (MYR37.00*12) and cleaning machine (MYR52*12). The total of the building cost is MYR356.20 including the renovations and approximately MYR6767.80 is provision from other costs such as training.

4.4.3 Assigning centre cost to activities

The remanufacturing activities such as grinding (34%), polishing (30%) and cleaning (36%) as shown in Table 4.11 is determined from the reallocated of amount MYR35620.00 of the apportioned overhead for remanufacturing department from the Table 4.10.

Table 4.11 : Assigning remanufacturing centre cost to activities

Overhead category	Remanufacturing centre activities						
	Grinding 34%		Polishing 30%		Cleaning 36%		
Wages	46.8%	5667.85	46.8%	5001.05	46.8%	6001.26	
Depreciation	21.25%	2573.55	21.25%	2270.78	21.25%	2724.93	
Consumables	7.31%	885.30	7.31%	781.15	7.31%	937.38	
Energy	6.6%	799.31	6.6%	705.28	6.6%	846.33	
Building cost	1.25%	151.39	1.25%	133.58	1.25%	160.29	
Other cost	16.79%	2033.40	16.79%	1794.18	16.79%	2153.02	
Total (MYR)		12110.80		10686.00		12823.20	35620.00

The operation of grinding activity is responsible for grinding the crankpins according to the standards given by OEM. There are 4 workers are responsible for grinding and polishing, and 2 workers are responsible for cleaning and their rates is MYR300.00, MYR150.00 and MYR 140.00 respectively. Only 1 head remanufacturing centre is hired to monitor all the workers in each activity. The amount of MYR2573.55 is cover the depreciation overhead including machine maintenance and tools, air conditioners, computers, telephones, and printers that are required for setup for service needed. The amount of MYR885.30 is used per year for overhead consumables including tissues, detergents, papers, goggles, and safety shoes. The apportion of energy which is electricity is measured in kilowatts is allocated about MYR799.31 per year. The amount of electricity is depending on using of grinding, polishing, and cleaning machines. The cost of building is about MYR151.39 for a better setup and more efficient in remanufacturing.

Polishing activity is the operation that responsible to remove the artifacts of grinding. Only 1 head remanufacturing centre is hired to monitor 4 workers that responsible on grinding and polishing and 2 workers that responsible for cleaning and their rates is MYR300.00, MYR150.00 and MYR140.00 respectively. The amount of MYR2270.78 is covered the depreciation overhead including printers, telephones, computers, machine maintenance and tools, fax machines for setup for service needed. Tissues, goggles, coveralls, safety shoes, detergent, and papers can be categorized as the overhead consumables and the amount is spending is MYR781.15 per year. The apportion of energy which is electricity is measured in kilowatts is allocated about MYR705.28 per year. The amount of electricity is depending on using of grinding, polishing, and cleaning machines. The cost of building is about MYR133.58 for a better setup and more efficient in remanufacturing.

Cleaning activity is the operation that responsible to remove the potential harmful contaminants such as debris and dust from remanufacturing process. 1 head of remanufacturing centre, 4 workers are responsible on grinding and polishing, and 2 workers are responsible for cleaning with their rates of MYR300.00, MYR155.00, and MYR148.00 respectively. The amount of MYR2724.93 is covered depreciation of overhead including fax machines, printers, telephones, air conditioners, machine maintenance and tools for setup for service needed. Tissues, goggles, safety shoes, laser cartridge powder, and detergents can be categorized as the overhead consumable is spend the amount of MYR937.38 per year. The apportion of energy which is electricity is measured in kilowatts is allocated about MYR846.33 per year. The amount of electricity is depend on using of grinding, polishing, and cleaning machines. The cost of building is about MYR160.29 for a better setup and more efficient in remanufacturing.

4.4.4 Estimates the cost per unit of activity driver

Activity driver can be explained by a cost driver that used to estimate the costs for an activity expended by the cost objects. The costs of the object will distort during selecting the activity drivers. Activity drivers can be more than one per activity. Table 4.12 show the cost per unit of activity driver that calculate and the estimation of the quantity of activity driver is obtained for each activity for the year.

Table 4.12: Activities and activity cost per unit of activity drivers

Activity centre with activities	Activity cost (MYR)	Activity driver	Predict quantity of activity driver	Cost per unit of activity driver (MYR)
Administration				
Process receivables	5550.00	No. of invoices	500 units	11.10
Process payables	6240.00	No. of purchase orders	475 units	13.14
Operating IT system	9000.00	No. of CPU time-hours	8760 hours	1.03
Preparing payroll	2500.00	No. of pay slips	200 persons	12.50
	23290.00			
Corporate management				
Providing continuity for organization	6767.80	None available	Facility activity	-
Appointing a chief executive	5986.90	None available	Facility activity	-
Governing the organization	5206.00	None available	Facility activity	-
Acquiring resources for organization operation	8069.30	None available	Facility activity	-
	26030.00			
Factory management				
Program production	5070.00	No. of man hours	20000 hours	0.25
Expediting order	4300.00	No. of grinding machines	12 units	89.58
		No. of polishing machines	12 units	89.58
		No. of cleaning machines	11 units	97.73
		No. of man power	12 persons	89.58
Managing plant	3700.00	No. of crankshaft	400 units	9.25
Training production personnel	2000.00	No. of training-hours	4500 units	4.44
	15070.00			
Quality control				
Tools and equipment maintenance	8000.00	No. of tool-hours	2500 hours	3.20
Hardness measurement	5200.00	No. of crankshaft	500 units	10.40
Inspection process	3500.00	No. of crankpins	2900 units	1.21
Leak testing	5100.00	No. of testing hours	4900 units	1.04
Training on quality	4230.00	No. of training hours	800 units	5.29
	26030.00			
Remanufacturing				
Grinding	12110.80	No. of machine hours	9000 hours	0.67
		No. of setup hours	8320 hours	0.73
Polishing	10686.00	No. of machine hours	9000 hours	0.70
		No. of setup hours	8320 hours	0.53
Cleaning	12823.20	No. of machine hours	3500 hours	1.78
		No. of setup hours	7500 hours	0.88
	35620.00			
Sales and Dispatch				
Process sales order	2525.00	No. of sales orders	175 units	14.43
Packaging plan	5700.00	No. of man hours	4800 hours	1.19
Packaging training	2735.00	No. of training hours	760 hours	3.60
	10960.00			
Total Cost	137, 000.00			

Based on the remanufacturing activities centre in the Table 4.12, the amount of activity cost of grinding is MYR12110.80 which means the longer the machine and setup hours, the larger the cost of grinding activity. Since the continuous of usage, the grinding machines, it will cause the higher depreciation cost. Hence, the higher consumable costs are caused by using the protective personal equipment including safety shoes, coveralls, and goggles. For the activity cost of polishing, it shows the amount of MYR10686.00 which is less than the cost of grinding. The longer the machine and setup hours, the larger the cost of polishing. The higher depreciation costs are caused by the continuous of usage the polishing machine that is responsible to remove the excess metal on the surface of all the crankpins. The higher cost of remanufacturing is MYR12823.20 that indicates the cleaning cost. So, the longer machine setup hours, the larger cost of the cleaning activity. Therefore, the costs of depreciation and consumable are also increase as same the grinding and polishing machines. The energy cost is increased based on the usage of electricity of all the machines.

4.4.5 Preparing a bill of activities for each engine model

Referring to Table 4.13, a bill of activities is prepared for the Mtu183 engine model. This engine model is considering 15 units of crankshafts with 2 crankpins that are used. So, the crankshafts have an estimated cost of MYR687.90 per unit with remanufacturing and non-remanufacturing cost of MYR145.74 and MYR542.22 respectively. This research keeps the similar unit of grinding, polishing, and cleaning machines of expediting order which is 2 to make a fair judgement for all those bills of engine model prepared.

Table 4.13: Activity –based product cost (Mtu183)

Activity Level	Activity	Cost per unit of activity driver (MYR)	Annual quantity of cost driver consumed	Annual Cost (MYR)	Cost per unit of product (MYR)
Unit	Measure hardness	10.40	15 units	156.00	
Unit	Inspection process	1.21	30 units	36.30	
Unit	Grinding-machine hours	0.67	75 hours	50.25	
Unit	Grinding-setup hours	0.73	135 hours	98.55	
Unit	Polishing-machine hours	0.70	30 hours	21.00	
Unit	Polishing-setup hour	0.53	120 hours	63.60	
Unit	Cleaning-machine hours	1.78	85 hours	151.30	
Unit	Cleaning-setup hour	0.88	100.4 hours	88.36	
Unit	Perform leak testing	1.04	70 hours	72.80	
Unit	Packing plan	1.19	60.5 hours	72.00	
Batch	Program production	0.25	1659.5 hours	414.88	
Batch	Expedite order-grinding machines	89.58	2 units	179.16	
Batch	Expedite order-polishing machines	89.58	2 units	179.16	
Batch	Expedite order-cleaning machines	97.73	2 units	195.46	
Batch	Expedite order-man powers	89.58	3 persons	268.74	
Facility	Manage Plan	9.25	15 units	138.75	
Total remanufacturing activity cost				**2186.31**	**145.74**
Unit	Tools and equipment maintenance	3.20	49.5 hours	158.40	
Batch	Process receivables	11.10	150 units	1665.00	
Batch	Process Payable	13.14	150 units	1971.00	
Batch	Operate IT system	1.03	2112 hours	2175.36	
Batch	Prepare payroll	12.50	18 persons	225.00	
Batch	Process sales order	14.43	90 units	1298.70	
Facility	Training production personnel	4.44	48 hours	213.12	
Facility	Training on quality	5.29	48 hours	253.92	
Facility	Packaging training	3.60	48 hours	100.80	
Total non-remanufacturing activity cost				**8133.30**	**542.22**
Total crankpin cost per unit					**687.90**

Referring to Table 4.14, a bill of activities is prepared for the MAN engine model. This engine model is considering 15 units of crankshafts with 2 crankpins that are used. So, the crankshafts have an estimated cost of MYR731.40 per unit with remanufacturing and non-remanufacturing cost of MYR149.90 and MYR581.49 respectively. This research keeps the similar unit of grinding, polishing, and cleaning machines of expediting order which is 2 to make a fair judgement for all those bills of engine model prepared. Hence, this research is also maintains the similar number of annual operating IT hour which is 2112 hour which is considered of work of 8 hours per day and 22 days per month.

Table 4.14: Activity –based product cost (Man)

Activity Level	Activity	Cost per unit of activity driver (MYR)	Annual quantity of cost driver consumed	Annual Cost (MYR)	Cost per unit of product (MYR)
Unit	Measure hardness	10.40	15 units	156.00	
Unit	Inspection process	1.21	45 units	54.45	
Unit	Grinding-machine hours	0.67	102 hours	68.34	
Unit	Grinding-setup hours	0.73	156 hours	113.88	
Unit	Polishing-machine hours	0.70	52 hours	36.40	
Unit	Polishing-setup hour	0.53	142 hours	75.26	
Unit	Cleaning-machine hours	1.78	103.2 hours	183.70	
Unit	Cleaning-setup hour	0.88	114.6 hours	100.85	
Unit	Perform leak testing	1.04	92 hours	95.68	
Unit	Packing plan	1.19	73.4 hours	87.35	
Batch	Program production	0.25	1665.9 hours	416.48	
Batch	Expedite order-grinding machines	89.58	2 units	179.16	
Batch	Expedite order-polishing machines	89.58	2 units	179.16	
Batch	Expedite order-cleaning machines	97.73	2 units	195.46	
Batch	Expedite order-man powers	89.58	3 persons	268.74	
Facility	Manage Plan	9.25	15 units	138.75	
Total remanufacturing activity cost				**2349.66**	**156.64**
Unit	Tools and equipment maintenance	3.20	59.5 hours	190.40	
Batch	Process receivables	11.10	170 units	1887.00	
Batch	Process Payable	13.14	170 units	2233.80	
Batch	Operate IT system	1.03	2112 hours	2175.36	
Batch	Prepare payroll	12.50	18 persons	225.00	
Batch	Process sales order	14.43	100 units	1443.00	
Facility	Training production personnel	4.44	48 hours	213.12	
Facility	Training on quality	5.29	48 hours	253.92	
Facility	Packaging training	3.60	48 hours	100.80	
Total non-remanufacturing activity cost				**8722.40**	**581.49**
Total crankpin cost per unit					**738.13**

4.5 COST COMPARISON AMONG METHOD COMBINATION

Quality and cost is the most important aspects in decision making. MTS or traditional inspection can be achieved through quality and cost can be derived by conventional or ABC system methods. Based on Figure 4.10, it shows those methods that are related to each other. MTS is the best significant contribution among contribution because this method is achieves the cheapest final cost compared to others. When the cheaper final cost achieves, it also gives the higher potential and profit.

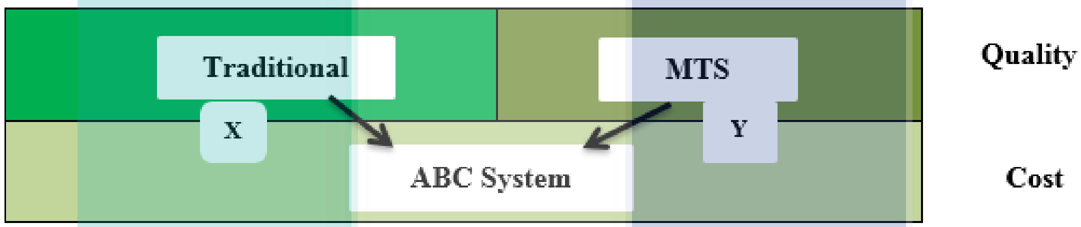


Figure 4.10 : Combination of methods

Based on the observation and combination of type X and type Y, this combination will produce the cost whereby type X is describe as traditional inspection method that used 6 crankpins diameter. This traditional method is applied to ABC system to estimate the accurate cost incurred. Table 4.15 is show the cost per unit of crankshaft that belongs to MTU183 engine model. The remanufacturing cost of this engine model is MYR754.37 and non-remanufacturing cost of MYR212.15 and MYR542.22 respectively. There are altogether 15 units of crankshaft. The highest cost is spent in remanufacturing cost at program production is MYR664.88. This is because program production is the key section of the state plan in a target for the sale and production to achieve a certain quantity output.

Table 4.15: Cost by ABC system from traditional inspection (Mtu183)

Activity Level	Activity	Cost per unit of activity driver (MYR)	Annual quantity of cost driver consumed	Annual Cost (MYR)	Cost per unit of product (MYR)
Unit	Measure hardness	10.40	15 units	156.00	
Unit	Inspection process	1.21	90 units	108.90	
Unit	Grinding-machine hours	0.67	175 hours	117.25	
Unit	Grinding-setup hours	0.73	285 hours	208.05	
Unit	Polishing-machine hours	0.70	95.6 hours	66.92	
Unit	Polishing-setup hour	0.53	240 hours	127.20	
Unit	Cleaning-machine hours	1.78	205 hours	364.90	
Unit	Cleaning-setup hour	0.88	250.6 hours	220.53	
Unit	Perform leak testing	1.04	110 hours	114.40	
Unit	Packing plan	1.19	60.5 hours	72.00	
Batch	Program production	0.25	2659.5 hours	664.88	
Batch	Expedite order-grinding machines	89.58	2 units	179.16	
Batch	Expedite order-polishing machines	89.58	2 units	179.16	
Batch	Expedite order-cleaning machines	97.73	2 units	195.46	
Batch	Expedite order-man powers	89.58	3 persons	268.74	
Facility	Manage Plan	9.25	15 units	138.75	
Total remanufacturing activity cost				**3182.30**	**212.15**
Unit	Tools and equipment maintenance	3.20	49.5 hours	158.40	
Batch	Process receivables	11.10	150 units	1665.00	
Batch	Process Payable	13.14	150 units	1971.00	
Batch	Operate IT system	1.03	2112 hours	2175.36	
Batch	Prepare payroll	12.50	18 persons	225.00	
Batch	Process sales order	14.43	90 units	1298.70	
Facility	Training production personnel	4.44	48 hours	213.12	
Facility	Training on quality	5.29	48 hours	253.92	
Facility	Packaging training	3.60	48 hours	100.80	
Total non-remanufacturing activity cost				**8133.30**	**542.22**
Total crankpin cost per unit					**754.37**

Table 4.16 is show the cost per unit of crankshaft that belongs to MAN engine model. The remanufacturing cost of this engine model is MYR799.37 and non-remanufacturing cost of MYR217.88 and MYR581.49 respectively. There are altogether 15 units of crankshaft. The highest cost is spent in remanufacturing cost at program production is MYR664.75. This is because program production is the key section of the state plan in a target for the sale and production to achieve a certain quantity output.

Table 4.16: Cost by ABC system from traditional inspection (Man)

Activity Level	Activity	Cost per unit of activity driver (MYR)	Annual quantity of cost driver consumed	Annual Cost (MYR)	Cost per unit of product (MYR)
Unit	Measure hardness	10.40	15 units	156.00	
Unit	Inspection process	1.21	90 units	108.90	
Unit	Grinding-machine hours	0.67	195.4 hours	130.92	
Unit	Grinding-setup hours	0.73	255 hours	186.15	
Unit	Polishing-machine hours	0.70	100 hours	70.00	
Unit	Polishing-setup hour	0.53	280 hours	148.40	
Unit	Cleaning-machine hours	1.78	215 hours	382.70	
Unit	Cleaning-setup hour	0.88	220.4 hours	193.95	
Unit	Perform leak testing	1.04	180 hours	187.20	
Unit	Packing plan	1.19	65.5 hours	77.95	
Batch	Program production	0.25	2659 hours	664.75	
Batch	Expedite order-grinding machines	89.58	2 units	179.16	
Batch	Expedite order-polishing machines	89.58	2 units	179.16	
Batch	Expedite order-cleaning machines	97.73	2 units	195.46	
Batch	Expedite order-man powers	89.58	3 persons	268.74	
Facility	Manage Plan	9.25	15 units	138.75	
Total remanufacturing activity cost				**3268.19**	**217.88**
Unit	Tools and equipment maintenance	3.20	62.5 hours	200.00	
Batch	Process receivables	11.10	170 units	1887.00	
Batch	Process Payable	13.14	170 units	2233.80	
Batch	Operate IT system	1.03	2112 hours	2175.36	
Batch	Prepare payroll	12.50	18 persons	225.00	
Batch	Process sales order	14.43	100 units	1443.00	
Facility	Training production personnel	4.44	48 hours	213.12	
Facility	Training on quality	5.29	48 hours	253.92	
Facility	Packaging training	3.60	48 hours	100.80	
Total non-remanufacturing activity cost				**8732.00**	**582.13**
Total crankpin cost per unit					**800.01**

Lastly, Type Y utilize the MTS with critical crankpins applied to the ABC system which has been analyzed previous. The results of both engine model are show in Table 4.17 which is the Type Y is cheaper than Type X. So, it can prove that the combination of method that apply the MTS method is the best significant to the final cost.

Table 4.17: Cost per unit comparison among the engine models

Engine Model	Cost per unit (MYR)	
	ABC System	
	Traditional (Type X)	MTS (Type Y)
MTU 183	754.37	687.90
MAN	800.01	738.13

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter concluded all the research work and its finding based on the objective made which started with the conclusion of the research, discusses possible future research that be done by other researchers and limitation of the research.

5.2 CONCLUSION OF THE RESEARCH

Based on MTS method, the EOL of crankshaft can be classified into remanufacturable, rejected or repairable. In this work, the MD of MTU183 engine model were developed for rejected (0.003165, 0.005667), remanufactured (0.005233, 0.00583) and repairable (0.003105, 0.003264) whereby the MD of Man engine model were developed for remanufacturable (0.386108,2.004725) and repairable (0.724391, 1.510771).

The Taguchi's orthogonal array is used to identify the critical and non-critical parameter of crankpin. This work found that there are 2 critical and 4 non-critical crankpins in MTU183 engine model whereby the Man engine model has 3 critical and 3 non-critical crankpins.

Lastly, this research also integrates ABC system with MTS method to consider the critical parameters of crankpin diameter. By integrated the critical crankpin obtained during parameter evaluation, the cost per unit of MTU183 engine model was MYR687.90 and for Man engine model was MYR738.13. The cost per unit integrated of ABC with traditional for MTU183 engine was MYR754.37 and for Man engine model was MYR800.01. So, it can conclude that integrated of ABC system with MTS system have cheaper cost than traditional method.

5.3 RECOMMENDATION FOR THE FUTURE RESEARCH

The method to generate the MD value using MTS consist of three which are T-Method 3, MTS Adjoint and MTGS. Since MTS is a new tool in pattern recognition and to ensure this tool can complete with other well-established tools, it is very important to compare the result with others method which are, artificial neural network, logistic regression, or decision tree in the remanufacturing automotive sector.

The data should be normally distributed after applied the T-Method 1. Based on the previous researcher, T-Method 2 is not clearly show the classification of populated data. Then, when the output is more than one, the analysis should have carried out or not?

There are two editions two upgrade the ABC system which are time-driven ABC (TABC) and Fuzzy Performance Focused ABC (PFABC). Firstly, a time-driven ABC (TABC) will measure the time that spent in many different parts that use the same rate and appropriate cost. Lastly, the combination of programming and performance management will focus to PFABC that identify all the activities that related to ABC. So, this PFABC is advance to explore in remanufacturing of automotive components.

5.4 LIMITATION OF THE RESEARCH

In this research, the original crankshaft that is provided by OEM should be a unit data or healthy data on pattern recognition. In this research, the highest number of EOL crankshaft is considered as unit data. In this work, there no software is used to generate automatically of MD values of unit data and signal data. So, scatter diagram is also failure to show the result scatter diagram in single data with all the classification.

Based on T-Method 3 which is parameter evaluation, the Taguchi's robust is to use for improving the engineering quality which considered the noise. But it is also fail for this company because lack of knowledge to apply this method.

In a conclusion, the ABC system is provided the overhead cost which depend on the actual cost in the real condition in the management of company. All the calculation is doing manually because no software is detected to calculate all the cost. So, if any company to apply ABC system in their company, this company must always up-to date the accounting system because it is accurate to get the actual cost based on the activities.

UMP

REFERENCES

Baykasoğlu, A., & Kaplanoğlu, V. (2008). Application of activity-based costing to a land transportation company: A case study. International Journal of Production Economics, 116(2), 308-324.

Chen, W.-C., & Kurniawan, D. (2014). Process parameters optimization for multiple quality characteristics in plastic injection molding using Taguchi method, BPNN, GA, and hybrid PSO-GA. International Journal of Precision Engineering and Manufacturing, 15(8), 1583-1593.

Banker, R. D., Bardhan, I. R., & Chen, T.-Y. (2008). The role of manufacturing practices in mediating the impact of activity-based costing on plant performance. Accounting, organizations and society, 33(1), 1-19.

El-Banna, M. (2015). A novel approach for classifying imbalance welding data: Mahalanobis genetic algorithm (MGA). The International Journal of Advanced Manufacturing Technology, 77(1-4), 407-425.

Feng, S., Hiroyuki, O., Hidennori, T., Yuichi, K., & Hu, S. (2011). Qualitative and quantitative analysis of gmaw welding fault based on mahalanobis distance. International Journal of Precision Engineering and Manufacturing, 12(6), 949-955.

Haldar, N. A. H., Khan, F. A., Ali, A., & Abbas, H. (2017). Arrhythmia classification using Mahalanobis distance based improved Fuzzy C-Means clustering for mobile health monitoring systems. Neurocomputing, 220, 221-235.

Jin, X., & Chow, T. W. (2013). Anomaly detection of cooling fan and fault classification of induction motor using Mahalanobis–Taguchi system. Expert Systems with Applications, 40(15), 5787-5795.

John, B. (2014). Application of Mahalanobis-Taguchi system and design of experiments to reduce the field failures of splined shafts. International Journal of Quality & Reliability Management, 31(6), 681-697.

Kim, K.-j., & Han, I. (2003). Application of a hybrid genetic algorithm and neural network approach in activity-based costing. Expert Systems with Applications, 24(1), 73-77.

Lin, W.-C. (2012). Financial performance and customer service: An examination using activity-based costing of 38 international airlines. Journal of Air Transport Management, 19, 13-15.

Liparas, D., Angelis, L., & Feldt, R. (2012). Applying the Mahalanobis-Taguchi strategy for software defect diagnosis. Automated Software Engineering, 19(2), 141-165.

Mohan, D., Saygin, C., & Sarangapani, J. (2008). Real-time detection of grip length deviation during pull-type fastening: a Mahalanobis–Taguchi System (MTS)-based approach. The International Journal of Advanced Manufacturing Technology, 39(9), 995-1008.

Qian, L., & Ben-Arieh, D. (2008). Parametric cost estimation based on activity-based costing: A case study for design and development of rotational parts. International Journal of Production Economics, 113(2), 805-818.

Reséndiz, E., Moncayo-Martínez, L. A., & Solís, G. (2013). Binary ant colony optimization applied to variable screening in the Mahalanobis–Taguchi system. Expert Systems with Applications, 40(2), 634-637.

Ríos-Manríquez, M., Colomina, C. I. M., & Pastor, M. L. R.-V. (2014). Is the activity based costing system a viable instrument for small and medium enterprises? The case of Mexico. Estudios gerenciales, 30(132), 220-232.

Maiga, A. S. (2014). Assessing self-selection and endogeneity issues in the relation between activity-based costing and performance. Advances in Accounting, 30(2), 251-262.

Saygin, C., Mohan, D., & Sarangapani, J. (2010). Real-time detection of grip length during fastening of bolted joints: a Mahalanobis-Taguchi system (MTS) based approach. Journal of Intelligent Manufacturing, 21(4), 377-392.

Srinivasaraghavan, J., & Allada, V. (2006). Application of mahalanobis distance as a lean assessment metric. The International Journal of Advanced Manufacturing Technology, 29(11), 1159-1168.

Theverapperuma, L. S., Hendrix, C. M., Mason, C. R., & Ebner, T. J. (2006). Finger movements during reach-to-grasp in the monkey: amplitude scaling of a temporal synergy. Experimental brain research, 169(4), 433-448.

Thyssen, J., Israelsen, P., & Jørgensen, B. (2006). Activity-based costing as a method for assessing the economics of modularization—A case study and beyond. International Journal of Production Economics, 103(1), 252-270.

Baykasoğlu, A., & Kaplanoğlu, V. (2008). Application of activity-based costing to a land transportation company: A case study. International Journal of Production Economics, 116(2), 308-324.

Chen, W.-C., & Kurniawan, D. (2014). Process parameters optimization for multiple quality characteristics in plastic injection molding using Taguchi method, BPNN, GA, and hybrid PSO-GA. International Journal of Precision Engineering and Manufacturing, 15(8), 1583-1593.

Banker, R. D., Bardhan, I. R., & Chen, T.-Y. (2008). The role of manufacturing practices in mediating the impact of activity-based costing on plant performance. Accounting, organizations and society, 33(1), 1-19.

El-Banna, M. (2015). A novel approach for classifying imbalance welding data: Mahalanobis genetic algorithm (MGA). The International Journal of Advanced Manufacturing Technology, 77(1-4), 407-425.

Feng, S., Hiroyuki, O., Hidennori, T., Yuichi, K., & Hu, S. (2011). Qualitative and quantitative analysis of gmaw welding fault based on mahalanobis distance. International Journal of Precision Engineering and Manufacturing, 12(6), 949-955.

Haldar, N. A. H., Khan, F. A., Ali, A., & Abbas, H. (2017). Arrhythmia classification using Mahalanobis distance based improved Fuzzy C-Means clustering for mobile health monitoring systems. Neurocomputing, 220, 221-235.

Jin, X., & Chow, T. W. (2013). Anomaly detection of cooling fan and fault classification of induction motor using Mahalanobis–Taguchi system. Expert Systems with Applications, 40(15), 5787-5795.

John, B. (2014). Application of Mahalanobis-Taguchi system and design of experiments to reduce the field failures of splined shafts. International Journal of Quality & Reliability Management, 31(6), 681-697.

Kim, K.-j., & Han, I. (2003). Application of a hybrid genetic algorithm and neural network approach in activity-based costing. Expert Systems with Applications, 24(1), 73-77.

Lin, W.-C. (2012). Financial performance and customer service: An examination using activity-based costing of 38 international airlines. Journal of Air Transport Management, 19, 13-15.

Liparas, D., Angelis, L., & Feldt, R. (2012). Applying the Mahalanobis-Taguchi strategy for software defect diagnosis. Automated Software Engineering, 19(2), 141-165.

Mohan, D., Saygin, C., & Sarangapani, J. (2008). Real-time detection of grip length deviation during pull-type fastening: a Mahalanobis–Taguchi System (MTS)-based approach. The International Journal of Advanced Manufacturing Technology, 39(9), 995-1008.

Qian, L., & Ben-Arieh, D. (2008). Parametric cost estimation based on activity-based costing: A case study for design and development of rotational parts. International Journal of Production Economics, 113(2), 805-818.

Reséndiz, E., Moncayo-Martínez, L. A., & Solís, G. (2013). Binary ant colony optimization applied to variable screening in the Mahalanobis–Taguchi system. Expert Systems with Applications, 40(2), 634-637.

Yang, C.-H., Lee, K.-C., & Chen, H.-C. (2016). Incorporating carbon footprint with activity-based costing constraints into sustainable public transport infrastructure project decisions. Journal of Cleaner Production, 133, 1154-1166.

Yang, T., & Cheng, Y.-T. (2010). The use of Mahalanobis–Taguchi System to improve flip-chip bumping height inspection efficiency. Microelectronics Reliability, 50(3), 407-414.