PAPER • OPEN ACCESS

Costing improvement of remanufacturing crankshaft by integrating Mahalanobis-Taguchi System and Activity based Costing

To cite this article: M Y Abu *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **342** 012006

View the article online for updates and enhancements.

Costing improvement of remanufacturing crankshaft by integrating Mahalanobis-Taguchi System and Activity based Costing

M Y Abu[1], E E Mohd Nor[1] and M S Abd Rahman[2]

[1]Faculty of Manufacturing Engineering, Universiti Malaysia Pahang
[2]Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka

E-mail:myazid@ump.edu.my

Abstract. Integration between quality and costing system is very crucial in order to achieve an accurate product cost and profit. Current practice by most of remanufacturers, there are still lacking on optimization during the remanufacturing process which contributed to incorrect variables consideration to the costing system. Meanwhile, traditional costing accounting being practice has distortion in the cost unit which lead to inaccurate cost of product. The aim of this work is to identify the critical and non-critical variables during remanufacturing process using Mahalanobis-Taguchi System and simultaneously estimate the cost using Activity Based Costing method. The orthogonal array was applied to indicate the contribution of variables in the factorial effect graph and the critical variables were considered with overhead costs that are actually demanding the activities. This work improved the quality inspection together with costing system to produce an accurate profitability information. As a result, the cost per unit of remanufactured crankshaft of MAN engine model with 5 critical crankpins is MYR609.50 while Detroit engine model with 4 critical crankpins is MYR1254.80. The significant of output demonstrated through promoting green by reducing re-melting process of damaged parts to ensure consistent benefit of return cores.

1. Introduction

In the early 20th century, remanufacturing has been proven by industry and it expended by the need to reuse military machinery and vehicles during and after the Second World War [1]. In China, Volkswagen established a remanufacturing plant for modern engine at Shanghai [2] which offered an inferior market price and same quality of new products, in addition remanufactures existing product into a new product with same warranty [3]. Remanufacturing is a chain of manufacturing phases which performed on the transformation industrial process that refurbished and recycled of a product in order to return it to an exceptional performance and it was not worse compare to the original product [4]. Economic and environmental potential, both are importance in remanufacturing industry which provides cost savings up to 90% of raw materials, ratio range of six to one for original production and remanufacturing in energy consumption, high efficiency and able to process high quality cores [5]. In fact, the manufacturing process of large and expensive engine parts are energy intensive and generate large amounts of environmental emissions especially during the critical steps in remanufacturing [6],

because there is no available method to decide which critical crankshaft are eligible to that process forward it will generate a lot of waste with respect to the energy, material, time and cost [7].

Mahalanobis distance (MD) and principle of Taguchi method, both is used in Mahalanobis-Taguchi System (MTS) approach by constructing a measurement of abnormality of patterns and make accurate prediction [8], where the interdependence between the variables is influential in pattern analysis. Hence, the class imbalance problem will be resolved and the data distribution is not affected. A vector analysis such as orthogonal arrays (OA) and signal-to-noise ratios (SN) is used to consolidate data from many parameters of a system into a single group or dimension [9]. By integrating the MTS, it has provided profit worth considering in many various applications [10]. Work by [11] applied MTS to present a multi-criteria evaluation framework and ranking candidates for MBA program by considering several criteria. [12] presented the MTS to designate the health condition of cooling fan and induction motor based on vibration signal by anomaly detection wherein the different unbalanced electrical faults of induction motor can be classified with a higher accuracy. [13] implemented the Gompertz binary particle swarm optimization algorithm to solve the problem of combinatorial optimization from variable selection which detected by MTS in the manufacturing process of automotive pedals components. [14] solved the combinatorial optimization problem of variable selection with applied the binary ant colony optimization algorithm in the application of the MTS.

In recent year, common approaches to service and product costing have been focus to continue and diverse condemnation. Nevertheless, the level of change in management accounting system has created to stimulate and several improvements have created as much attentiveness as activity based costing (ABC) which has developed during the last span as one means of addressing the flaws of the traditional cost accounting (TCA) method [15] which only assigns costs to product based on an average overhead rate. Therefore, ABC are introduced as allocates the costs of manufacturing a product according to the activities needed to produce the item. The application of ABC has been reported in organizational, hospital, supply chain, cellular manufacturing, farm management, transportation, decision making, radiotherapy and in numerous energy and environmental issues. Work by [16] performed the 0-1 mixed integer programming using ABC system and life cycle assessment (LCA) which assign resources and funding for energy saving activities to each green building through appropriate cost drivers. [17] proposed a cost estimation of safety by using activity of risk assessment for the initial stages of construction bidding phase since the fatal construction accidents are major problem in construction industry and construction project scheduling by focusing on construction activities. Furthermore, [18] resolved the strategic decision making under resource constraints and the carbon footprint factor which is the perspective of sustainable transport and the criterion of decreasing traffic energy consumption are the most significant evaluation factors by the connection with ABC evaluation and LCA. [19] proved that the ABC models for inter-firm cost accounting are appropriate in the context of supply chain environment by developing the conceptual framework. Therefore, it is hard to find any previous works that integrating the MTS and ABC to improve simultaneously quality and costing system.

This work identifies critical variables in the remanufacturing process in order to improve the quality inspection. Factorial effect graph has been developed to observe which variables were critical to the remanufacturing process. Meanwhile, the structure of costing system has been improved to obtain accurate cost of product and to gain accurate profitability.

2. Methodology

This work selected crankpin of crankshafts as a subject matter and the number of sample is shown in table 1. The data were collected from a remanufacturing industry which located at Rawang, Malaysia.

Table 1. Data collection for crankpin of crankshaft.

Engine Model	No. of sample	Remanufacturable tolerance (*mm*)	
		Lower limit	Upper limit
Detroit	59	114.262	114.305
MAN	84	112.020	112.040

Subsequently, this work need to develop a clustering between both engine model to indicate their Mahalanobis Distance (MD) value. Higher the MD value indicated that the off-target sample have a distinctive pattern from the target sample while, smaller value of MD indicated that the off-target sample have closer pattern to the target sample. MAN engine model have been selected as the target sample due to the pattern was closer to the original crankshaft while Detroit engine model as the off-target sample. The calculation of MD as shown in equation (1) whereby Y represented the normalized Y_1 and Y_2, A represented the inverse matrix, Y^T represented transposition of Y and k represented number of variables.

$$\text{Mahalanobis distance} = \frac{YAY^T}{k} \tag{1}$$

The MD for each sample of both engine model was then used as response to evaluate the criticality of variables. The diameters of crankpin were used as input and the MDs were used as output. The data should be normal or densely populated in the medium range to apply this method by creating a histogram. The target data is the highest sample while off-target data is the remaining samples number. Normalization process is required in order to develop a dimensionless condition of the off target data. The normalization is used to make the data more flexible by diminishing their redundancy. Equation (2) and equation (3) are used to calculate the normalization.

$$X_{ij} = \acute{x}_{ij} - \bar{x}_j \tag{2}$$

$$M_i = \acute{y}_i - m_0 \tag{3}$$

Proportional coefficient β and SN ratio η are determined using equation (4) and equation (5).

$$\text{Proportional coefficient, } \beta_1 = \frac{M_1 X_{11} + M_2 X_{21} + \cdots + M_l X_{l1}}{r} \tag{4}$$

$$\text{SN ratio, } \eta_1 = \begin{cases} \dfrac{\frac{1}{r}(S_{\beta 1} - V_{el})}{V_{el}} \left(when\ S_{\beta 1} > V_{el} \right) \left(when\ S_{\beta 1} \leq V_{el} \right) \\ 0 \end{cases} \tag{5}$$

Positive value of SN ratio η indicated that the variable was significant for the first filtration and it will be considered for the second filtration. Proportional coefficient, β represented the steepness of the line in a scatter diagram. The integrated estimate value is then calculated as shown in equation (6) by using the critical variable which have been evaluated during first evaluation. In addition, the calculation also based on the orthogonal array which have been assigned from number of original parameters consideration.

$$\text{Integrated estimate value, } \widehat{M}_i = \frac{\eta_1 \times \frac{X_{i1}}{\beta 1} + \eta_2 \times \frac{X_{i2}}{\beta 2} + \cdots + \eta_k \times \frac{X_{ik}}{\beta k}}{\eta_1 + \eta_2 + \cdots + \eta_k} \tag{6}$$

As a result, equation (7) contributed to the criticality of variables for the second filtration. However, it can be observed from factorial effect graph.

$$\text{Integrated estimate SN ratio, } \eta = 10 \log \left[\frac{\frac{1}{r}(S_\beta - V_e)}{V_e} \right] \tag{7}$$

When the parameters were used by the SN ratio is larger and when the parameter is not used with the SN ratio is smaller, so the level of contribution to be positive and is classified as a critical variable. In other words, on factorial effect graph, descending the line indicated that the variable is significant. The

critical variables were considered into the costing using ABC. To perform the method, this work need to identify centres with their activities that give a major contribution to the production process. Then, resources cost is assigned to activity centres. This is actually done by estimating an amount of overhead for that year to be apportioned in percentage to those activity centres. The costs of the resources are already recorded in the existing accounting system. Then, activity centre cost is assigned to activities. The cost just apportioned in the second stage should be apportioned to the different types of product in terms of percentages based on their activity load. Similarly, overhead also would be apportioned by using percentage for such categories as wages, depreciation, consumables, energy, building cost and other costs. Fourthly, the cost per unit of activity driver is estimated. An activity driver is a cost driver used to estimate the cost of an activity consumed by the cost object. The activity driver should be proportional to the activity cost or activities that consume costs. Finally, is preparing a bill of activities for a unit of crankshaft. A cost object is any product for which management wants a separate measure of the cost. Cost per unit of activity driver would multiply with annual quantity of cost driver consumed to obtain the total of annual cost. The outcome is a total cost for each product that consists of a list of the activities used by the product and their costs.

3. Result and discussion

At this stage, this work was developed MD value for each sample of both engine model. According to the figure 1 (a) which specifically for MAN engine model, the distribution of samples inside the scatter diagram is quite fair because the sample numbers of remanufacturable (40) and repairable (44) of crankpin diameter are approximately equal. Obviously, there was no sample distribution belonging to the rejected group. Consequently, the MD value for Man engine model with 84 samples is between 0.092534 to 7.446333 with an average of 1.0, which is the unit data in this crankshaft classification. According to the figure 1 (b), since the sample numbers of remanufacturable (29) of crankpin diameter are greater than the rejected (16) and the repairable (14), the distribution of samples inside the scatter diagram is dense on the right side. Then, the threshold of MD for Detroit engine model with 59 samples is between 153277.39 to 164993.55 with an average of 160844.42, which is closer to the target sample. The overall classification can be seen as shown in figure 1 (c) which combined for both engine model. This explained that the pattern of Detroit engine model was obviously distinctive.
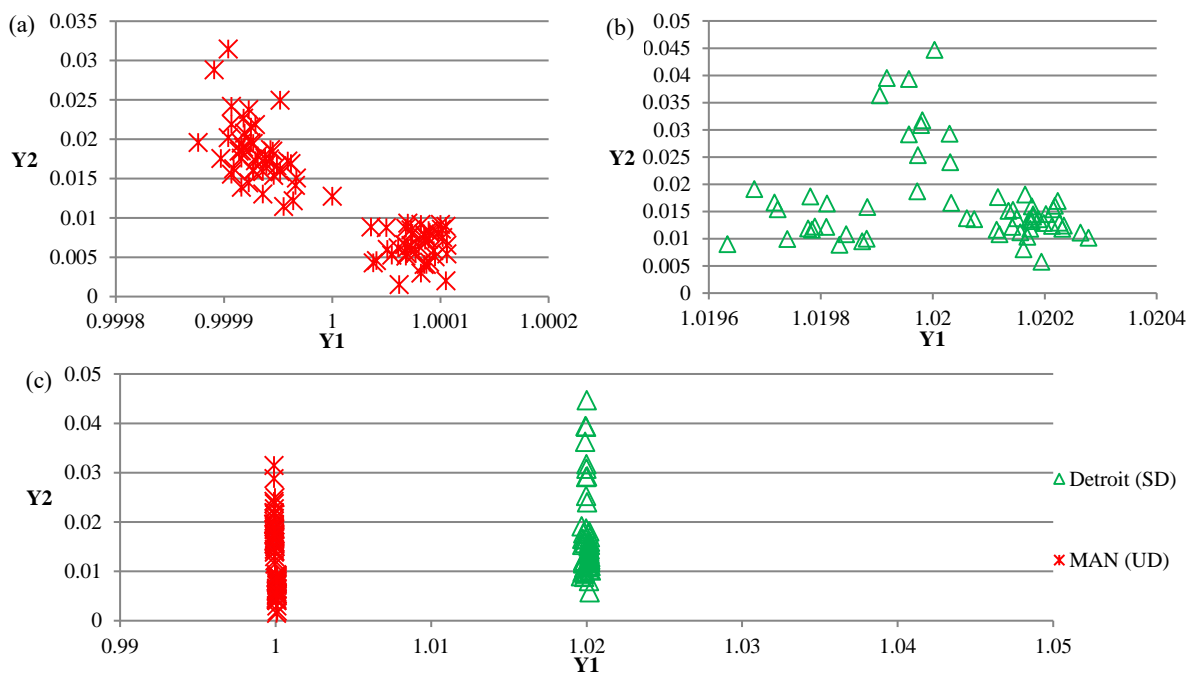

Figure 1. Scatter diagram of (a) MAN, (b) Detroit and (c) combination of both engine model.

The parameter evaluation was started with the result of first filtration for MAN engine model based on the value of proportional coefficient β and SN ratio η as shown in figure 2. Ascending the line to the right indicates that the parameter has positive value of proportional coefficient β. However, their steepness is increasing from diameters 6, 4 and 5. Then, SN ratio η indicates the relationship between the parameter and output: the larger the SN ratio η is, the stronger the relationship. The relationships get stronger starting from diameters 2, 6, 4, 5, 1 and 3. Therefore, these crankpin diameters are well suited for the purpose of integrated estimate value.
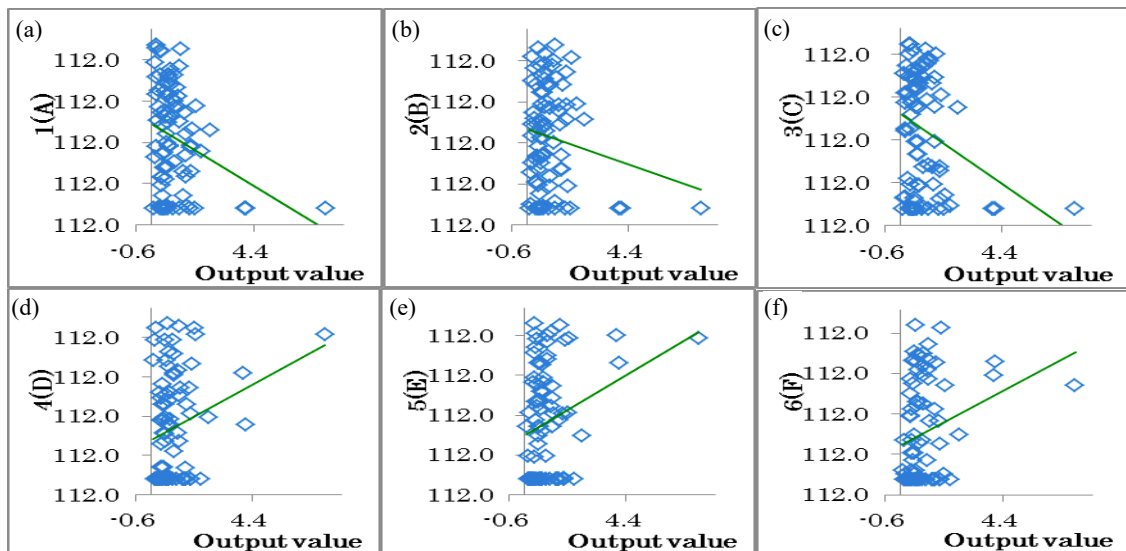
Figure 2. First filtration of (a) Diameter 1, (b) Diameter 2, (c) Diameter 3, (d) Diameter 4, (e) Diameter 5 and (f) Diameter 6.

With respect to the figure 3 of Detroit engine model, the steepness is increasing from diameter 3, 6, 4, 2, 5 and 1 while their relationship gets stronger starting from diameter 5, 4, 2 and 1. Therefore, those crankpin diameters are well suited to the purpose of integrated estimate value except for diameter 3 and 6 because both values are -6.20 db and -3.02 db respectively. When SN ratio η turned negative due to the $S_\beta \leq V_e$, the value will be treated as zero and not considered into integrated estimate value.
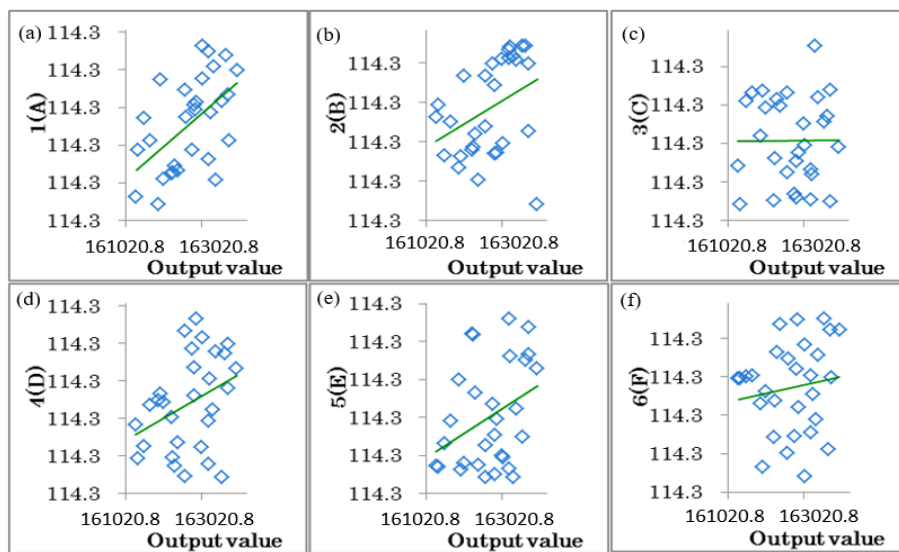
Figure 3. Scatter of output MD and crankpin of (a) Diameter 1, (b) Diameter 2, (c) Diameter 3, (d) Diameter 4, (e) Diameter 5 and (f) Diameter 6.

By considering the figure 4 for MAN engine model, among the 6 crankpin diameters of 84 remanufacturable and hybrid crankshafts, only 83% are critical and 17% are non-critical. Furthermore, some improvements can be made on the inspection quality and savings with respect to the cost, time and energy expended can be made. In addition, this work can increasingly rank their criticality according to their contribution from diameters 4, 5, 6, 1 and finally 3.
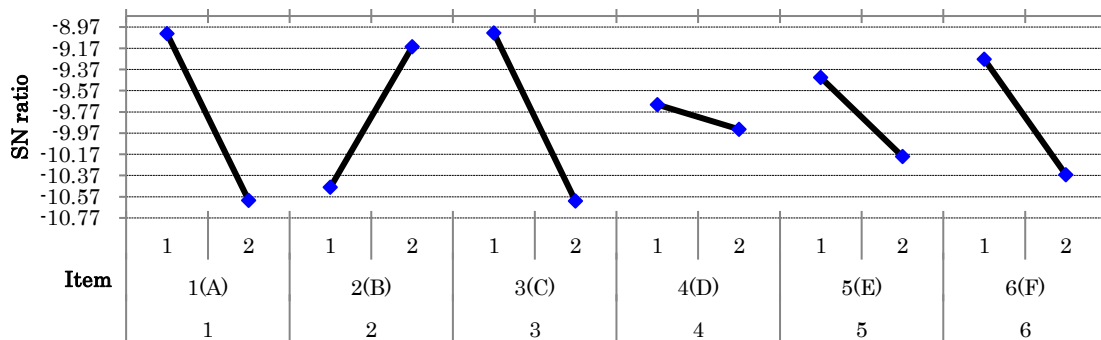

Figure 4. Evaluation importance through factorial effect graph of MAN engine model.

With respect to Detroit engine model, among those 6 crankpins diameter of 29 remanufacturable crankshafts, only 67% are critical while 33% are non-critical as shown in figure 5. Furthermore, some improvements can be made on the quality of inspection including savings with respect to the cost, time and energy expended. In addition, this research is able to increasingly rank their criticality according to their contributions from diameters 5, 4, 2 and finally 1.
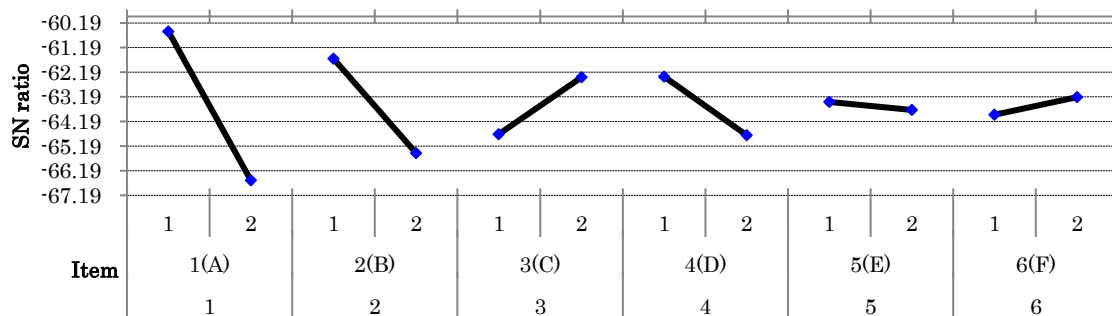

Figure 5. Evaluation importance through factorial effect graph of Detroit engine model.

Subsequently, those significant variables were considered into the costing using ABC. There were six departments which really affected to the industry's business such as administration, corporate management, factory management, quality control, remanufacturing, and sales and dispatch. Activity driver is a cost driver used to estimate the costs of an activity consumed by the cost objects. In selecting an activity driver, there must be a linear relationship between the activity costs and the activity drivers, otherwise the costs of the object will be distorted. Activity drivers can be more than one per activity. Estimation of the quantity of activity driver is obtained for each activity for the year so that the cost per unit of activity driver may be calculated as shown in table 2. The longer the machine and setup hours are, the larger the costs of the grinding activity. Continuous usage of the grinding machines to remove excess metal on the surface of crankpins indicates that maintenance or depreciation costs would increase. Similarly, the protective personal equipment being used such as coveralls, safety shoes and goggles would also increase the consumable costs. The longer the machine and setup hours, the larger the costs of polishing. Similarly, continuous usage of the polishing machines to remove excess metal on the surface of crankpins indicates that maintenance or depreciation costs would increase. The coveralls, safety shoes and goggles used tend to increase consumable costs.

Table 2. Activities and activity cost per unit of activity drivers.

Activity centre with activities	Activity cost	Activity driver	Predict quantity of activity driver	Cost per unit of activity driver (RM)
Administration				
Process receivables	15000	No. of invoices	800 units	18.75
Process payables	24000	No. of purchase orders	750 units	32.00
Operating IT system	26250	No. of CPU time-hours	9000 hours	2.92
Preparing payroll	9750	No. of pay slips	300 persons	32.50
	75000			
Corporate management				
Providing continuity for organization	19500	None available	Facility activity	-
Appointing a chief executive	17250	None available	Facility activity	-
Governing the organization	15000	None available	Facility activity	-
Acquiring resources	23250	None available	Facility activity	-
	75000			
Factory management				
Program production	16500	No. of man hours	26000 hours	0.64
Expediting order	14000	No. of grinding machines	12 units	291.67
		No. of polishing machines	12 units	291.67
		No. of cleaning machines	11 units	318.18
		No. of man power	20 persons	175.00
Managing plant	13000	No. of crankshafts	450 units	28.89
Training production personnel	6500	No. of training-hours	550 hours	11.82
	50000			
Quality control				
Tools and equipment maintenance	18750	No. of tools-hours	2700 hours	6.95
Hardness measurement	11250	No. of crankshafts	700 units	16.07
Inspection process	15000	No. of crankpins	3100 units	4.84
Leak testing	17250	No. of testing-hours	5000 hours	3.45
Training on quality	12750	No. of training-hours	950 hours	13.42
	75000			
Remanufacturing				
Grinding	33000	No. of machine hours	11000 hours	1.50
		No. of setup hours	8320 hours	1.98
Polishing	32000	No. of machine hours	11000 hours	1.46
		No. of setup hours	7780 hours	2.06
Cleaning	35000	No. of machine hours	4000 hours	4.38
		No. of setup hours	8240 hours	2.13
	100000			
Sales and dispatch				
Process sales order	8740	No. of sales orders	250 units	34.96
Packaging plan	15200	No. of man hours	5160 hours	2.95
Packaging training	14060	No. of training-hours	880 hours	15.98
	38000			
Total cost	413000			

A bills of activity is prepared for the MAN engine model as shown in Table 3. The crankshafts have an estimated cost of MYR609.05 per unit after considering 84 units of crankshaft with 5 critical crankpins. This research maintains the similar number of annual operating IT hour (2112 hour) based on the assumption of work of 8 hours per day and 22 days per month. This explained that, ABC is able to estimate the cost of product accurately based on the number of activities used.

Table 3. 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	16.07	84 units	1350.09	
Unit	Inspection process	4.84	420 units	2013.75	

Unit	Grinding-machine hours	1.50	756 units	1134.00	
Unit	Grinding-setup hours	1.98	1512 hours	2997.54	
Unit	Polishing-machine hours	1.46	210 hours	305.55	
Unit	Polishing-setup hour	2.06	1428 hours	2938.11	
Unit	Cleaning-machine hours	4.38	672 hours	2940.00	
Unit	Cleaning-setup hour	2.13	1334 hours	2856.00	
Unit	Perform leak testing	3.45	336 hours	1159.20	
Unit	Packing plan	2.95	176.4 hours	519.50	
Batch	Program production	0.64	6437.4 hours	4087.75	
Batch	Expedite order-grinding machines	291.67	2 units	583.34	
Batch	Expedite order-polishing machines	291.67	2 units	583.34	
Batch	Expedite order-cleaning machines	318.18	2 units	636.37	
Batch	Expedite order-man powers	175.00	4 persons	700.00	
Facility	Manage Plan	28.89	29 units	2426.76	
Total remanufacturing activity cost				**27249.28**	**324.40**
Unit	Tools and equipment maintenance	6.95	151.2 hours	105.09	
Batch	Process receivables	18.75	179 units	3356.25	
Batch	Process Payable	32.00	179 units	5728.00	
Batch	Operate IT system	2.92	2112 hours	6156.48	
Batch	Prepare payroll	32.50	26 persons	845.00	
Batch	Process sales order	34.96	110 units	3845.60	
Facility	Training production personnel	11.82	72 hours	850.86	
Facility	Training on quality	13.42	72 hours	966.24	
Facility	Packaging training	15.98	72 hours	1150.38	
Total non-remanufacturing activity cost				**23948.90**	**285.10**
Total crankpin cost per unit					**609.50**

A bill of activities is prepared for the Detroit engine model as shown in table 4. The crankshaft has an estimated cost of MYR1254.80 per unit after taking into consideration 29 units of crankshaft with 4 crankpins. For all those bills of engine model, in order to make a fair judgement, this research keep similar unit of grinding, polishing and cleaning machines of expediting order which is 2. This proved that all the activities required to produce the remanufactured were transparently listed. In order to increase the accuracy of the cost, the company might perform other analysis to find the critical activity driver as well.

Table 4. Activity-based product cost (Detroit).

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	16.07	29 units	466.10	
Unit	Inspection process	4.84	116 units	561.15	
Unit	Grinding-machine hours	1.50	266.8 units	400.20	
Unit	Grinding-setup hours	1.98	487.2 hours	965.88	
Unit	Polishing-machine hours	1.46	92.8 hours	135.03	
Unit	Polishing-setup hour	2.06	464 hours	954.68	
Unit	Cleaning-machine hours	4.38	255.2 hours	1116.50	
Unit	Cleaning-setup hour	2.13	440.8 hours	936.70	
Unit	Perform leak testing	3.45	127.6 hours	440.22	
Unit	Packing plan	2.95	78.3 hours	230.59	
Batch	Program production	0.64	2212.7 hours	1405.07	
Batch	Expedite order-grinding machines	291.67	2 units	583.34	
Batch	Expedite order-polishing machines	291.67	2 units	583.34	
Batch	Expedite order-cleaning machines	318.18	2 units	636.37	
Batch	Expedite order-man powers	175.00	4 persons	700.00	
Facility	Manage Plan	28.89	29 units	873.81	

Total remanufacturing activity cost				**10952.96**	**377.69**
Unit	Tools and equipment maintenance	6.95	60.9 hours	422.95	
Batch	Process receivables	18.75	200 units	3750.00	
Batch	Process Payable	32.00	200 units	6400.00	
Batch	Operate IT system	2.92	2112 hours	6156.48	
Batch	Prepare payroll	32.50	26 persons	845.00	
Batch	Process sales order	34.96	140 units	4894.40	
Facility	Training production personnel	11.82	72 hours	850.86	
Facility	Training on quality	13.42	72 hours	966.24	
Facility	Packaging training	15.98	72 hours	1150.38	
Total non-remanufacturing activity cost				**25436.30**	**877.21**
Total crankpin cost per unit					**1254.80**

4. Conclusion

The critical and non-critical variables are identified for inspection whereby MAN engine model had 83% critical and 17% non-critical while Detroit engine model had 67% critical and 33% non-critical. Subsequently, the cost for MAN and Detroit engine model are MYR609.50 and MYR1254.80 respectively by considering the critical variable. This work has proposed a good idea in order to improve the quality inspection and costing system but at the same time reducing a lot of waste. The application of ABC has proved that the costing was totally relying on the number of activities. Meanwhile, the method also very transparent to observe any cost drivers which directly related to the production of remanufactured crankshaft. Therefore, integration of MTS and ABC has a great impact to the development of remanufacturing industries in Malaysia.

Acknowledgement

References
[1]   Ridley SJ and Ijomah WL 2015 A novel pre-processing inspection methodology to enhance productivity in automotive product remanufacture: an industry-based research of 2196 Engines *Journal of Remanufacturing* **5** 1-12.

[2]   Chen M 2005 End-of-life vehicle recycling in China: now and the future *The Journal of The Minerals, Metals & Materials Society* **57** 20-6.

[3]   Piñeyro P and Viera O 2015 The economic lot-sizing problem with remanufacturing: analysis and an improved algorithm *Journal of Remanufacturing* **5** 1-13.

[4]   Zhichao L, Afrinaldi F, Zhang HC and Jiang Q 2016 Exploring optimal timing for remanufacturing based on replacement theory *CIRP Annals - Manufacturing Technology* **65** 447–50.

[5]   Matsumoto M, Yang S, Martinsen K and Kainuma Y 2016 Trends and research challenges in remanufacturing *International Journal of Precision Engineering and Manufacturing-Green Technology* **3** 129-42.

[6]   Dong JH, Xue BS, Xue N, Wang HP and Li HY 2013 Development of remaining life prediction of crankshaft remanufacturing core **1** 91-6.

[7]   Kareem B 2015 Evaluation of failures in mechanical crankshafts of automobile based on expert opinion *Case Studies in Engineering Failure Analysis* **3**:25–33.

[8]   Haldar NAH, Khan FA, Ali A and Abbas H 2016 Arrhythmia classification using mahalanobis distance based improved fuzzy c-means clustering for mobile health monitoring systems *Neurocomputing* **220** 221-35.

[9]   Pal A and Maiti J 2010 Development of a hybrid methodology for dimensionality reduction in mahalanobis taguchi system using mahalanobis distance and binary particle swarm

optimization *Expert Systems With Applications* **37** 1286–93.

[10] Holcomb S 2016 Mahalanobis Taguchi System (MTS) for pattern recognition, prediction and optimization *International Conference of Modeling and Simuation* **34** 1–8.

[11] Ketkar M and Vaidya OS 2014 Evaluating and ranking candidates for MBA program : mahalanobis Taguchi system approach *Procedia Economics and Finance* **11** 654–64.

[12] Jin X and Chow TWS 2013 Anomaly detection of cooling fan and fault classification of induction motor using mahalanobis-taguchi system *Expert System Applications* **40** 5787-95.

[13] Reséndiz E and Rull-flores CA 2013 mahalanobis-taguchi system applied to variable selection in automotive pedals components using gompertz binary particle swarm optimization *Expert Systems with applications* **40** 2361–65.

[14] Reséndiz E, Moncayo-martínez LA and Solís G 2013 binary ant colony optimization applied to variable screening in the mahalanobis-taguchi system *Expert systems with applications* **40** 634-37.

[15] Tsai WH, Chen HC, Leu JD, Chang YC and Lin TW 2013 A product-mix decision model using green manufacturing technologies under activity-based costing *Journal of Cleaner Production* **57** 178–87.

[16] Tsai WH, Yang CH, Chang JC and Lee HL 2014 An activity-based costing decision model for life cycle assessment in green building projects *European Journal of Operational Research* **238** 607-19.

[17] Gurcanli GE, Bilir S and Sevim M 2015 Activity based risk assessment and safety cost estimation for residential building construction projects *Safety Science* **80** 1–12.

[18] Yang CH, Lee KC and Chen HC. 2016 Incorporating carbon footprint with activity-based costing constraints into sustainable public transport infrastructure project decisions *Journal of Cleaner Production* **133** 1154–66.

[19] Schulze M, Seuring S and Ewering C 2012 Applying activity-based costing in a supply chain environment *Intern. Journal of Production Economics* **135** 716–25.