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Integration of Mahalanobis-Taguchi system and traditional cost accounting for remanufacturing crankshaft

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Abstract. Remanufacturing is a sustainability strategic planning which transforming the end of life product to as new performance with their warranty is same or better than the original product. In order to quantify the advantages of this strategy, all the processes must implement the optimization to reach the ultimate goal and reduce the waste generated. The aim of this work is to evaluate the criticality of parameters on the end of life crankshaft based on Taguchi's orthogonal array. Then, estimate the cost using traditional cost accounting by considering the critical parameters. By implementing the optimization, the remanufacturer obviously produced lower cost and waste during production with higher potential to gain the profit. Mahalanobis-Taguchi System was proven as a powerful method of optimization that revealed the criticality of parameters. When subjected the method to the MAN engine model, there was 5 out of 6 crankpins were critical which need for grinding process while no changes happened to the Caterpillar engine model. Meanwhile, the cost per unit for MAN engine model was changed from MYR1401.29 to RM1251.29 while for Caterpillar engine model have no changes due to the no changes on criticality of parameters consideration. Therefore, by integrating the optimization and costing through remanufacturing process, a better decision can be achieved after observing the potential profit will be gained. The significant of output demonstrated through promoting sustainability by reducing re-melting process of damaged parts to ensure consistent benefit of return cores.

1. Introduction

In 19th century, remanufacturing was applied during World War II when the manufacturers converted their usual product to the products of military. This shown that the remanufactured products keep increasing in used as the countries encounter with materials shortage. Remanufacturing is "the used parts are replaced" and "testing is carried out to specification of manufacturer and standards of original production" [1]. The end of life (EOL) products are disassembled into parts then they will be cleaned and inspected followed by process of repair and replacement for the worn-out parts. Finally, the product is reassembled in purpose to function like a new product. Several benefits of remanufacturing such as: (1) More profitable than traditional manufacturing because used less labor skills, energy, materials and cost of disposal, (2) The work environment in assembly lines is dull in traditional manufacturing while in remanufacturing, the work environment is more diverse. Workers have a set of broader skill and higher fulfillment of work, (3) The critical information on design of product and project developments are provided by activities of remanufacturing and failure mode information can be acquire through it,

(4) Product that has high-quality and cheaper can be obtained by customers. The remanufactured product prices are 30% to 40% less than the new products and (5) The lead times is shorter for the remanufactured products [2]. Mahalanobis-Taguchi System (MTS) is a method for diagnosis of behavior patterns and forecast corresponding to sets of multivariate patterns that proposed by Genichi Taguchi. The application of MTS has been reported in hospital [3], green manufacturing [4], green technologies [5], decision making [6] and computational [7]. [8] examined relationship between the MTS with the health condition of cooling fan and induction motor. [9] presented an effect of MTS on inspection time in electronics industry for flip-chip bumping height inspection. [10] analyzed the capability of MTS as a response detector for the brain on a single-trial (ST) basis. [11] discussed the application of MTS for identifying the optimum hardness profile to avoid failures of the shafts to reduce in wasting of money. In order to make a right decision, [12] presented applied MTS for analysis of software defects, in particular fault-prone software modules and can help analyze which of the variables describing the software modules that contribute the most to the abnormality. In work by [13], the authors described the case of quality awards on the effect of performance aggregation based on MTS. [14] applied MTS approach to hospital is an effective method that determines the decision for the obstructive sleep apnea (OSA) patients. Due to competitive pressure forces from manufacturers to produce more products with shorter life span and better quality, yet at a lower cost, [15] presented a significant factor to determine the best configuration in the cutting process by applied MTS. In order to improve the agriculture, [16] assessed how the implementation of MTS can assist in making decision to identify the classification within each category. [17] proved that, the application of MTS is a practical method in making decision. [18] discussed the implementation of MTS in machining in order to improve the energy saving and efficiency of the production. [19] presented a combination of MTS and self-organization mapping (SOM) system to monitoring the bearing condition, indicate the current degradation state and tracking the degradation trend dynamically. The traditional cost accounting (TCA) are used to allocate the overhead of manufacturing to produce units of product. Industries are mostly using TCA because of the cost of product that act as a key function and also assist in accomplish the goals and to apply principles like estimate competitors, growth and improvement targets, synchronize between quantities and processes and measurement and control.

Therefore, it is very important for this work to identify critical parameters using MTS to improve the quality inspection. Factorial effect graph has been developed to observe which parameters were critical to the remanufacturing process. Eventually the cost was estimated using TCA by considering those critical parameters for better profit.

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. Collection data of crankpin.

Engine model	Number of sample	Remanufacturable tolerance (mm)	
		Lower limit	Upper limit
Caterpillar	70	117.000	117.043
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 sample have a distinctive pattern from the reference sample while, smaller value of MD indicated that the sample have closer pattern to the reference sample. In this work, MAN engine model have been selected as a reference sample due to the pattern was closer to the original crankshaft. 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 parameters. The diameters of crankpin will be used as input and the MD will be used as output. The data should be normal or densely populated in the medium range to apply this method by creating a histogram. The unit data is the highest sample while signal data is the remaining samples number. Normalization process is required in order to develop a dimensionless condition of the signal 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).

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

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

Positive value of SN ratio η indicated that the parameter 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 significant parameter 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 parameter 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 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 parameter. In other words, on factorial effect graph, descending the line indicated that the parameter is significant. The critical parameters were considered into the costing using TCA. The cost-driver value for the appropriate duration is determined and the predetermined overhead rate is calculated. Predetermined overhead rate is used to implement the overhead cost to product costs for a period. Finally, implement the overhead cost to the product by using predetermined overhead rate. For each activity, overhead costs assigned to the products obtained by multiplying the predetermined overhead rate. Then, the actual cost of producing a single unit of crankshaft was estimated based on critical parameters.

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 Caterpillar engine model, since the sample numbers of remanufacturable (35) and rejected (35) of crankpin diameters are equal, the distribution of sample inside the scatter diagram is stable for both regions. The MD value for this engine model with 70 samples was between 774002.21 to 798279.92 with the average of 787586, which is far from the unit data. According to figure 1 (b), 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 threshold of MD 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. The overall classification can be seen as shown in figure 1 (c) which combined for both engine model. This explained that the pattern of Caterpillar engine model was obviously distinctive.

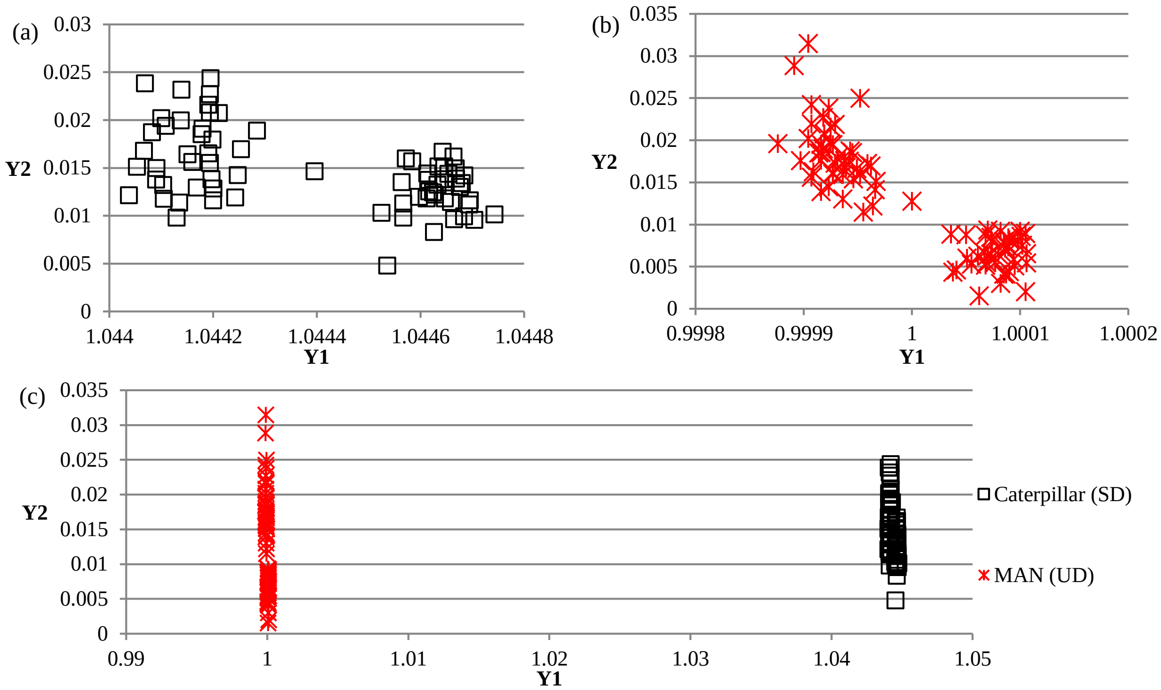

Figure 1. Scatter diagram of (a) Caterpillar, (b) MAN and (c) combination of both engine model.

The parameter evaluation was started with Caterpillar engine model by considering 6 crankpin diameters ranging from 117.0002 mm to 117.0428 mm as inputs and MD ranging from 788974.3 to 798279.9 as outputs. From that, a histogram as shown in figure 2 was constructed and the highest peak is between 796000 to 797000 of MD with the frequency of 9 and a bit skewing to the right.

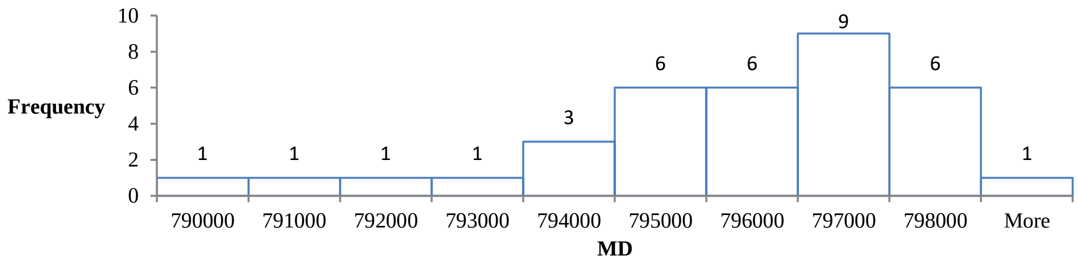

Figure 2. Histogram of Caterpillar.

MAN engine model was considering 6 crankpin diameters ranging from 112.020 mm to 112.0399 mm as inputs and MDs ranging from 0.092534 to 2.495802 as outputs with 84 samples belonging to the remanufacturable and hybrid crankshafts. From that, a histogram as shown in figure 3 been constructed and the highest peak with the frequency of 18 and a bit skewing to the left.

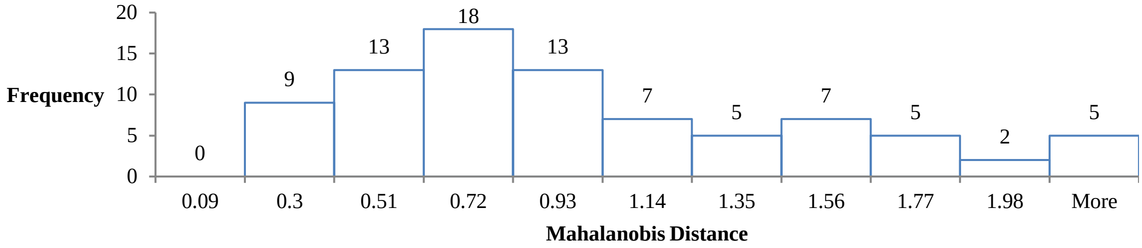

Figure 3. Histogram of MAN.

The result of first filtration for Caterpillar engine model based on the value of proportional coefficient β and SN ratio η as shown in figure 4. Ascending the line to the right indicates that the parameter has positive value of proportional coefficient β. However, their steepness is increasing from diameter 6, 2, 3, 4, 5 and 1. Then, SN ratio η indicates the relationship between the parameter and output: the larger the SN ratio η is, the stronger the relationship. The relationship started stronger from diameter 2, 6, 4, 1, 3 and 5. Therefore, those crankpins diameter are well suited to the purpose of integrated estimate value.

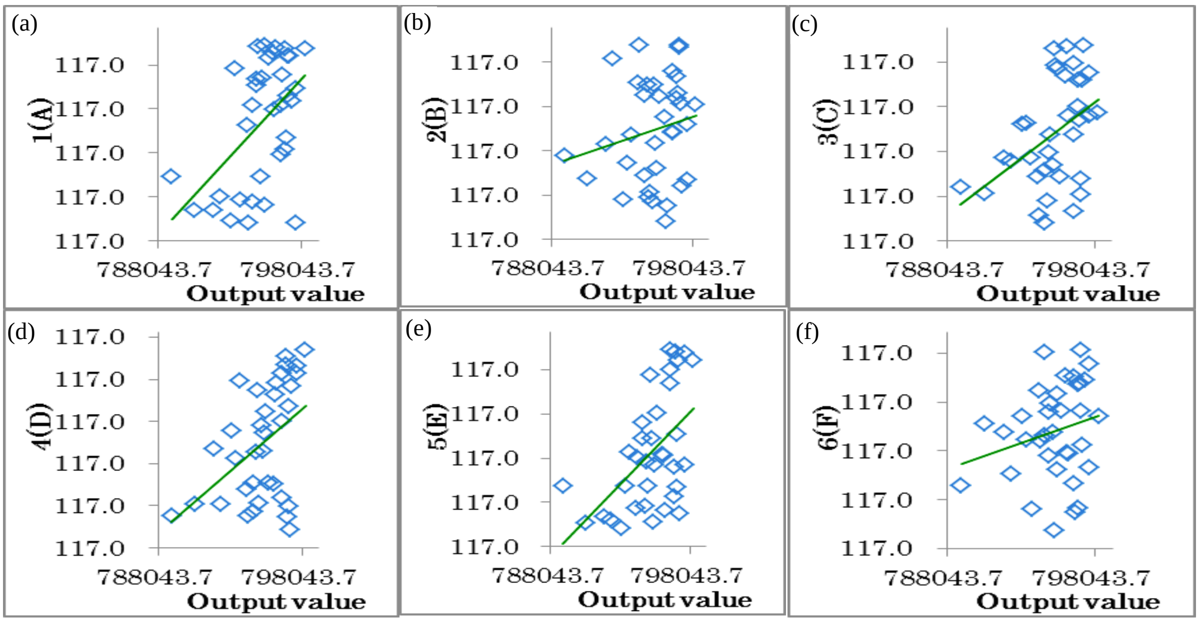

Figure 4. First filtration of (a) Diameter 1, (b) Diameter 2, (c) Diameter 3, (d) Diameter 4, (e) Diameter 5 and (f) Diameter 6.

With respect to figure 5, the steepness for MAN engine model was increasing from diameters 6, 4 and 5. Descending the line to the right indicates that the parameter has negative value of proportional coefficient β. However, their steepness is increasing from diameters 2, 1 and 3. 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.

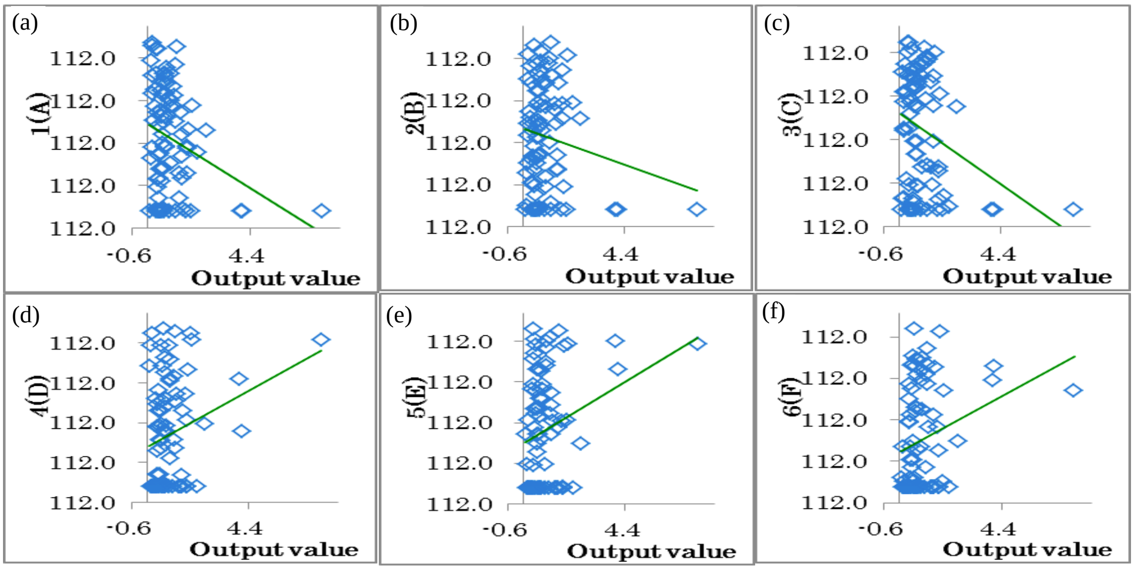

Figure 5. Scatter of output MD and crankpin of (a) Diameter 1, (b) Diameter 2, (c) Diameter 3, (d) Diameter 4, (e) Diameter 5 and (f) Diameter 6.

By using those values of proportional coefficient β and SN ratio η from figure 4, this work obtained the value of integrated estimate value. Thus, the larger the SN ratio η is, the greater the degree of its contribution to the integrated estimates of MD value. The parameter evaluation was performed using L_8 type orthogonal array and the result was translated into a factorial effect graph as shown in figure 6. Descending the line from left (level 1) to right (level 2) indicated that the parameter has an effect (degree of contribution) of elevating the output. When the crankpin diameter 5 is used (level 1) with a larger relationship (SN ratio = 67.2 db) to the output and when the parameter is not used (level 2) with a smaller relationship (SN ratio = 70.6) to the output, the larger degree of contribution (3.38 db) of the parameter will be gained (critical). It means that this crankpin diameter 5 has the highest contribution to the output.

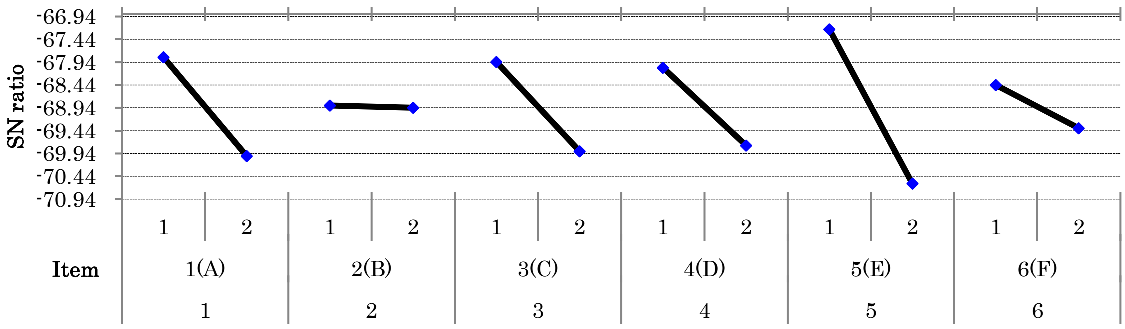

Figure 6. Evaluation importance through factorial effect graph of Caterpillar.

Therefore, among those 6 crankpins diameter of 35 remanufacturable crankshafts, these were 100% critical. Furthermore, no improvement can be made on inspection quality and no saving with respect to the cost, time and energy for the time being. In addition, this work concluded their criticality according to their contribution from diameter 2, 6, 4, 3, 1 and finally 5. By considering the figure 7 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 research can increasingly rank their criticality according to their contribution from diameters 4, 5, 6, 1 and finally 3.

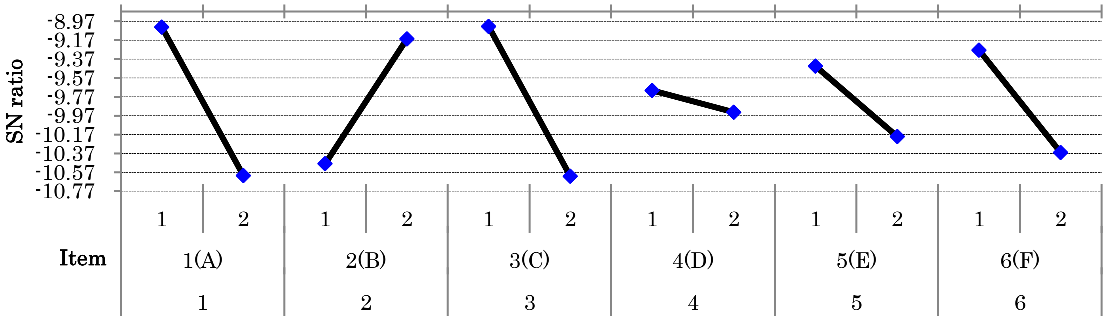

Figure 7. Evaluation importance through factorial effect graph of MAN engine model.

Table 2 showed the Caterpillar engine cost per unit of crankshaft equal to MYR1323.09 which is identical to the yearly overhead to be MYR 10608.33 but when divided by 35 units of crankshaft, the overhead per unit crankshaft equal to MYR 303.09. Time taken to produce each unit of crankshaft is 13.6 hours.

Table 2. Cost by TCA system from inspection of traditional (Caterpillar).

Process	Duration per crankpin (hour)	Number of crankpin (unit)	Duration per crankshaft (hour)	Man power	Working rate/hour (MYR)	Cost per unit (MYR)	Number of crankshaft (unit)	Annual cost per unit (MYR)
Inspection	0.2		1.2			90.00		
Grinding	0.7	6	4.2			315.00		
Polishing	0.6		3.6			270.00		
Cleaning			1.0	1	75	75.00		
Leak testing			2.5			187.50		
Packaging			1.1			82.50		
Total direct labor						1020.00		35700.00
Overhead						303.09	35	10608.33
Total						1323.09		46308.33

Table 3 shows the MAN engine cost per unit of crankshaft equal to MYR 1401.29 which is identical to the yearly overhead to be MYR 10608.33 but when divided by 84 units of crankshaft, the overhead per unit crankshaft equal to MYR 126.29. Time taken to produce each unit of crankshaft is 17.0 hours.

Table 3. Cost by TCA system from inspection of traditional (MAN).

Process	Duration per crankpin (hour)	Number of crankpin (unit)	Duration per crankshaft (hour)	Man power	Working rate/hour (MYR)	Cost per unit (MYR)	Number of crankshaft (unit)	Annual cost per unit (MYR)
Inspection	0.3		1.8			135.00		
Grinding	0.9	6	5.4			405.00		
Polishing	0.8		4.8			360.00		
Cleaning			1.2	1	75	90.00		
Leak testing			2.6			195.00		
Packaging			1.2			90.00		
Total direct labor						1275.00		107100.00
Overhead						126.29	84	10608.33
Total						1401.29		117708.33

Table 2 and table 3 was then been compared with the costing with optimization using MTS. Since the critical parameters of Caterpillar engine model have not changed, subsequently this work proceed with the comparison for MAN engine model. Table 4 showed the cost per unit of crankshaft equal to

MYR1251.29 which is identical to the yearly overhead to be MYR10608.33 but when divided by 84 units of crankshaft, the overhead per unit crankshaft equal to MYR126.29.

Table 4. Cost by TCA system from MTS (MAN).

Process	Duration per crankpin (hour)	Number of crankpin (unit)	Duration per crankshaft (hour)	Man power	Working rate/hour (MYR)	Cost per unit (MYR)	Number of crankshaft (unit)	Annual cost per unit (MYR)
Inspection	0.3		1.5			112.50		
Grinding	0.9	5	4.5			337.50		
Polishing	0.8		4.0	1	75	300.00		
Cleaning			1.2			90.00		
Leak testing			2.6			195.00		
Packaging			1.2			90.00		
Total direct labor						1125.00	84	94500.00
Overhead						126.29		10608.33
Total						1251.29		105108.33

This work proved that, the contribution of MTS was obviously optimized the process of remanufacturing on identification on the critical parameters.

4. Conclusion

By utilizing the MTS, the critical and non-critical parameter can be identified in the remanufacturing process. Reduction of parameters number can improved the inspection quality. As a result, the integration of MTS and TCA has proven that the cost per unit of remanufactured crankshaft of MAN engine model has been reduced from MYR1401.29 to MYR1251.29. The company also can reduce a lot of waste after identified the non-critical parameters especially the costs to other processes of remanufacturing.

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